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Load Modelling of Buildings in Mixed Energy Distribution Systems

Doctoral thesis
for the degree of philosophiae doctor

Trondheim, February 2007

Norwegian University of Science and Technology
Faculty of Engineering Science and Technology
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PREFACE

The work for this thesis has been undertaken at the Department of Energy and Process Engineering at the Norwegian University of Science and Technology (NTNU) from August 2003 to February 2007, as part of a joint project between NTNU and Sintef Energy Research called SEDS - Sustainable Energy Distribution Systems.

First of all, I would like to thank my supervisor, NTNU Associate Professor Rolf Ulseth, for his valuable advise, encouragement, and constructive (and not necessarily so constructive, but very amusing), discussions throughout this thesis work. I would also like to thank my two co-supervisors, Dr. Jacob Stang and Professor Arne T. Holen, as well as Dag Eirik Nordgård for their valuable contributions.

The SEDS project group, with representatives from both NTNU and Sintef Energy Research, and my fellow PhD-students, have also contributed to this work during several workshops and project meetings.

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I would also like to thank Nicolai Feilberg for his input regarding load modelling, Nancy Bazilchuck for her careful English editing, the EKB-group at NTNU and Sintef Energy Research for the professional and especially the social inputs, and TEV Fjernvarme and BKK Varme for providing measured load data for the purpose of this thesis.

And to all my friends and family; Thank you for your encouragement, but most of all thank you for recreational time. And finally, but most importantly, an enormous thanks to my best friend and daily companion Vebjørn for all your love and support!

Trondheim, February 2007
Linda Pedersen

ABSTRACT

The main topic of this thesis has been the development of a new method for load modelling of buildings in mixed energy distribution systems. The method estimates design load profiles, yearly load profiles, load duration profiles and annual expected energy demand for a specified planning area, all divided into heat and electricity purposes. The heat load demand includes end-uses such as space heating, ventilation heating and hot tap water, while electricity load demand includes end-uses such as lighting, pumps, fans, and electrical appliances.

The model has been based on statistical analyses of simultaneous hourly district heat and electricity consumption data for a number of buildings. Consumption data have been collected from TEV Fjernvarme and BKK Varme, two district heating companies in Trondheim and Bergen respectively.

The heat load model has been based on piece-wise linear regression analyses to estimate the change-point temperature for temperature-dependent heat consumption. Linear regression analyses have been performed on the temperature-dependent consumption for all hours of the day for two different day types, weekdays and weekends/holidays. The normal distribution has been used on the temperature-independent consumption, which is mainly hot tap water. Expected values and standard deviations for all buildings analysed have been calculated for both temperature-dependent and temperature-independent consumption.

The electricity load model has been based on continuous probability distributions, such as normal distribution, lognormal distribution and Student's t distribution. The last distribution has shown the best fit for all hours and day types in most cases. Expected values and standard deviations for all buildings analysed have been calculated for winter, spring/fall and summer seasons.

Generalised relative load profiles have been developed for various building categories based on the heat and electricity load model. Single family houses and apartment blocks, office buildings, educational buildings, hospital buildings, and hotels and restaurants are the building categories that have been analysed. Specific heat and electricity load and energy indicators, given in [W/m^2] and $[\mathrm{kWh/m^2 \cdot yr}]$, have also been developed for all building categories. The specific load indicators have been used to restore the design load profiles from relative to real values in order to find the maximum heat and electricity demand for a specified planning area. The specific energy indicators have been used to convert the normalised yearly load profiles, and consequently, the normalised load duration profiles into real values.

A method for load aggregation for a specified planning area has also been developed based on the sum of independent variables from the same distribution. 95% quantile analysis based on the Student's t distribution has been applied to incorporate the uncertainty in the load profiles developed. The installed capacity, and thereby the investment costs for the energy production unit(s) and distribution system(s), are decided by the design load profiles and load duration profiles. The system's operation costs are given by the yearly load profiles and annual expected energy demand.

A theoretical case study has been performed to illustrate how to apply the generalised relative load profiles, along with the specific load and energy indicators, for the purpose of planning for mixed energy distribution systems.

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List of Symbols

A	Area for every building component, [m^2]
AB	Apartment Blocks
AT	Archetype
A, **B**	Vectors; **A** = [α_1 α_2 α_3 ... α_{23} α_{24}], **B** = [β_1 β_2 β_3 ... β_{23} β_{24}]
$\mathbf{A_R}$,$\mathbf{B_R}$	Vectors; $\mathbf{A_R}$ = [$\alpha_{R,1}$ $\alpha_{R,2}$ $\alpha_{R,3}$ ... $\alpha_{R,23}$ $\alpha_{R,24}$], $\mathbf{B_R}$ = [$\beta_{R,1}$ $\beta_{R,2}$ $\beta_{R,3}$ ... $\beta_{R,23}$ $\beta_{R,24}$]
α, β	Regression coefficients
$\bar{\alpha}$,$\bar{\beta}$	Average regression coefficients
$\alpha_{R,j}$	Relative specific regression coefficient for a given hour j
$\beta_{R,j}$	Relative specific regression coefficient for a given hour j
BNES	Building Network's Energy Statistics
CAV	Constant air volume
c_p	Specific heat capacity of air at $\theta_{i,int}$, [$kJ/kg \cdot K$]
DH	District Heat
DRY	Design Reference Year
e_i	Residual; error of the fit
E	Expected value
EB	Educational Buildings
ECI	Energy Consumption Indicator, [$kWh/m^2 \cdot yr$]
EL	Electricity
ELCI	Electricity Consumption Indicator, [$kWh/m^2 \cdot yr$]
EPBD	Energy Performance of Buildings Directive
EUI	Energy Use Indicator, [$kWh/m^2 \cdot yr$]
GAS	Natural gas
Φ_{HL}	Total heat load demand, [W]
Φ_{htw}	Heat load demand for hot tap water, [W]
Φ_I	Load demand to cover heat losses caused by infiltration, [W]
$\Phi_{M,j}$	Maximum load for hour j in the day, [W]
$\Phi_{R,j}$	The relative load for hour j of the day, [-]
Φ_T	Load demand to cover thermal transmittance losses, [W]
Φ_V	Load demand to cover heat losses caused by ventilation, [W]
HB	Hospital Buildings
HCI	Heat Consumption Indicator [$kWh/m^2 \cdot yr$]

HR	Hotel and Restaurants
H_T	Transmission heat loss coefficient, [W/K]
H_V	Ventilation heat loss coefficient, [W/K]
η	The temperature efficiency of the heat exchanger, [-]
MOE	Measures Of Effectiveness
μ	Mean or expected value of a random variable X
NMI	Norwegian Meteorological Institute
NMT	Norwegian Middle Time (Norsk normaltid)
OB	Office Buildings
ρ	Air density at $\theta_{i,int}$, [kg/m^3]
R	Empirical correlation, correlation coefficient
RMSE	Root Mean Square Error
σ	Standard deviation of random variable X
σ^2	Variance of random variable X
σ_{XY}	Covariance of X and Y, where X and Y are random variables with joint probability distribution
SE	Systems Engineering
SEDS	Sustainable Energy Distribution Systems
SH	Single family Houses
STD	Standard deviation
θ_{dmt}	Daily mean temperature, [°C]
θ_e	Outdoor temperature, [°C]
$\theta_{i,int}$	Indoor temperature, [°C]
TEK	Technical Regulations to the Planning and Building Act
TMY	Typical Meteorological Year
TRY	Test Reference Year
U	Coefficient of thermal transmittance for every building component, [W/($m^2 \cdot K$)]
UTC	Universal Time Coordinated (Greenwich Mean Time - GMT)
V	The building volume, [m^3]
VAV	Variable air volume
$\dot{V}_i$	Air flow rate supplied through the ventilation system, [m^3/h]
WYEC	Weather Year for Energy Calculations

DEFINITIONS

Coincidence factor

The ratio between the maximum load for the specified area and the sum of each customer's maximum load. The coincidence factor is always less or equal to unity.

Diversity factor

The inverse coincidence factor; the ratio of the sum of each customer's maximum load to the maximum load of the specified area. The diversity factor is always equal or greater than unity.

End-use

Division of energy demand into different purposes such as space heating, ventilation heating, hot tap water, lighting, pumps/fans, electrical appliances, and cooling.

Energy demand

The energy demand is the load demand integrated over a certain period of time, such as one day, one month or one year. [kWh/yr] is the most used term in this thesis.

Electricity load demand

All end-uses that have to be supplied by electricity as energy carrier, such as lighting, electrical appliances, pumps and fans.

Energy carrier

An energy carrier is a medium in which energy is storable and transportable. This thesis deals with electricity (EL), district heating (DH) and natural gas (GAS) as energy carriers for mixed energy distribution systems.

Heat load demand

All end-uses that can be supplied by electricity, district heating and natural gas alone, such as space heating, ventilation heating and hot tap water.

Load demand

The instant power/heat demand, given in [kWh/h] in this thesis. The time resolution might also be shorter for load measurements, such as 5 or 15 minutes measurement intervals.

Load curves vs. load profile

Different graphical presentations of actual measured load data vs. different graphical presentations of estimated load demand.

Load profiles

Variation in estimated load over a limited period of time; typically day, week, month and year, with a certain time resolution such as per hour or day.

Method

The different estimation techniques developed for load modelling and energy estimations.

Methodology

The fundamental background for the different methods.

Outdoor temperature

The dry-bulb temperature measured by electronic resistance thermometers.

Purposes

In this thesis; load demand for heat and electricity purposes. Heat purposes include the end-uses space heating, ventilation heating and hot tap water. Electricity purposes include the end-uses lighting, pumps/fans and electrical appliances.

ERRATA SHEET

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173 The ratio between the specific standard deviation and the specific heat or electricity load is always higher for **weekdays than weekends**.

174 The ratio between the specific standard deviation and the specific electricity load for educational buildings for both day types is much **lower** than for any other building category.

195 OB6 has not been included in this analysis due to the continuous operation of the ventilation system during both day types.

Appendix A p III and p IV

OBs in Figure 0.5 through Figure 0.8 have been labeled with wrong numbers.

Table 0.1 Corrected labels Figure 0.5 through Figure 0.8 in Appendix A

Order in label in thesis	**Correct order in label Figure 0.5 and 0.6**	**Correct order in label Figure 0.7 and 0.8**
OB1	OB2	OB7
OB2	OB7	OB6
OB3	OB6	OB4
OB4	OB4	OB5
OB5	OB5	OB1
OB6	OB1	OB3
OB7	OB3	OB2

1 Introduction

Energy planning for mixed energy distribution systems is a complex task that includes many uncertainties, such as available energy resources and energy carriers, distribution systems, expected maximum load, yearly load profiles and expected yearly energy demand. Load profiles and yearly energy demand divided into different purposes, such as heat and electricity, need to be estimated. The problem is, how should the energy planner estimate maximum load, load profiles and yearly energy demand for a specified planning area? Energy planners need this information to be able to design and operate an optimal energy system from an economically, technologically and environmentally sound basis.

1.1 Background

This thesis has been part of a project called SEDS - Sustainable Energy Distribution Systems: Planning Methods and Models. The project had two main objectives (SEDS, 2002):

1. The first objective was the development of methods and models for complex energy systems. These methods and models should optimally integrate multiple energy sources and energy carriers into the existing power system. In Norway this meant integrating with the electrical power system.
2. The second objective was the development of a scientific knowledge base. This base should be built on concepts for mixed energy systems and a consistent terminology.

A mixed energy distribution system has been defined by the SEDS project to be "*…a local energy system with different energy carriers (electricity, district heating, natural gas, hydrogen) and a mix of distributed energy sources and end-users.*" (SEDS, 2002). Figure 1.1 shows an example of a mixed energy distribution system, comprised of energy production, distribution and consumption.

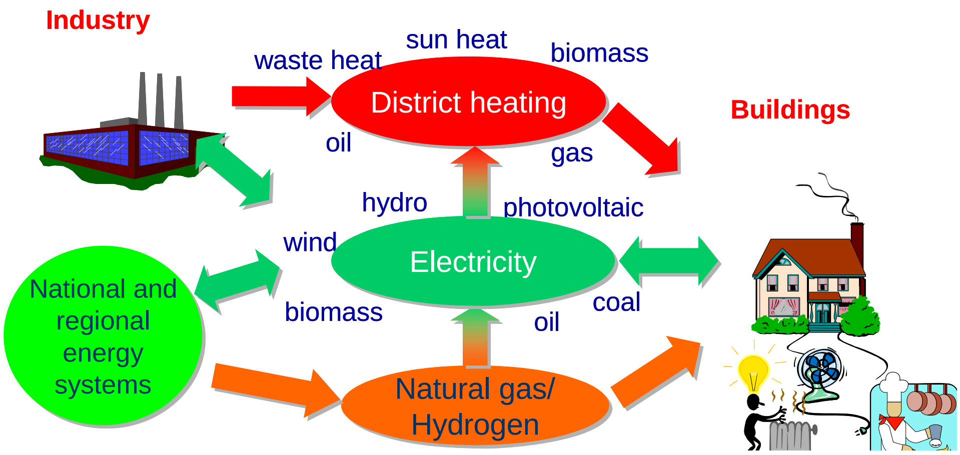

Figure 1.1 An example of a mixed energy distribution system (SEDS, 2002).

Three PhD students in the SEDS project have worked on the following topics:

- Multi-criteria planning of local energy systems with multiple energy carriers
- Quality and reliability of supply in mixed energy distribution systems
- Load modelling of buildings in mixed energy distribution systems

This thesis is the result of the third PhD study, but the work of the other two PhD projects has also been important in the progress and development of the current work.

1.2 Objectives

The objective of this thesis was to develop a method that estimates simultaneous heat and electricity load profiles primarily for design conditions, yearly load profiles, load duration profiles, and yearly energy demand for different building categories. The number of input variables have been deliberately limited. As a result, the method is relatively time-efficient and easy to use for providing load input information for the purpose of energy planning for mixed energy distribution systems.

Developing an approach to load modelling of buildings in mixed energy distribution systems meant devising a method based on a defined methodology to estimate the future heat and electricity load profiles and yearly energy demands for a specified planning area. This resulted in the requirement for the development of a method for load aggregation of the individual building category load profiles.

A planning area may include a residential housing area or the size of a small Norwegian town. For the purpose of this work, buildings in the planning area have been divided into different categories, such as single family houses and apartment blocks, office buildings, educational buildings, hospital buildings, and hotels and restaurants.

Different building categories have various uses and are also supplied by different energy carriers. In Norway, this is most likely to be electricity produced by hydropower. In White Paper No. 29 (1998-99), “Norwegian Energy Policy”, the Norwegian government has stated that the country’s power supply should be changed so that it is more flexible. One of the objectives is to increase the use of hydronic heating based on heat pumps, renewable energy sources and waste heat, with a goal of 4 TWh/year by the end of 2010. A focus on sustainable energy distribution systems may make an important contribution in reaching this goal.

1.3 Specific contributions from this thesis

This thesis makes specific contributions to the field of energy planning in general, and load modelling and yearly energy estimations divided into different purposes in particular. The specific contributions from this thesis are summarized below:

- A new method has been developed to estimate heat and electricity load profiles for various buildings based on the building’s hourly simultaneous district heat and electricity measurements.
- A new procedure has been developed to determine the change-point temperature for dividing temperature-dependent and temperature-independent heat consumption such as space heating, ventilation heating and hot tap water.

- The Student's t distribution has been found to give the best fit for hourly electricity consumption measurements, such as lighting, pumps, fans, electrical appliances and others, when divided into hours of the day and day types.
- New and generalised heat and electricity load profiles have been developed for various building categories, such as single family houses and apartment blocks, office buildings, educational buildings, hospital buildings, and hotels and restaurants.
- The division of buildings into different archetypes has been identified in relation to load profiles, especially for heat load profiles in educational buildings. The building's age and whether or not it has been subject to rehabilitation play a very important role in determining the generalised load profiles' categorisation, and not just the building category.
- Specific load and energy indicators, in [W/m^2] and [$kWh/m^2 \cdot yr$] respectively, have been calculated for heat and electricity purposes for several building categories.
- A procedure for estimating yearly load profiles and load duration profiles divided into heat and electricity purposes for the different building categories has been developed, based on generalised daily load profiles.
- A method for load aggregation has been developed to estimate the design load profiles, yearly load profiles, load duration profiles and yearly energy demand for a specified planning area, all of which have been divided into heat and electricity purposes.

1.4 Thesis organisation

The thesis is divided into nine chapters starting with the introduction. Chapter 1 is followed by a chapter that defines the problem statement and sets the system boundaries in a systems engineering manner. Load modelling from an energy planning perspective is a complex task and the problem was broken down into smaller parts in order to develop a method.

Chapter 3 describes the principal methodologies that previously have been used for load modelling and energy estimations. The advantages and disadvantages of the different methodologies have been discussed.

The theory behind the methodology most suitable for load modelling of buildings in mixed energy distribution systems has been presented. This includes a brief presentation of different statistical analyses methods.

Chapter 4 gives an overview of the different end-uses, i.e. a division of energy demand into space heating, hot tap water, lighting, electrical appliances, and more. The energy demand for different end-uses can be met by several energy carriers. The focus in this thesis has been on conductor- and pipe-based infrastructure and the energy carriers electricity, district heating and natural gas. These energy carriers have been discussed in relation to different end-uses. Finally, the different building categories used in this thesis have been discussed. Chapter 4 is intended to give the reader an overview of the field of heat and electrical energy demand.

The background information needed for load modelling is discussed in Chapter 5. The main concerns in this chapter have been the measured load data, the influence of climatic parameters on the load profile and energy demand, physical determinants, and the technical installations in the buildings, as well as the behavioural determinants influencing the load.

Chapter 6 presents the method that has been developed for load modelling of buildings in mixed energy distribution systems. The heat load model was based on regression analyses, and the electricity load model was based on normal and lognormal probability distributions. A method for the aggregation of heat and electricity load profiles has also been presented in this chapter.

The analyses and results are presented in Chapter 7 in relation to specific load and energy indicators, generalised load profiles, yearly load profiles and load duration profiles for the different building categories. The method has been verified through comparison to real measured load data for several building categories. Finally, different methods developed for load modelling in mixed energy distribution systems have been presented and compared.

In Chapter 8, the method developed for load profile aggregation divided into heat and electricity purposes has been applied to a theoretical case study.

The thesis completes with Chapter 9, which outlines concluding summary and recommendations for further work.

2 Defining the problem

2.1 Introduction

The purpose of this chapter is to define the problem, set the system boundaries and show the final solution algorithms for relative load profiles, divided into heat and electricity, generalised load profiles for different building categories, as well as an aggregation of load profiles for a specified planning area.

In order to properly define the problem, this thesis has employed techniques originally developed for systems engineering. The problem statement is the background for the doctoral thesis and will be outlined in this chapter. The chapter also provides a short introduction to systems engineering including definitions and a description of the systems engineering process. Finally, the chapter will describe how systems engineering theory, which forms the underpinnings of several important systems engineering models, has been applied in this thesis to load modelling of buildings in mixed energy distribution systems.

2.2 Problem statement

There are four questions which are important to answer when defining the problem statement:

1. What is the problem?
2. Why is this a problem?
3. What have others done?
4. What needs to be done?

When these questions are answered, the problem can be solved. The first two questions are fully answered in this chapter. The third question is mainly answered in Chapter 3: Different methodologies for load modelling, but a short answer is also presented in this chapter. The answer to the last question is the main task of this thesis and has been thoroughly investigated in Chapter 6 through Chapter 8.

2.2.1 What is the problem?

Energy planning for a mixed energy distribution system is a complex task that is complicated by many uncertainties. The most important aspect of energy planning is the economics of a project. This is closely related to access to different energy resources, energy carriers, available infrastructure and technology, as well as expected maximum load and yearly energy demand for the area in question. In order to plan for mixed energy distribution systems, it is important to estimate the expected maximum load profile and yearly energy demand divided into different purposes such as heat (space heating, ventilation heating, and hot tap water) and electricity (lighting, electrical appliances, pumps/fans, cooling, and others).

The problem is that no satisfactory methods have been found by the candidate for estimating the load profiles and energy demands divided into heat and electricity purposes applicable for energy planning for mixed energy distribution systems.

2.2.2 Why is this a problem?

It is important to know the expected maximum load and yearly energy demand divided into different end-uses or purposes throughout a system's life-cycle. Based on this information, it is possible to develop an optimal mixed energy distribution system in terms of economics, technology and environmental impact.

The maximum load value for a specific area shows the load level that the energy production unit(s) has(have) to meet and the design load profile also helps to establish which existing technology that can meet the requirements. The investment costs for a mixed energy distribution system are directly related to the maximum load value in terms of production and distribution systems.

The operation costs and the environmental impact of the energy system are dependent on the operation of the system. The annual load profile for the specific area will give an indication of the system's behaviour throughout the year and will also show the optimal operation of the mixed energy distribution system according to annual efficiency and utilisation time.

It is important to estimate the total energy demand in terms of the possible exploitation of available energy resources in the surrounding area in relation to sustainable development. The total energy demand will also have an influence on the choice of energy carrier or carriers, i.e. only electricity or a mixture of electricity and district heating/natural gas.

2.2.3 What have others done?

There are three methodologies that mainly have been used in the estimation of load profiles and energy demands for a given building or a specified planning area. These are:

1. Statistical analyses
2. Energy simulation programs
3. Intelligent computer systems

The principal methodologies and several methods derived from them are described in more detail in Chapter 3.2, including references to the various methods. Some common features recognized by the review of the latter methods are presented in the following paragraphs.

The investigated methods mainly look at total load profiles and energy demands, such as total electricity demand for buildings with electricity as the only energy carrier, or at a very specific type of load profiles and energy demands, such as electrical appliances including dish washers, stoves, and washing machines. Most methods that have been reviewed focus on very specific analyses on the individual building level or on an aggregated level including large district heating systems or electricity measurements on an aggregated level for an entire residential area, among others.

Another common factor for existing methods is that the focus has been on the energy demand alone, and not the maximum load level and the load profiles. Werner (1984) identified the problem of missing load profiles in his thesis, stating that "...*The diurnal variation in the heat load has been considered a separate problem, worth an analysis of its own*."

No methods were discovered during the review part of this thesis that would fulfil the problem statement's "What is the problem?" satisfactory.

2.2.4 What needs to be done?

To address the problem stated, a method for load modelling of buildings in mixed energy distribution systems needs to be developed. This means developing a model based on a defined methodology to enable the estimation of load profiles divided into different purposes. This task will require a great deal of data collection; the data will have to be processed and different methods will have to be reviewed. The method's input variables have to be identified in terms of their impact on the load level and energy consumption over time. A model will eventually be developed and a case study will be undertaken.

2.3 A brief introduction to Systems Engineering

Systems engineering is a discipline that can be applied when handling complex problems, such as planning an energy system with different energy producers, multiple energy carriers and distribution systems, as well as complex customer groups. Table 2.1 provides a definition of systems engineering.

Table 2.1 Definition of Systems Engineering (Sage, 1992)

Systems Engineering (SE)	Management technology to assist and support policy making, planning, decision making, and associated resource allocation or action deployment.

The key words here are "to assist and support" in terms of "planning and decision making" as load modelling of buildings is one of the most important input parameters in energy planning.

This thesis employs systems engineering through use of its process, which is "*...the ordered set of engineering steps that engineers use to go from user needs to specifications for all the components to be designed or procured*" (Keegan et al., 1997). The process may be used in a physical as well as in a conceptual system such as the development of a method for load modelling of buildings.

The systems engineering process can be broken down into five steps, as shown in Figure 2.1.

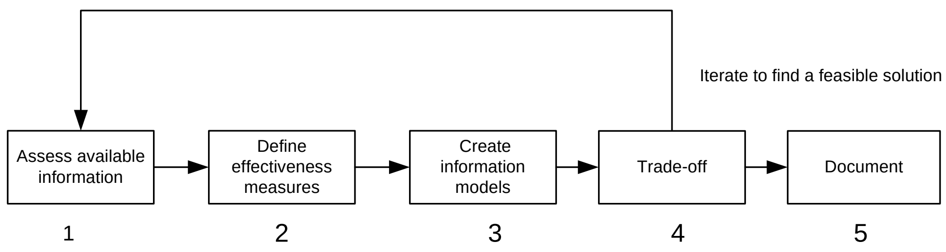

Figure 2.1 Graphical presentation of the systems engineering process (Dahl, 2003).

A brief description of the systems engineering process (Keegan et al., 1997) will help in identifying the different steps that have been employed in this thesis:

1. Assess available information in terms of evaluation and categorisation. Missing information should be obtained. It is important to identify the stakeholders in this step.
2. Define measures of effectiveness. The definition of effectiveness measures is "...*the small subset of the requirements that are so important that the system will fail if they are not met and will be a huge success if they are met. They are the important things that the product will do*" (Sproles, 2000). The stakeholders should all agree on these measures of effectiveness to avoid conflicts at a later stage in the process.
3. Create consistent information models. There are four different models that are relevant in systems engineering. These are:
   - Requirement traceability information model
   - Behaviour information model
   - Interface information model
   - Hierarchical structure information model
4. When the models have been obtained, it is necessary to make a trade-off between the different performance requirements. The best feasible design is selected on the basis of effectiveness measure values. From this step the process can either proceed to the last step, or it can be iterated to find a more feasible solution.
5. When a feasible solution has been obtained, a plan is created. This means implementing the plan into the selected architecture.

This thesis has applied selected steps from the systems engineering process to load modelling of buildings. The main focus has been on the information models.

2.4 Systems Engineering applied to the doctoral thesis

The systems engineering process has mainly been used to provide an overview of the problem, define the system and establish the system boundaries.

Systems engineering classifies a system in four different ways (Fet, 1997):

1. Closed or open
2. Natural or man-made
3. Physical or conceptual
4. Static or dynamic

An energy system, including load modelling, is an open system that features interactions with the environment. An open system is defined by information, energy and material flowing throughout the system boundaries (Blanchard and Fabrycky, 1990).

An energy system can be considered man-made in terms of energy production, distribution and consumption. These systems often have a negative effect on natural systems (Fet, 1997). An energy system affects the environment as a result of the emission of green house gasses in a global perspective. The exploitation of energy resources may cause negative ripple effects in local areas.

An energy system in itself is a physical system because it has an extension and occupies space. The development of a load model, on the other hand, is a conceptual system because it consists of ideas, specifications and plans (Fet, 1997). A conceptual system can only exist in a physical system, and in this case the load model will exist in a computer.

Finally, both the energy system and load modelling are dynamic systems that change over time. Technological and economic development, changing human behaviour, new environmental restrictions and new price incentives may all affect the method developed for load modelling. A perfect model should allow for every imaginable variable that might change the output, but naturally some future developments are impossible to foresee. To allow for all the variables that influence the load is an issue that is also beyond the scope of this thesis.

2.4.1 Assess available information

An important component of the systems engineering process is identifying stakeholders in the system. The stakeholders can be defined as "...*those who, either through "hard" or "soft" methodology, have demonstrated their need and willingness to be involved in seeking a solution*" (Sproles, 2000). This includes the parties who have an interest in the system. This group can be subdivided into (Fet, 2003):

- The customers - who pay for and own the system.
- The users - who actually make use of the system. May in some cases be identical to the customers.
- The developers - who bring the system into being by designing, developing, manufacturing and implementing the system.
- The government and the public authorities - who establish the rules for the design and operation of the system.
- The "Third Parties" - who experience unintended effects of the system.

There are many stakeholders who take an interest in load modelling of buildings in mixed energy distribution systems. Some parties are interested in the method developed, while the majority are mostly interested in the final product, which is the load profiles divided into different purposes and building categories, see Chapter 4 for more information.

The main focus in this thesis has been on the development of a method for load modelling of buildings, which is of most interest to core stakeholders as well as energy researchers. The core stakeholders are the author of this thesis as well as her supervisors.

The final product will involve a great number of stakeholders because load profiles and predicted energy demand are important parts of energy planning. The customers and users of the load profiles may be decision makers in energy utilities. This includes both producers and distributors in terms of electricity, district heating and natural gas.

The developers of new energy infrastructures might be contractors and energy utilities, of course.

On a governmental level, the Ministry of the Environment and the Ministry of Petroleum and Energy set the rules for the design and operation of energy systems. The Norwegian Water Resources and Energy Directorate has the overall responsibility for administering the country’s water and energy resources. This includes making certain that energy resources are exploited in an environmentally friendly way, as well as guaranteeing that energy systems are cost effective and that energy consumption is efficient.

The "Third Parties" are the energy consumers who in most cases can be considered dormant stakeholders.

Only the core stakeholders have had an active part in defining effectiveness measures, while the remaining stakeholders are outside the scope of this thesis.

2.4.2 The definition of measures of effectiveness (MOE)

Effectiveness measures are the most important needs and requirements of the system. These are the criteria upon which the core stakeholders should agree; these criteria are considered when making trade-off decisions. It is important that any effectiveness measures are quantifiable in some way.

The primary effectiveness measure in this thesis was to develop a method that enables the estimation of load profiles divided into heat and electricity load demand for a specified planning area. The heat load demand includes space heating, ventilation heating and hot tap water. The electricity load demand includes all end-uses that must be supplied by electricity. The specified planning area may include a few or several energy consuming buildings. The load and energy losses in the transmission and distribution of different energy carriers were also included.

The MOEs have been broken down into more precise measures:

- The method should be able to calculate load profiles divided into heat and electricity load demand for a specified planning area.
- The method must be able to handle more than one energy carrier at the same time.
- The method should have a limited number of input variables that can be obtained without extensive investigation.
- The output from the method should be adjusted to fit the input requirements from any multi-criteria planning tool that will be used.

2.4.3 Create consistent information models

There are three information models which are most relevant for load modelling and which have been used; these are the requirement traceability information model, the behaviour information model and the interface information model. This last model has been selected to obtain an overview of the energy system in general and the load modelling in particular.

Interface information model

The interface information model shows how the system interacts with surrounding systems and the environment. The system boundaries are defined using this model, with the inputs and outputs of the system defined as material, energy and information crossing the boundaries (Blanchard and Fabrycky, 1990). When applying this model in the thesis, it was important to ask "What has an impact on the system?" and "What does the system affect?"

The conceptual load model is part of the physical energy system shown in Figure 2.2. The environment is always part of an interface information model. The figure shows the energy and cash flow of the energy system. The energy flow starts with energy production, transforming primary energy resources into energy carriers. In a mixed energy distribution system, the energy carriers might be electricity, district heating and natural gas. The energy carriers are distributed through different infrastructures such as pipelines and transmission grid systems. Finally, the energy is consumed by the energy customers. The surrounding environment puts restrictions on the emission from the energy production, distribution and consumption.

In a liberalized energy market such as is found in Norway, energy trading is a very important part of the energy system in handling the energy producers' offers and the energy consumers' requests.

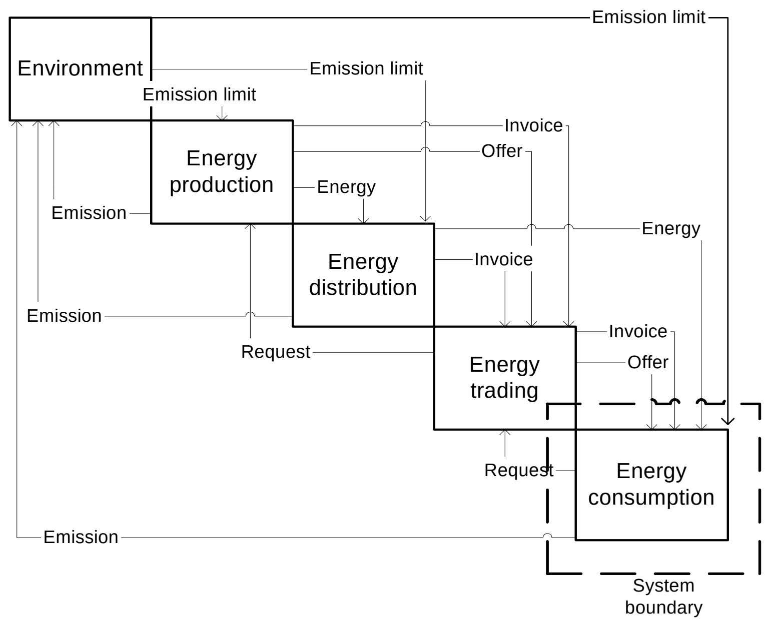

Figure 2.2 Interface information model of the physical energy system including the energy trading.

In load modelling of buildings, the main system is comprised of energy consumers, and the system boundaries have therefore been set by the energy consumption. The system should also include distribution/ transmission losses. There are several factors that influence the energy demand and load level, which will be elaborated on in Chapter 5.

The conceptual system for load modelling of buildings is presented in Figure 2.3. The three doctoral theses under the SEDS project are linked in terms of their inputs and outputs. The load modelling of buildings interacts with the environment and the development project in terms of input variables for the calculation method. The output from the load modelling of buildings is various load profiles and energy demands that are required for multi-criteria planning in particular, and in energy planning in general. This information may also be required for analyses of quality and reliability of supply.

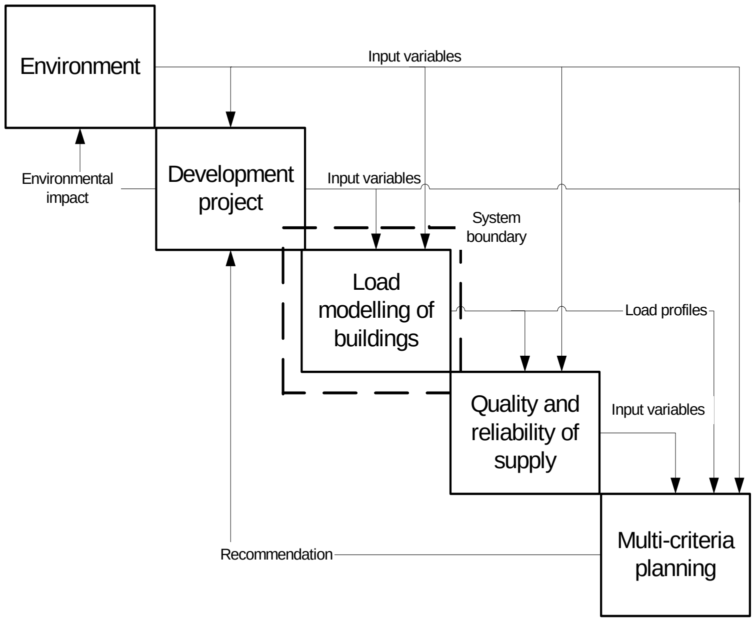

Figure 2.3 Interface information model of the conceptual SEDS-project

Behaviour information model

This model shows the desired behaviour of the system by indicating functions and their inputs and outputs. In a detailed model, the way the different inputs affect the functions are also shown.

A simplification of the behaviour information model with input and output variables is shown in Figure 2.4. The model does not show how the different inputs affect the function. The function, or in this case the method developed for load modelling of buildings, is only shown as a box. The importance of the various input variables will be discussed in Chapter 5. The methods developed for load modelling of buildings are introduced in Chapter 6 and the different outputs are presented in Chapter 7.

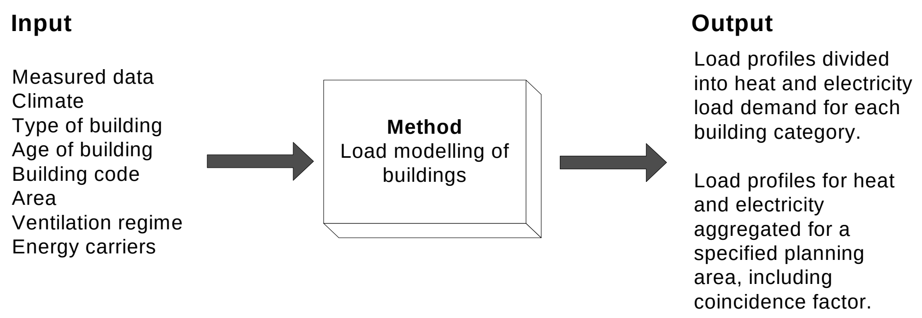

Figure 2.4 Simplified behaviour information model for the load modelling of buildings method developed.

Requirement traceability information model

The requirement traceability information model gives an overview of the needs and requirements of the system as well as the performance of the method developed for load modelling.

The system performance requirements have to be defined based on the customers' needs. Once the requirements have been defined, the system's performance specifications should be determined. This means establishing performance criteria for the total system, including subsystems and elements. These criteria should be both definable and measurable. To simplify this task, the system can be displayed in a flow chart. A flow chart shows the sequences of processes linked by input and output variables and also gives a good overview of the system (Fet, 1997).

A flow diagram (Figure 2.5) has been used to decompose the conceptual load model system in order to define input design criteria. The requirement traceability information model shows the breakdown from a source document to the allocation of functions. The breakdown of a source document into components and/or stakeholders will show how the physical components are interrelated and how the different parts of the system interact with surrounding systems (Purves and Baker, 1998).

Figure 2.5 shows that the requirements have been defined based on the source document and have been broken down into specified requirements. The final requirements call for one function and every function is performed by one component or stakeholder.

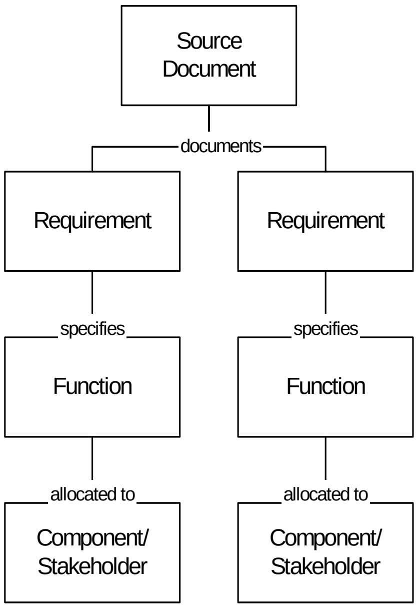

Figure 2.5 The different steps in the breakdown of a requirement traceability information model (Dahl, 2003).

In order to establish a requirement traceability information model in relation to the conceptual system of load modelling of buildings, the system's performance requirements had to be defined. These requirements are derived from the customers' needs as defined by the source document and the stakeholders.

Three source documents have been specified in the requirement traceability information model presented in this thesis; these are the Energy Act (Energiloven, 1991), the Planning and Building Act (Plan og bygningsloven, 1986) and the Energy Performance of Buildings Directive (EPBD, 2002). These source documents all concern energy planning and load modelling of buildings in mixed energy distribution systems.

Figure 2.6 shows the first step in a modified requirement traceability information model where the source documents are related to the requirements for load modelling of buildings.

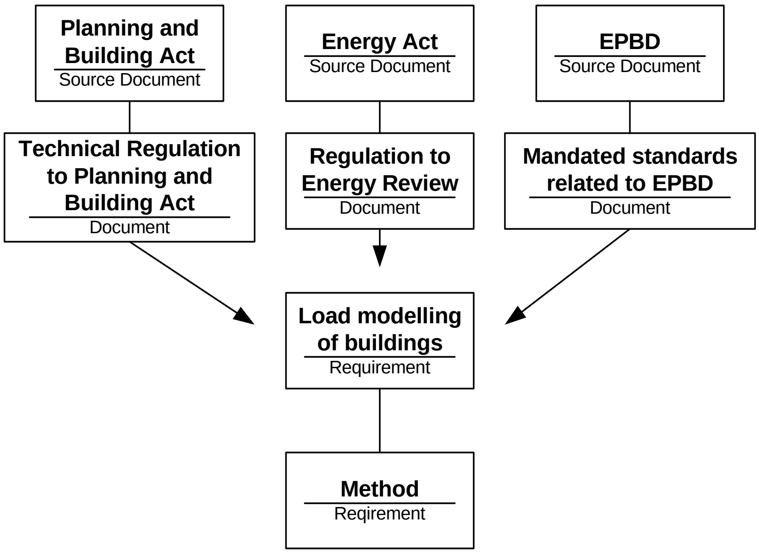

Figure 2.6 Source documents related to the requirement for load modelling of buildings and to the requirement for method development.

The Energy Act

In §7-6 in the Energy Act the law says that "*...the department can issue regulations to carry out and supplement the scope and extent of the Act.*" On the basis of this paragraph the Energy Review regulation was passed on December 16, 2002. This regulation states in §10-1 that "*...the territorial concessionaires shall prepare, yearly revise and publish energy reviews for every municipal in the concessionary area.*" Furthermore, §11-2 states that "*...the Energy Review shall include a description of expected stationary energy demand in the municipality, divided into the different energy carriers and end-users.*"

Load modelling of buildings in mixed energy distribution systems focus on stationary energy demand divided into different energy carriers and end users, defined as building categories in this thesis.

The Planning and Building Act

The Planning and Building Act includes instructions that influence the physical energy system identified by the interface information model. Both energy consumption and energy distribution are referred to in the Act itself and in the Technical Regulations (TEK) under the Planning and Building Act (1997).

There are many requirements to the buildings' technical installations and design in the Instructions to the Technical Regulations under the Planning and Building Act (Instructions to TEK, 1999). Changes in the building codes from 1949 and to present day have influenced the maximum load and yearly energy demand in buildings from the various construction periods. This influence are discussed in more detail in Chapter 5: Background information for load modelling of buildings.

In § 8-22 in the revised TEK, dating January 26, 2007, the energy supply of buildings is referred to. The revised TEK states that the infrastructure within the buildings shall be adjusted in such a way that a substantial part of the heat demand can be supplied by other energy carriers than electricity and/or fossil fuels. As a consequence, energy planning for mixed energy distribution systems for new development areas will be even more important in the near future. Heat and electricity load modelling of buildings are essential input parameters in such planning projects.

The Energy Performance of Buildings Directive

Directive 2002/91/EC of the European Parliament and of the Council of December 16, 2002 on the energy performance of buildings, or the Energy Performance of Buildings Directive, was passed on June 7, 2002 and came into force on January 4, 2003. The Directive involves all members of the European Union as well as Norway through the EEA agreement and was implemented on January 4, 2006.

"*The objective of this Directive is to promote the improvement of the energy performance of buildings within the Community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness.*" (EPBD, 2002) This includes developing a methodology that calculates the energy performance of buildings as well as establishing a platform for the energy certification of buildings. The latter includes different ratings that are divided into different energy carriers as well as different end-uses. The European and national standards derived from the Directive are currently being prepared (February 2007).

The main requirement for load modelling of buildings based on the source documents has been the development of a method with defined terminology. Figure 2.7 shows the second step in the breakdown of the requirements for a method. The main requirement has been divided into three underlying requirements; assess available data, process data and finally, present data.

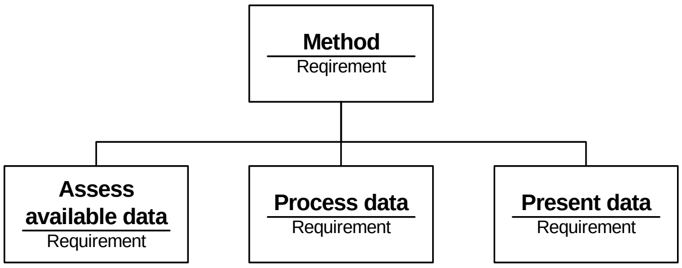

Figure 2.7 The second step in the breakdown of the requirements in a requirement traceability information model for load modelling of buildings.

Figure 2.8 gives an overview of the entire requirement traceability information model based on the requirement for load modelling of buildings.

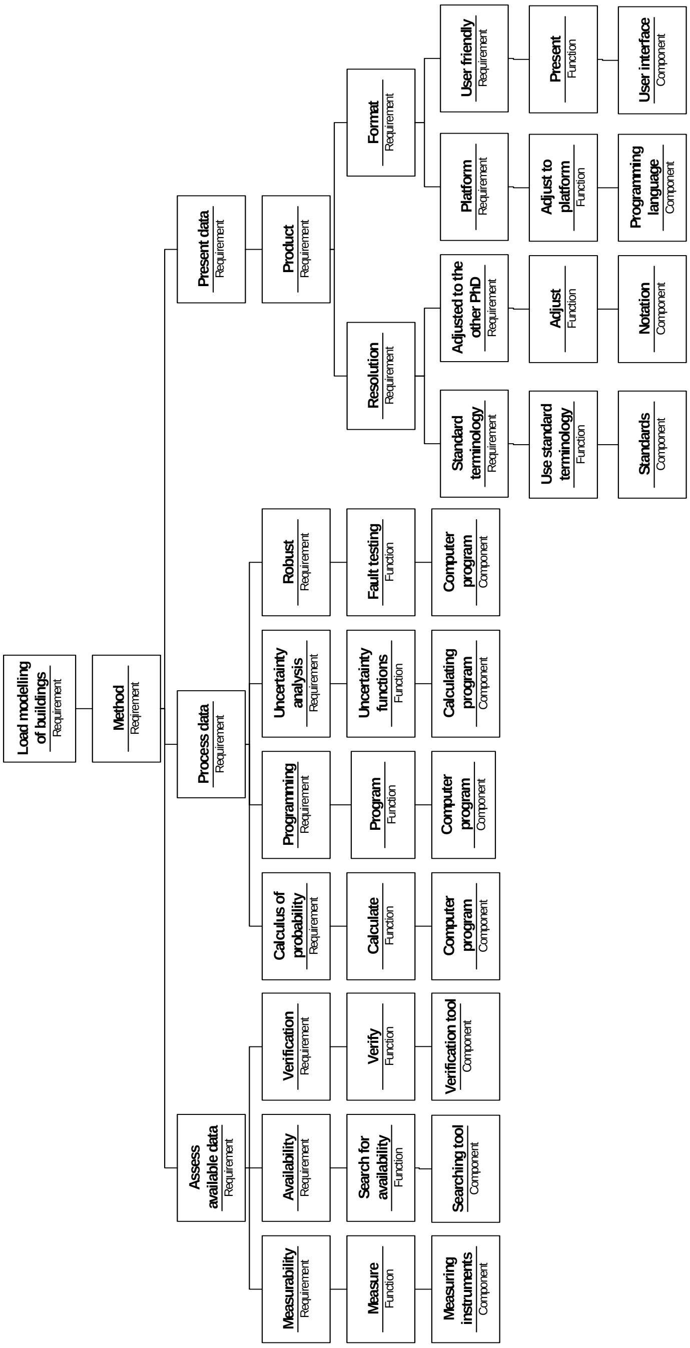

Figure 2.8 Requirement traceability information model for load modelling of buildings in the SEDS context.

Assess available data

The accession and assessment of data required for this thesis, requires measurability, availability and verification of the data collected.

Measurability requirement

This requirement included hourly simultaneous measurements of different end-uses in order to analyse load variations over time. To measure every kind of end-use in several buildings over a certain period of time is an enormous task. The main focus of this thesis has been on load demand divided into different energy carriers, i.e. thermal and electrical, and therefore, the focus has been on hourly load measurements in buildings with simultaneous district heat and electricity consumption.

District heat and electricity consumption are easily measured through automatic metering equipment. Some district heating companies in Norway have installed hourly metering equipments, a move that has become particularly widespread in large buildings. The electricity consumption in these buildings is also measured on an hourly basis.

Availability requirement

The hourly measured and collected load data had to be available to the candidate. This required obtaining permission from the various building owners in order to use the data for this research project. When the permission was granted, the load data could be accessed and downloaded from the Internet.

Verification requirement

The data have been verified in terms of quality assurance. Some data were missing while other data were incorrect. A procedure for removing incorrect data from the analysis has been established.

Process data

The data collected, which represents an extremely large quantity of information, have been processed and interpreted. This required both probability calculations and the use of computer programs. It was important to perform uncertainty analyses when analysing empirical data. The last requirement for processing data was the requirement for a robust method.

Requirement for calculus of probability

Certain tools have to be used when analysing large quantities of data. In this case statistics and probability analyses have been chosen.

Requirement for computer programs

The requirement for a program that can handle large amounts of data was crucial. The collected data have been downloaded into Excel files where the data were rearranged and coupled with other data such as year, day of the week, date, climatic parameters and more. All data have been imported to Matlab where the actual analyses were performed.

Requirement for uncertainty analysis

Even though the data have been assessed and verified, it was important to conduct an uncertainty analysis when processing the data. The sensitivity of the calculation method developed has been investigated. This also included analysing the load profiles in terms of standard deviations and quantile analyses.

Robust requirement

The method developed for load modelling had to be robust, i.e. it had to be able to analyse different kinds of buildings using the same method.

Presentation of data

The presentation of the data required a product that in itself required a certain resolution and a certain format.

Resolution requirement

The resolution needed to be adjusted to the parameters of the PhD project, which included the consideration of multi-criteria planning tools as well as the use of standard terminology.

Format requirement

The format required the product to have a specified platform and also to be user friendly.

The main focus in this thesis has been on the requirement for assessing available data and processing it, as well as some parts of the requirement for presentation of data. The format requirement has not been emphasised at this point.

2.4.4 Trade-offs and feasible solution

This thesis has involved many trade-offs and iterations in accordance to the systems engineering process. Many ideas were rejected immediately, some have been investigated and found to be inadequate, and a few led in the direction of the development of a method for load modelling of buildings in mixed energy distribution systems.

Three solution algorithms have eventually been developed for load modelling of buildings in mixed energy distribution systems:

1. An algorithm for the estimation of relative heat and electricity load profiles for individual buildings.
2. An algorithm for the generalisation of heat and electricity load profiles for each building category/archetype.
3. An algorithm for the aggregation of heat and electricity load profiles for a specified planning area.

The different solution algorithms are presented in flow charts in the following figures. The actual methods developed for load modelling of buildings are presented entirely in Chapter 6.

The main concern in this thesis has been the first algorithm. It was very important to develop a method that calculates load profiles for the simultaneous provision of heat and electricity. The load profiles had to be relative for all of the buildings analysed in order to compare several buildings under the same building category. The solution algorithm for relative load profiles for heat and electricity is shown in Figure 2.9. The different steps in the solution algorithm are thoroughly discussed in Chapter 6.

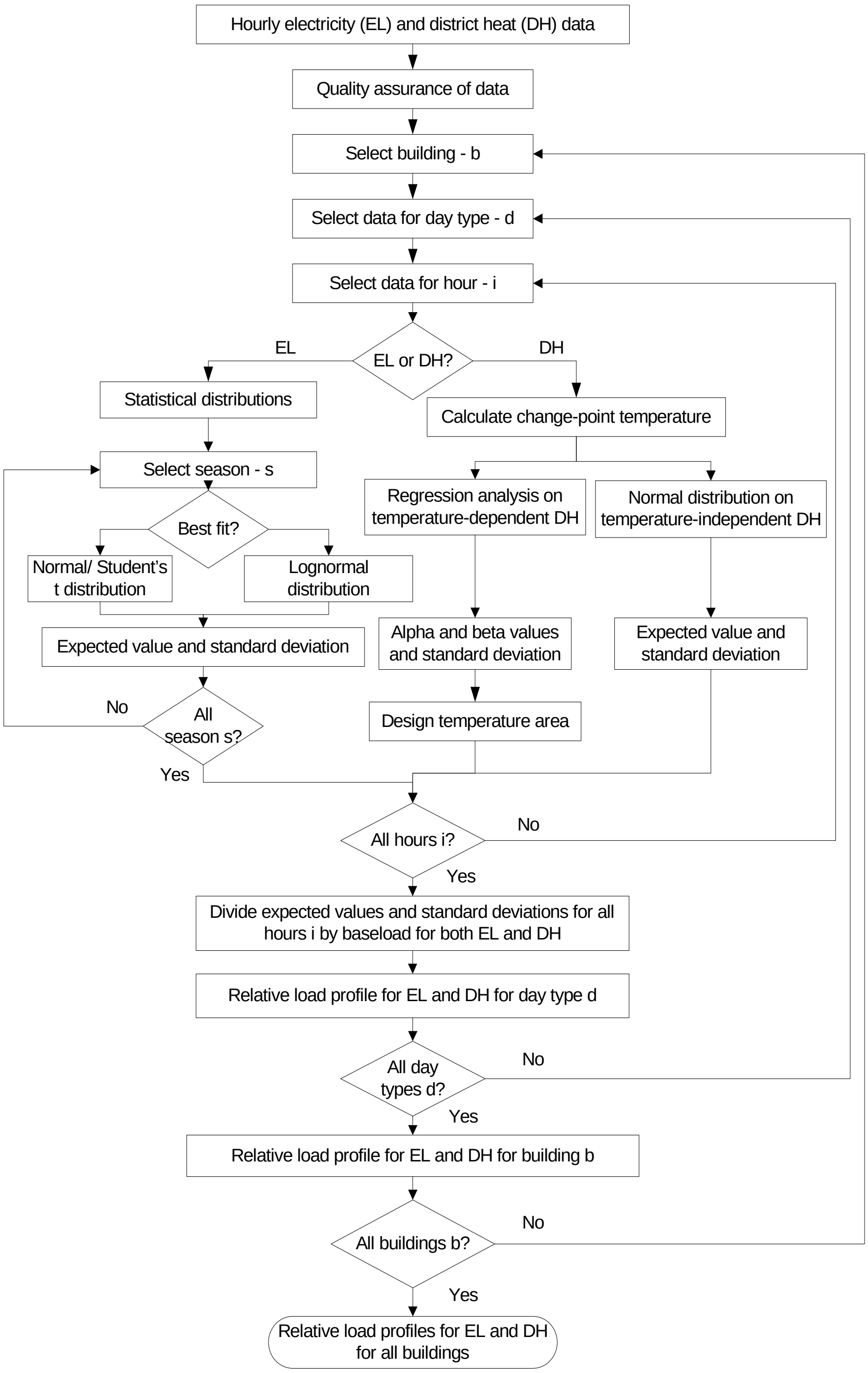

Figure 2.9 Flow chart showing the method for the estimation of relative heat and electricity load profiles for different buildings.

Figure 2.10 shows the flow chart for the generalisation of relative load profiles. The term archetype is a specific division of buildings based on criteria other than just building category, as explained more in Chapter 4.5. The generalisation algorithm is described in more detail in Chapter 6.

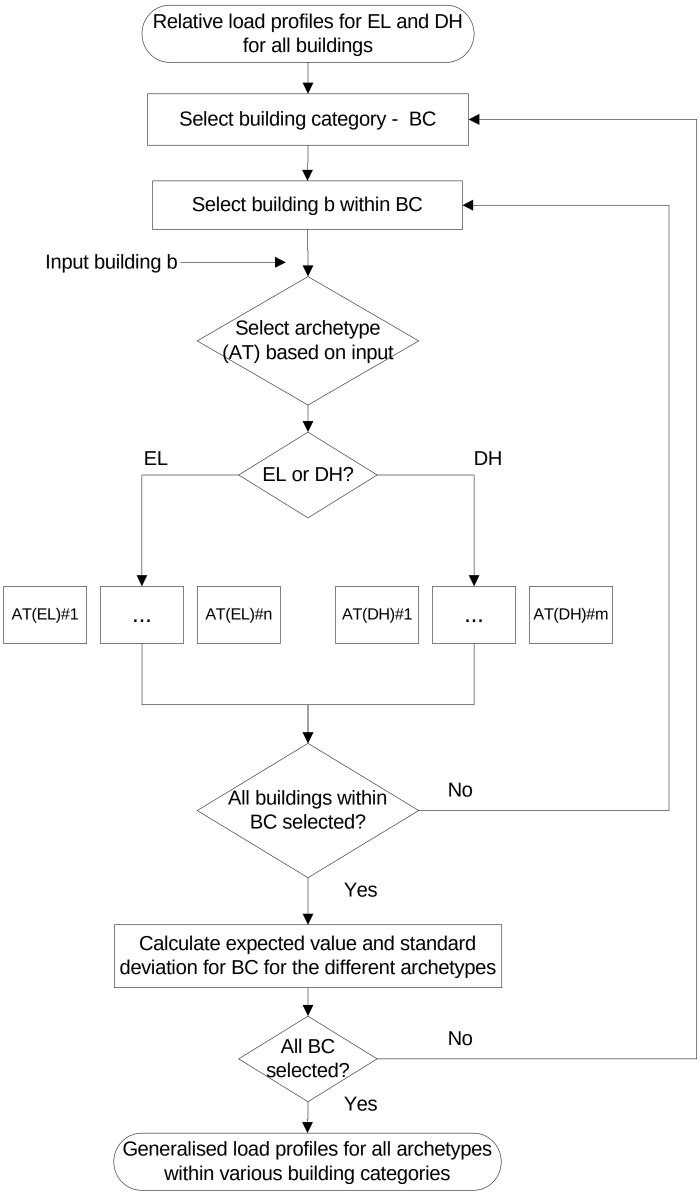

Figure 2.10 Generalisation of relative heat and electricity load profiles for a given building category or archetype.

Figure 2.11 shows the process of aggregating generalised load profiles and yearly load profiles for a specified planning area. The aggregation method is presented in Chapter 6.5 and a case study is performed in Chapter 8 in order to exemplify the aggregation method.

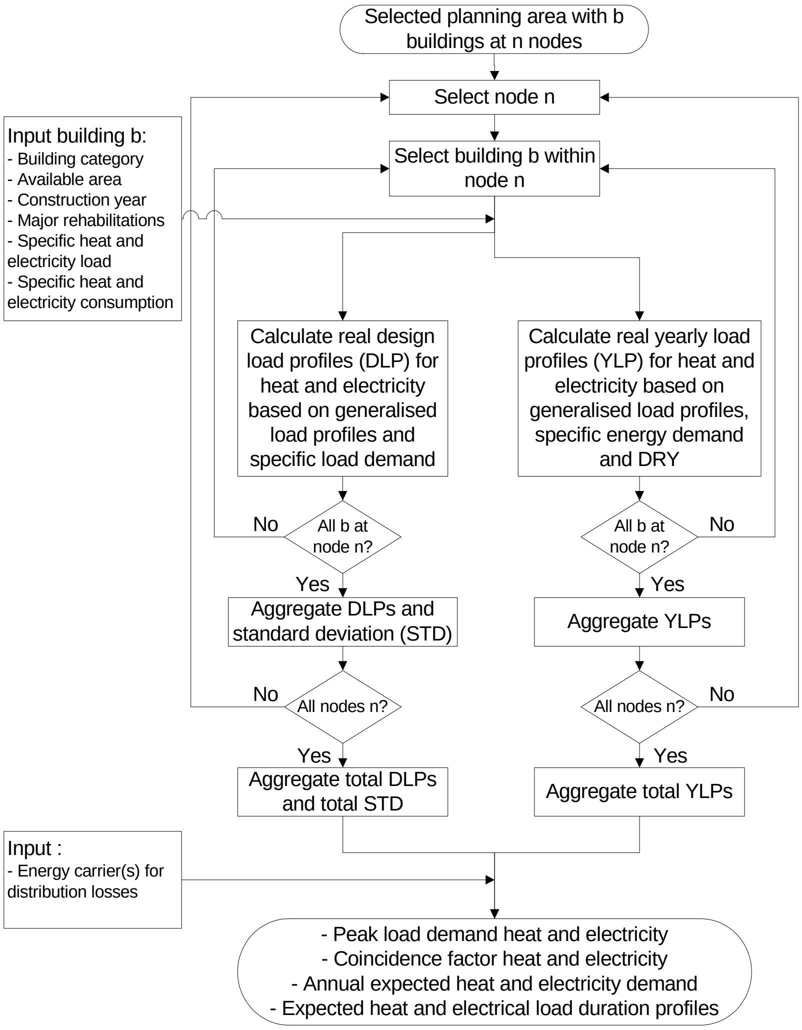

Figure 2.11 Aggregation of generalised heat and electricity load profiles and energy demand to a specified planning area including transmission load and energy losses

3 Different methodologies for load modelling of buildings

3.1 Introduction

The purpose of this chapter is to explore how other researchers have approached load modelling, as well as to provide a brief mathematical foundation for the statistical analyses applied in this thesis.

Several different methodologies have been developed for load modelling and energy estimations in buildings, and the principal methodologies are presented here in a brief literature review. Based on the literature review and the scope of this thesis, statistical analyses were chosen for load modelling of buildings in mixed energy distribution systems. As a consequence, the theoretical background for regression analyses and probability distributions are presented in Chapter 3.3.

3.2 Methodology review

Some of the paragraphs in this methodology review chapter have been taken from Pedersen (2007).

Computers and computational expansion over the last 40 years have led to the rapid evolution and improvement of calculation methods for load modelling and energy estimations (Clark, 2001). An investigation of the different methodologies being used today are presented in this chapter.

The following specifies the difference between the methodology concept and the method concept used in this thesis.

Table 3.1 Definition of the methodology and method concepts used in this thesis

Methodology	The fundamental background for the different methods.
Methods	The different estimation techniques developed for load modelling and energy estimations.

Based on an analysis of selected publications, load modelling and energy estimations can be classified according to three methodologies:

1. Statistical analyses
2. Energy simulation programs
3. Intelligent computer systems

These methodologies are elaborated on in Chapter 3.2.1 through Chapter 3.2.5.

Different methods have been developed based on these methodologies to fulfil the energy planner's requirements for an acceptable planning tool. Load modelling and energy planning tools have different requirements in terms of input data, as well as various applicabilities.

A summary of some of the specific methods developed for load modelling and energy estimations presented in the following chapters are listed in Table 3.2 in relation to the methodology they were based on.

Table 3.2 The different methodologies for load modelling and energy estimations, with examples of methods derived from them.

Methodology	**Method**
Statistical analyses	ARX model Conditional demand analysis – CDA Energy-signature EModel Finnish load model USELOAD
Energy simulation programs	DOE-2 Engineering method – EM ESP-r EnergyPlus FRES
Intelligent computer systems	Feedback Artificial Neural Networks - ANN Feed Forward Neural Networks Neural Networks – NN Probabilistic Neural Network - PNN

3.2.1 Statistical analyses

A statistical analyses approach to load modelling and energy estimation is based on large amounts of measured energy consumption data. The probability sample must have a high level of statistical significance in order to meet the accuracy requirements of the stakeholders/energy planners.

Load modelling and energy estimations are mainly based on linear or multivariate regression analyses or probability distributions. A regression analysis expresses the mathematical correlation between different variables, if a correlation in fact is present. This analysis also gives an indication of the quality of the correlation between various energy consumption measures and climatic parameters, such as load and outdoor temperature.

The representation of climatic as well as behavioural determinants are very important in terms of load modelling. Customer behaviour is more or less reflected in measured energy consumption data, but the weather data should be presented as a yearly representation of the climate at the specific location.

A selection of relevant load modelling and energy estimation methods based on statistical analyses are presented in the following paragraphs.

Werner (1984) used multiple linear regression analyses on the total district heat consumption for six different district heating companies in Sweden for heat load estimations. The focus was on the aggregated daily load level and the model was developed based on outdoor temperature, wind velocity, solar radiation, hot tap water supply, heat losses in the distribution network, as well as additional workday load.

The Energy-Signature method has been used by Aronsson (1996), among others. The method was based on linear regression analysis of heat consumption versus outdoor temperature, on a daily, weekly and monthly basis. The daily district heat consumption versus daily mean temperature, along with the daily utilisation time, was applied to estimate the building's design heat load on an hourly basis. Aronsson (1996) analysed district heating measurements of 50 buildings in his thesis, including large and small apartment blocks, office buildings, and retirement homes. The average heat load profiles for the various building categories were estimated for February 1991. The maximum specific heat load, both measured and corrected using energy-signature and utilisation time, was presented for all buildings analysed. The Extreme Outdoor Temperature (EUT5) was applied for maximum load calculations. The EUT5 is the extreme 5 day average outdoor temperature during a 30-year period.

The EModel (1993) is a linear regression change-point model that was created by Kissock to determine energy use. Operational and maintenance problems in a building can be identified based on the building's energy measurements. As a result, the model can identify retrofit savings. EModel mainly deals with daily, weekly and monthly energy consumption, but the model can also use hourly load data as input (Kissock et al., 1998).

Change-point models are piece-wise linear regression models that divide the data into several intervals and perform separate regression analyses on each interval (Kissock et al., 2003). Kissock et al. (1998) have developed two, three, four and five-parameter regression models based on a combination of search methods and least-squares regression. The models are applicable for analysing energy measurements in buildings with heating and/or cooling demand.

The Conditional Demand Analysis (CDA) has also been based on regression analysis, with the regression level on the end-use, not the total energy demand (Aydinalp et al., 2003). Different appliances (electrical equipment, cooling and heating devices) at the customer level were summed to estimate the total energy demand for each particular customer. Energy consumption, electrical appliances, demographic features, energy market prices and weather data are necessary when applying the CDA method. The method alone was relatively inexpensive, but resulted in less precise estimates for the different end-uses (Bartels and Fiebig, 1996).

Jonsson and Palsson (2002) used an AutoRegressive model with eXternal inputs (ARX) to estimate hot tap water consumption profiles in district heating systems. The district heat consumption for one small and one large area were analysed, and models were developed for both the climate-dependent and climate-independent portion. An ARX model was applied to the climate-dependent consumption including both outdoor temperature and wind speed. A non-parametric model was used to estimate the hot tap water profiles, and the number of sun hours per days was included.

Ericsson (2006a and 2006b) applied multiple regression analyses to estimate households' demand for electricity in all electric buildings with direct load control. The load data analysed were based on hourly measurements of residential dwellings' electricity consumption during a six-month period. All measured buildings had installed load control technology. The model incorporated variables such as electricity price, daylight, outdoor temperature, and wind speed, as well as several dummy variables representing hours, type of day, day of week, and month of year, among others.

Various probability distribution functions have been used for load estimations in order to calculate expected values and standard deviations. As an example, this approach has been used by Seppälä (1996) in the Finnish load model. The latter model was based on probability distribution functions such as the normal distribution for high load hours and lognormal distribution for low load hours in order to derive load profiles for all electric buildings. Altogether 46 different load profiles were developed for various customer categories, and the model predicts the average hourly electricity load and standard deviation divided into month, day type and hour.

Norén and Pyrko (1998) have developed typical load shapes for schools and hotels in Sweden based on a normal distribution of hourly electricity load measurements within different outdoor temperature intervals of 5°C. Simple regression analysis has also been performed in order to establish a relationship between daily electricity consumption and outdoor temperature.

The probability distribution approach was also used by Jardini et al. (2000) in order to estimate load profiles for residential, commercial and industrial customers, in which the electricity consumption data was assumed to be temperature-independent in all electric buildings.

In Norway, the load estimation tool USELOAD has been developed for the purpose of segmenting the measured hourly load data in all electric buildings into end-use load profiles (Feilberg, 2002). The method was based on seasonal regression analyses as well as normal probability distribution for the purpose of aggregating electricity load for each hour of the day. Various buildings within different building categories have been analysed to produce typical load profiles, and the regression coefficients for each building have been stored in the USELOAD database. Several electrical appliances, lighting, and hot tap water consumption have been measured at an hourly interval, allowing for the development of typical load profiles for the various end-uses. The space heating load profiles were estimated as the difference between the whole building load profile minus the total of all measured end-use profiles. As a result, the ventilation heating was included in the space heating end-use.

An ASHRAE Research Project called "Compilation of diversity factors and schedules for energy and cooling calculations" was undertaken by the Energy Systems Laboratory at Texas A&M University during 1999 - 2000 (Abushakra et al., 1999a, 1999b, 2000). The first part of this project was a literature review that considered diversity factors and methods used in deriving load shapes. The focus was on commercial buildings and especially office buildings, as well as load shapes for electricity purposes only, with an emphasis on disaggregation of different end-uses. Most methods presented in the review were based on statistical analyses, as well as statistical analyses in combination with simulation programs. Examples of the latter methods have been presented in Chapter 3.2.3.

Although this thesis has focused on load demand divided into heat and electricity purposes, and not the different end-uses in particular, the ASHRAE Research Project provided valuable background information about load modelling.

3.2.2 Energy simulation programs

Simulation programs are “*…an attempt to emulate the reality*” (Clark, 2001). Consequently, energy simulations in buildings require a large amount of data, both precise weather parameters and detailed building descriptions. Simulation programs mainly model energy conservation in buildings, including transmission, ventilation and infiltration losses. In addition, the model may include hot tap water consumption as well as lighting, electrical appliances and internal heat gains (Clark, 2001).

Energy simulation programs are mainly based on two different modelling techniques; the response function method (an analytical method) and the numerical method. Response function methods solve linear differential equations that include time invariant parameters, while numerical methods use non-linear, time varying equation systems. Even though programs based on the response function method are easier to validate in most cases, the numerical methods are preferred because they can solve the equations simultaneously, handle complex flow path interactions and accommodate time varying system parameters (Clark, 2001).

The primary numerical method is a nodal network representation of the building. This means that the whole building, or one specific room, is divided into segments where each segment is represented by one node. Energy conservation equations are developed for each node and the entire nodal network is solved simultaneously. Many simulation programs are based on the nodal network model, but the differences lie in the solution techniques (Clark, 2001).

Examples of some energy simulation programs are ESP-r (Clark, 2001), EnergyPlus (EnergyPlus, 2003), Engineering Method – EM (Aydinalp et al., 2003), DOE-2 - Department of Energy (DOE-2, 2007), and FRES - Flexible Room Climate and Energy Simulator (FRES, 1993).

3.2.3 Hybrid models

There are also several hybrid methods derived from a combination of statistical analyses and simulation programs. Two examples of models based on both statistical analyses and simulation programs are presented in the following paragraphs.

The Energy-use Disaggregation Algorithm (EDA) developed at the Lawrence Berkely National Laboratory is an example of a hybrid model (Akbari, 1995). Preliminary HVAC (Heating, Ventilation and Air-Conditioning) end-use loads were estimated based on the building energy simulation program DOE-2. The non-HVAC end-uses were estimated based on installed capacities and reported schedules. Average whole-building Energy Use Indicators (EUI or ECI - Energy Consumption Indicators) were estimated for various building categories (Akbari et al., 1994). Finally, the EDA was applied to reconcile the preliminary end-use load shapes and the whole-building EUIs using a linear regression analysis of hourly electricity measurements. The temperature-dependent load was estimated using visual inspection of scatter plots (Akbari, 1995).

Another example of a hybrid method was developed by Katipamula and Haberl (1991). Various load shapes, including the mean values and the standard deviations, were derived for typical day types based on monitored non-weather-dependent electricity use. These load shapes were used as input into DOE-2 and three main day types were identified: HIGH, NORMAL and LOW (Abushakra et al., 1999a).

3.2.4 Intelligent computer systems

The last methodology for load modelling and energy estimations presented here is called intelligent computer systems, or artificial intelligence, where the systems consist of expert systems and artificial neural networks. Both computer systems go beyond straightforward programming. Expert systems “make decisions” based on an interpretation of data and a selection among alternatives. Neural networks are trained in relation to a set of data until the network recognizes the patterns presented. The artificial neural network may then make predictions based on new patterns (Kalogirou, 2001).

The latter system is the most suited for load modelling and energy estimations because it is able to handle incomplete data which might result from measured energy data and climatic parameters. Neural networks can also solve non-linear problems as well as “*…exhibit robustness and fault tolerance*” (Kalogirou, 2001).

Artificial neural networks were applied to identify different electricity load profiles in New Zealand homes (Tries et al., 2000). A pattern recognition probabilistic neural network (PNN) algorithm was used to classify electricity load profiles based on a large number of electricity measurements.

An example of an energy estimation method based on intelligent computer systems for the prediction of energy demand in Canadian households, called the Neural Network method (NN), has been presented by Aydinalp et al. (2003). The NN model estimates end-use energy consumption in buildings based on three networks developed; a hot tap water consumption network, a space heating network, and an appliance, lighting, and space cooling network. This last network included 55 input units alone.

González and Zamarreño (2005) developed a feedback artificial neural network model to predict hourly energy consumption in buildings, mainly electricity. Short-term load forecasting (STLF) can also predict electricity load for intervals of one minute to one week for buildings, regions and countries, based on the feedback artificial neural network

Karatasou et al. (2006) used feed forward neural networks along with statistical procedures to model energy use and load profiles in all electric buildings. Input variables such as temperature, solar flux, humidity, windspeed, hour of day, day of week, and day of year were included.

Two open competitions announced by ASHRAE, The Great Energy Predictor Shootout I and II, had the purpose of identifying good models for predicting hourly energy use in buildings (Kreider and Haberl, 1994; Haberl and Thamilseran, 1996). Among the six winners of the first Shootout were models based on both neural networks and piece-wise linear regression.

3.2.5 Comparison of the different methodologies

The methodologies presented here differ in many ways in terms of what kind of input data they require and when and where to use them. This chapter provides a short discussion of the input data as well as a discussion of when and where to use the different methodologies.

The amount of input data required by the methodologies differs according to the accuracy level of the calculations. Statistical analyses primarily need load measurements, but climatic parameters and some background information on the measured buildings are also important. Simulation programs, on the other hand, do not need load measurements, but climatic parameters and detailed information about the buildings are very important. The latter methodology also requires information about consumer behaviour, i.e. behavioural determinants. Intelligent computer systems process measured load data, climatic parameters, behavioural determinants and background information about the buildings. The more accurate information provided to the intelligent computer system, the better results the solution algorithm will give. This is also true for statistical analyses and simulation programs, because the quality of the input data will automatically reflect in the quality of the results.

All three methodologies can provide both short-term and long-term predictions for load and energy demand. Long-term predictions are the most interesting from the energy planner's point of view. The uncertainty factors concerning the input parameters are important to acknowledge, especially in terms of the climatic representation. The yearly representations of weather parameters are discussed in Chapter 5.3.3: Different representations of climatic parameters.

The methodologies presented have been further developed into more specific load modelling and energy estimation tools, but their applicability is based on the program foundation. Statistical analyses are primarily used in load modelling and energy estimations involving several customers, i.e. energy planning for a specific development area with many energy consumers. Because of the detailed nature of simulation programs, this load modelling and energy estimation tool is applicable for one or a few large customers. For example, simulation programs are very good at analysing retrofitting options of already existing buildings. Simulation programs may also be used for several customers, but the output would be based on theory alone, and not the real behaviour of the buildings. The application of intelligent computer systems may be used on the building level as well as the regional and national level.

Statistical analyses have been chosen as the methodological background for the method developed for load modelling of buildings in mixed energy distribution system in this thesis. The reasons for this are:

- Sustainable energy distribution systems (SEDS) involve energy planning for development areas with many buildings. Statistical analyses give good estimates for large samples.
- The objective of this thesis was to derive load profiles for different building categories divided into heat and electricity purposes. Analyses of actual energy consumption measurements provide a real picture of load patterns, including both physical and behavioural determinants, as well as control regimes.
- Statistical analyses of actual load measurements can estimate the expected load value and the standard deviation applicable for a planning area. The latter variable includes the uncertainty in the analyses. A large sample reduces the estimation errors of the statistical analyses.
- The building design load and the actual load may differ a great deal. As a consequence, a model based on statistical analyses of actual load data was preferred to the simulation programs.
- Energy simulation programs were found to be too detailed for the purpose of load modelling of buildings in mixed energy distribution systems, because of the large number of buildings included in a planning area. Simulation programs require a large amount of input data regarding the buildings in the system boundaries of the planning area. Collection of such data would be very time consuming for the energy planner.

- Statistical analyses will give approximately the same output as neural networks when physical relationships are already known. The number of input variables to a potential neural network model would have been limited.
- A method based on neural networks may find correlations that are incorrect due to the lack of transparency in the hidden or operational layer.

3.3 Methodology based on statistical analyses

Statistics are mainly used to analyse the possible relationship between collected data. First off all, the data set is analysed to see if any relationship exists. If so, the observed relation is investigated to see if the relation between data is significant or if the relation is due to chance. If a relationship is present, it is also interesting to see how strong the relationship between the data is.

The method developed for estimation of load profiles divided into heat and electricity demand is mainly based on regression analyses and probability distributions. This chapter presents background information on statistical analyses, with an emphasis on regression analyses and probability distributions.

3.3.1 Basic statistics

First of all, some basic theory regarding statistical analyses from Walpole et al. (1998) are presented in terms of:

- Mean value
- Variance and standard deviation
- Confidence interval for mean value

Mean value

The mean value is the expected value of the random variable X or the average of the probability distribution of X. The mean value is denoted as E(X).

Let X be a random variable with probability distribution f(x). The mean value or expected value of X is:

$$\mu = E(X) = \sum_{x} x f(x) \tag{3.1}$$

if X is discrete,

and:

$$\mu = E(X) = \int_{-\infty}^{\infty} x f(x) dx \tag{3.2}$$

if X is continuous.

A ***discrete probability distribution*** contains only random variables, and assumes each of its values with a certain probability. An example of such a variable could be the tossing of a coin several times and the probability of getting a head every time. A ***continuous probability distribution***, on the other hand, contains random variables which have a probability of zero of assuming exactly any of its values. An example of the latter distribution could be the height of all people above a certain age.

Load modelling is based on energy consumption measurements, with the resolution of the collected data dependent on the measuring equipment and the actual logging accuracy. The heat and electricity load values are characterized as continuous random variables, and consequently, the load modelling has been based on the continuous probability distributions.

Variance and standard deviation

Let X be a random variable with probability distribution f(x) and mean value, μ. The variance of X is:

$$\sigma^2 = E[(X-\mu)^2] = \int_{-\infty}^{\infty} (x-\mu)^2 f(x) dx \tag{3.3}$$

if X is continuous.

The variance for a discrete variable X is disregarded since continuous variables have been used in this thesis.

Standard deviation is the positive square root of the variance and is called sigma, σ.

Confidence interval for mean value

A (1-α)100% confidence interval of the mean value, μ, when the standard deviation, σ, is known, is given by:

$$\left(\bar{x} - \frac{z_{\frac{\alpha}{2}} \cdot \sigma}{\sqrt{n}} < \mu < \bar{x} + \frac{z_{\frac{\alpha}{2}} \cdot \sigma}{\sqrt{n}}\right) \tag{3.4}$$

$\bar{x}$ is the mean of a random sample of size *n* and the $z_{\alpha/2}$ is the z-value leaving an area of $\alpha/2$ to the right. The sample must be normally distributed or the number of measurements must exceed n = 30.

3.3.2 Regression analyses

Linear regression analyses have been used in order to analyse the measured district heat data. In this thesis the main focus was on simple linear regression analyses in terms of estimating heat load profiles in relation to outdoor temperature. District heat and electricity consumption have been simultaneously measured at hourly intervals, with these data collected for several buildings within different building categories. Background information concerning the buildings and different climatic parameters have also been collected and investigated. A thorough presentation of the background information for load modelling of buildings can be found in Chapter 5.

Some of the most commonly used concepts in the field of statistical analyses are investigated in this chapter in relation to regression analyses; these are:

- Empirical correlation
- Regression equation and the least square method
- Confidence intervals for the regression analyses
- T-test

These concepts have been used in the method developed for load modelling of heat demand and in the analyses of the results.

Empirical correlation

The correlations found in the data set are very interesting in the context of linear relation. The empirical correlation is based on the covariance, σ_{XY}, which is defined below (Løvås, 2004):

$$\sigma_{XY} = \frac{1}{n-1} \cdot \sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y}) \tag{3.5}$$

If we have *n* pairs of observations, their empirical correlation is called R. The numerical value of R is denoted *r*.

The empirical correlation R is defined as (Løvås, 2004):

$$R = \frac{\sigma_{XY}}{\sigma_X \cdot \sigma_Y} = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})^2} \cdot \sqrt{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}} \tag{3.6}$$

where σ_X and σ_Y are standard deviation of X and Y respectively. σ_{XY} is the covariance of X and Y, see Equation 3.5.

R is a stocastic variable with a certain probability distribution. The correlation has the following interpretation:

1. The value of *r* is between -1 and 1.
2. The absolute value of *r* indicates how strong the linear correlation between X and Y is. The greater absolute value, the stronger the correlation.
3. The sign of *r* indicates the trend of the correlation.

The r-value has been important in the development of the method for load modelling of heat load profiles.

Regression equation and the least square method

A simple linear regression model defines the correlation between a single independent regressor variable x and a single dependent random variable Y. The regression equation describes the relation (Løvås, 2004):

$$Y_i = \alpha + \beta x_i + e_i \tag{3.7}$$

where e_i describes the error in the fit and is called a residual. There are three requirements for the residuals (Løvås, 2004):

1. The variance of the residuals must be constant, and independent of x.
2. The residuals must be independent of each other.
3. The residuals must have a normal distribution.

To apply the linear regression model to a set of data, the least square method has been used in order to estimate the regression coefficients β and α (Løvås, 2004):

$$\hat{\beta} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=n}^{n}(x_i - \bar{x})^2} = r \cdot \frac{\sigma_Y}{\sigma_X}, \qquad \hat{\alpha} = \bar{y} - \hat{\beta}\bar{x} \tag{3.8}$$

When the regression coefficients are estimated, it is important to check how strong the relationship between the data sets is. The value of r^2 shows the percentage of the variation which can be explained by a linear relation. A correlation of $r = 0.8$ indicates that 64% of the data set has a linear relation.

Confidence intervals for the regression analyses

Confidence intervals are constructed in relation to different probability distributions, see Chapter 3.3.3 for examples. The idea is to find the probability of a variable occurring inside the given interval. The confidence interval is written as $(1-\alpha)100\%$, where the alpha value is the level of significance, and not the regression coefficient in Equation 3.7. The confidence interval may often vary from 90 to 99% for various levels of significance.

The assumption that each residual e_i, $i = 1, 2, ..., n$, is normally distributed has to be made in order to construct a confidence interval for a regression analysis. This also implies that $Y_1, Y_2, ..., Y_n$ are normally distributed. Walpole et al. (1998) conclude that the static T has a Student's t distribution and that a $(1-\alpha)100\%$ confidence interval for the coefficient β can therefore be constructed based on Theorem 8.4 and Theorem 8.5.

A $(1-\alpha)100\%$ confidence interval for the regression coefficient β in the regression line $\mu_{Y|x} = \alpha + \beta x$ is (Walpole et al., 1998):

$$\left(\hat{\beta} - \frac{t_{\frac{\alpha}{2}} \cdot s}{\sqrt{\sigma_x}} < \beta < \hat{\beta} + \frac{t_{\frac{\alpha}{2}} \cdot s}{\sqrt{\sigma_x}}\right) \tag{3.9}$$

where $t_{\alpha/2}$, with the alpha value defining the level of significance, is a value of the Student's t distribution with n - 2 degrees of freedom.

A $(1-\alpha)100\%$ confidence interval for the regression coefficient α in the regression line $\mu_{Y|x} = \alpha + \beta x$ is (Walpole et al., 1998):

$$\left(\hat{\alpha} - \frac{t_{\frac{\alpha}{2}} \cdot s\sqrt{\sum_{i=1}^{n} x_i^2}}{\sqrt{n\sigma_x}} < \alpha < \hat{\alpha} + \frac{t_{\frac{\alpha}{2}} \cdot s\sqrt{\sum_{i=1}^{n} x_i^2}}{\sqrt{n\sigma_x}}\right) \tag{3.10}$$

where $t_{\alpha/2}$ is a value of the Student's t distribution with n - 2 degrees of freedom.

The main focus of this thesis has been on the confidence limits for the mean value $\mu_{Y|x}$. A (1-α) 100% confidence interval for the mean response $\mu_{Y|x}$ for a given x-value is (Løvås, 2004):

$$\mu_{Y|x} = \hat{\alpha} + \hat{\beta}x \pm \left(t_{\frac{\alpha}{2}} \cdot s\right) \sqrt{\frac{1}{n} + \left(\frac{\frac{x-\bar{x}}{s}}{\mathrm{SE}(\hat{\beta})}\right)^2} \quad (3.11)$$

where $t_{\alpha/2}$ is a value of the Student's t distribution with n - 2 degrees of freedom. For more theory about confidence intervals in relation to regression analyses, the reader is referred to Løvås (2004), Walpole et al. (1998) or other books on statistics in general and regression analyses in particular.

T-test

A T-test may be applied when trying to determine if there is a relation between the variables x and y. This test has been used when analysing the district heat and electricity consumption. The null hypothesis has been established accordingly (Løvås, 2004):

H_0 No relation between the variables, i.e. $\beta = 0$

H_1 There is a relation between the variables, i.e. $\beta \neq 0$

A t-test is constructed based on the test observation:

$$\mathrm{T} = \frac{\hat{\beta}}{\mathrm{SE}(\hat{\beta})} \quad (3.12)$$

where:

$\mathrm{SE}(\hat{\beta})$ Standard error for the $\hat{\beta}$ found by the positive square root of Var(β)

The null hypothesis with level of significance α is rejected if $|\mathrm{T}| > t_{\alpha/2}$

3.3.3 Continuous probability distributions

Electricity consumption has been found to be less dependent on climatic conditions than district heat consumption. In order to analyse electricity consumption, the data measured have been analysed in relation to continuous probability distributions.

Examples of some continuous probability distributions are shown in the list below:

- Normal distribution
- Lognormal distribution
- Student’s t distribution/t (-scale) distribution
- Weibull distribution
- Chi-squared distribution
- Exponential distribution
- Gamme distribution
- Geometric distribution

Total electricity loads are most commonly assumed to have a normal distribution; however, Weibull distribution has also been applied, along with studies including several other distribution functions. On the other hand, a report concerning statistical methods for load research data analysis also concludes that "*...electric load variation does not follow any common probability density function.*" (Seppälä,1996).

The Finnish load model is based on hourly measurements of electricity consumptions in buildings with electricity as the only energy carrier, meaning that electricity is also used for heat purposes. In this thesis it has been desirable to investigate how the electricity load was distributed and if the electricity load followed any common probability density function in buildings with more than one energy carrier.

Seppälä (1996) has shown that the normal distribution applies for total electricity load during high load periods (day hours), while lognormal distribution applies during low load periods (night hours). Consequently, these distributions and others have been examined in relation to electricity load analyses in mixed energy distribution systems.

The following paragraphs explain some of the theory behind the normal, the lognormal and the Student's t distributions. The lognormal distribution applies when a natural log transformation results in a normal distribution (Walpole et al., 1998).

Normal distribution

A random variable X is normally distributed with mean value, μ, and standard deviation, σ, if the density function equals (Walpole et al., 1998):

$$n(x;\mu,\sigma) = \frac{1}{\sqrt{2\pi}\cdot\sigma}e^{\frac{-(x-\mu)^2}{2\sigma^2}}, \ (-\infty < x < \infty) \tag{3.13}$$

where:

π 3,14159...

e 2,71828...

The mean value, E(X), and the variance, Var(X), of the normal distribution are calculated from Equation 3.2 and Equation 3.3 respectively to be:

$$E(X) = \mu \tag{3.14}$$

$$Var(X) = \sigma^2 \tag{3.15}$$

From Walpole et al. (1998) we have these properties of the normal curve:

1. The mode occurs at x = μ, i.e. at the point on the horizontal axis where the curve is at maximum.
2. The curve is vertically symmetrical around the mean value, μ.
3. The points of inflection occurs at x = $\mu \pm \sigma$.
4. The normal curve approaches the horizontal axis asymptotically in either direction away from the mean value.
5. The total area above the horizontal axis and under the curve is equal to 1.

The normal distribution curve is a bell-shaped symmetric curve. Figure 3.1 shows three examples of normal distribution curves where the mean value and the standard deviation vary.

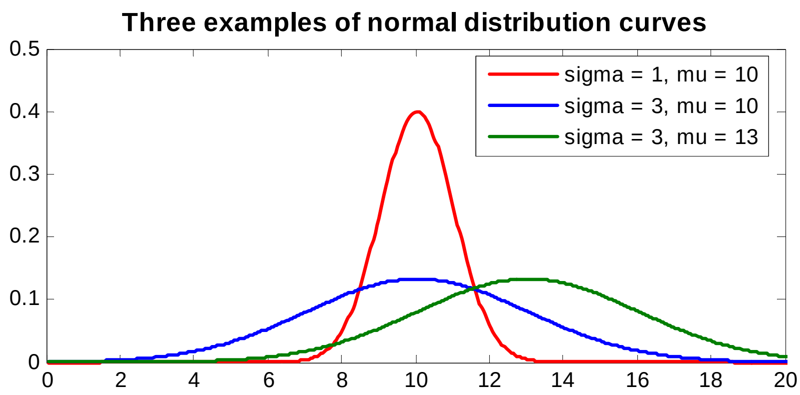

Figure 3.1   Three examples of normal distribution curves where the standard deviation (σ, sigma) and mean value (μ, mu) vary.

Another important aspect of the normal distribution is the central limit theorem. It says that if X is the mean of a random sample of size n, and the sample is taken from a population with mean, μ, and finite variance, σ^2, then the limiting form of the distribution of:

$$Z = \frac{\bar{X} - \mu}{\frac{\sigma}{\sqrt{n}}} \tag{3.16}$$

as $n \to \infty$, is the standard normal distribution n(z;0,1) (Walpole et al., 1998).

Lognormal distribution

If the random variable Y = ln(x) has a normal distribution with mean value, μ, and standard deviation, σ, the continuous random variable X has a lognormal distribution. The density function of X equals (Walpole et al., 1998):

$$f(x) = \begin{cases} \frac{1}{\sqrt{2\pi} \cdot \sigma \cdot x} e^{\frac{-(\ln(x) - \mu)^2}{2\sigma^2}} & x \geq 0 \\ 0 & x < 0 \end{cases} \tag{3.17}$$

The mean value, E(X), and the variance, Var(X), of the lognormal distribution are calculated from Equation 3.2 and Equation 3.3:

$$E(X) = e^{\mu + \frac{\sigma^2}{2}} \tag{3.18}$$

$$Var(X) = e^{2\mu + \sigma^2} \cdot (e^{\sigma^2} - 1) \tag{3.19}$$

Figure 3.2 shows three examples of lognormal distribution curves where the mean value and the standard deviation vary.

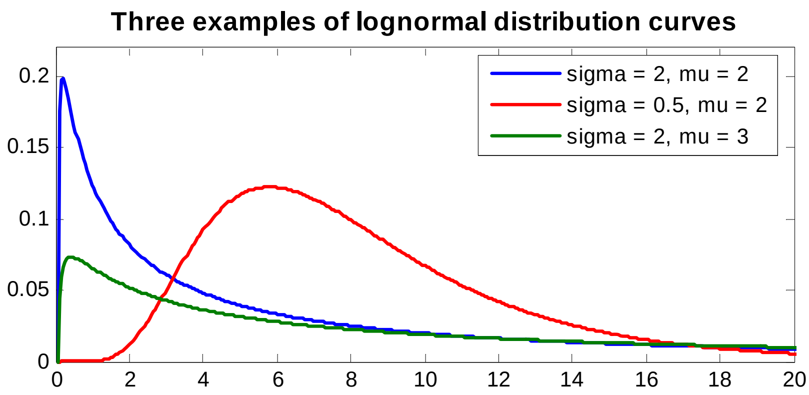

Figure 3.2 Three examples of lognormal distribution curves where the standard deviation (σ, sigma) and mean value (μ, mu) vary.

Student's t distribution

The central limit theorem assumes that the standard deviation σ is known. Often, the standard deviation *S* is the best guess of the value of σ. The probability distribution of the variable T is the following (Løvås, 2004):

$$T = \frac{\bar{X} - \mu}{\frac{S}{\sqrt{n}}} \tag{3.20}$$

The distribution of T is dependent on the sample size, and since the variables Z and T are almost identical, the variables' distributions are also quite similar.

In the Statistics toolbox in Matlab (2004), the Student's t distribution is presented as a family of curves. The curve is only dependent on the single variable ν (nu) which corresponds to the degrees of freedom. The Student's t distribution converges at the standard normal distribution as ν goes to infinity.

For all practical purposes, the Student's t distribution may be substituted by the normal distribution when the sample size exceeds 30. The sample for each hour specified by weekday or weekend includes several hundred measurements for every building analysed. For simplicity, the normal distribution has been applied for load hours showing the best fit to

Student's t or normal distributions when analysing the electricity load and the temperature-independent heat load. Lognormal distribution has been applied for load hours when this distribution showed the best fit.

4 Energy use in buildings

4.1 Introduction

The purpose of this chapter is to give an overview of and to classify the different end-uses for heat and electricity that have been examined as a part of this thesis. The energy carriers included in the SEDS project are presented along with building category division and the actual buildings analysed in this thesis.

The main focus of this thesis has been on stationary energy consumption, as was shown in the physical and conceptual interface information models in Chapter 2.4. Load modelling of buildings from an energy planning perspective also incorporates energy distribution, i.e. load and energy losses from the distributed energy production unit to the customers.

The focus has been on energy consumption in the building sector, and the vast differences in load and energy demand in the industry sector have not been included in the analysis. This is partly because of a lack of simultaneous heat and electricity measurements for this sector as well as the need for specific analyses of the individual industrial processes when incorporating industry in a distributed energy system. The transport sector has not been part of the SEDS project and therefore has not been analysed in this thesis.

Figure 4.1 gives an overview of building categories as defined in the Energy Performance of Buildings Directive, as well as different end-uses and conductor- and pipe-based energy carriers presented in this thesis.

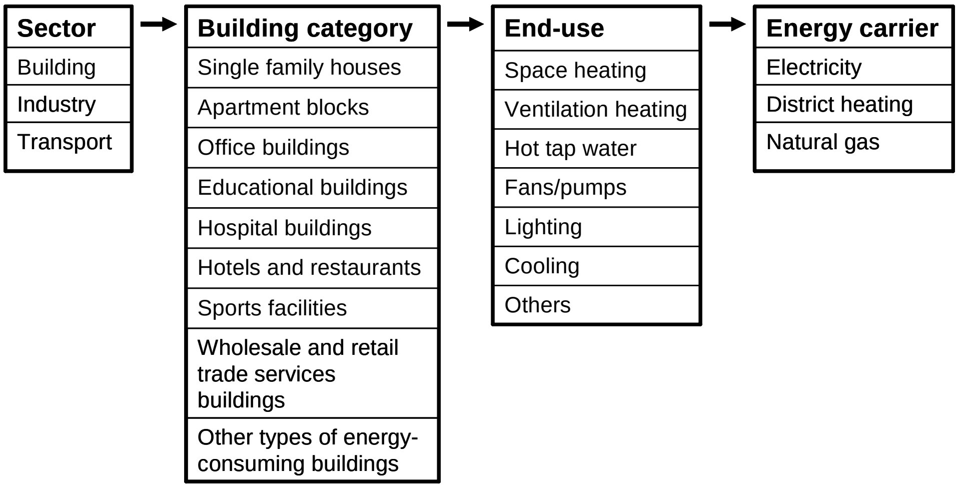

Figure 4.1 Overview of the building categories, end-uses and energy carriers that are presented in this thesis.

This chapter will first focus on energy consumption and the different end-uses. Secondly, the different energy carriers that can supply the different end-uses are discussed. Thirdly, the rationale behind the division of buildings into different categories according to standards, directives and level of detail is elaborated on. Finally, the concept of archetypes is introduced.

4.2 Energy end-use

Energy consumption may be divided into detailed end-uses such as space heating, lighting and electrical appliances, as is discussed in Chapter 4.2.1. On an aggregated level, energy consumption may be divided into heat and electricity consumption. The electricity load demand has been defined in this thesis to include all end-uses that must be supplied by electricity, while heat load demand includes the end-uses that may be supplied by other energy carriers such as district heating, natural gas and electricity. Heat and electricity load demand are presented in Chapter 4.2.2 and Chapter 4.2.3 respectively.

4.2.1 End-use divisions

The classification of different end-uses has been presented in the Norwegian Standard 3032 *"Energy and power budgets for buildings",* as well as in the Energy Performance of Buildings Directive.

The Norwegian Standard 3032 "*Energy and power budgets for buildings*"

The Norwegian Standard 3032 (1984) was designed for residential buildings, service buildings and minor industry, but it is also possible to apply this standard to other building categories.

In NS 3032 the load and energy demand are divided into eight subordinated end-use categories:

1. Space heating
2. Ventilation heating
3. Hot tap water
4. Fans/pumps
5. Lighting
6. Various
7. Cooling
8. Others

The different end-uses are discussed in detail in Chapter 4.2.2 and Chapter 4.2.3.

Due to the introduction of the Energy Performance of Buildings Directive, new standards for end-use, calculation methods, energy factors and related topics are under preparation (February 2007). As a consequence, many national standards will be replaced, including NS 3032.

The Energy Performance of Buildings Directive (EPBD)

One of the objectives of the Energy Performance of Buildings Directive is to improve the energy performance of buildings by introducing energy certification of buildings. The energy performance certificate of a building is defined in Article 2, § 3 (EPBD, 2002):

"A certificate, recognised by the Member State or a legal person designated by it, which includes the energy performance of a building calculated according to a methodology based on the general framework set out in the Annex."

The annex to the EPBD describes nine aspects in relation to end-use that at a minimum shall be included in the methodology for calculating the energy performance (EPBD, 2002):

a) Thermal characteristics of the building (shell and internal partitions, etc.). These characteristics may also include air-tightness,

b) Heating installation and hot water supply, including their insulation characteristics,

c) Air-conditioning installation,

d) Ventilation,

e) Built-in lighting installation (mainly the non-residential sector),

f) Position and orientation of buildings, including outdoor climate,

g) Passive solar systems and solar protection,

h) Natural ventilation,

i) Indoor climatic conditions, including the designed indoor climate,

In relation to the EPBD several CEN standards are under revision or construction. In Article 7, § 2 states that "*The energy performance certificate for buildings shall include reference values such as current legal standards and benchmarks in order to make it possible for consumers to compare and assess the energy performance of the building* " (EPBD, 2002).

In prEN 15603 (2006); "*Energy performance of buildings - Overall energy use, CO2 emissions and definition of ratings*", two principal options for the energy ratings of buildings have been proposed: ***measured rating*** and ***calculated rating****.*

Measured rating

- Based on measurements of actual energy consumption.
- Displays the actual energy performance of a building.

Calculated rating

- Based on calculations of the building's energy demand for heating, cooling, ventilation, hot tap water and lighting.
- Standard input data for climatic conditions and occupancy.
- Possible to compare different buildings.

Energy consumption under actual conditions is classified by measured rating, while energy consumption under standard conditions is classified by a calculated rating. Figure 4.2 shows a sketch of the different ratings for classifying energy consumption, either by measuring the different energy carriers or by calculating the demand for different end-uses.

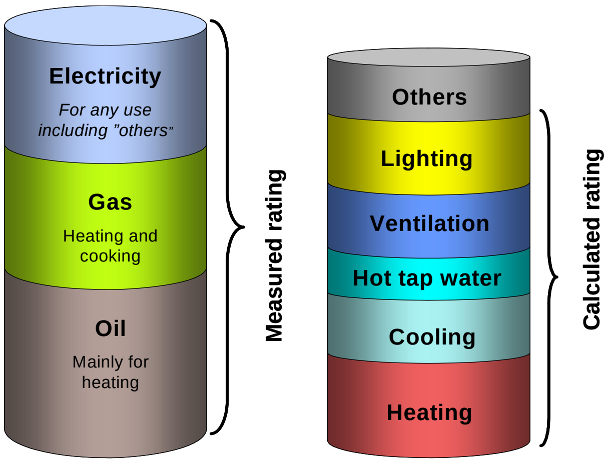

Figure 4.2 An illustration of the difference between measured and calculated ratings (prEN wi 4, 2004).

The main difference between the measured rating and the calculated rating is the human behaviour factor and various types and applications of electrical appliances included in the "Others" end-uses classification.

Comparison

The various end-use divisions are summarized and compared in Table 4.1. The end-use categories "Various" from NS 3032 and "Others" from EPBD include electrical appliances such as TVs, VCRs, DVDs, refrigerators, stoves, dishwashers, washing machines, and more. Some literature also characterizes these individual appliances as separate end-use categories. This level of detail is beyond the scope of this thesis and has consequently been disregarded.

Table 4.1 Comparison of different end-use divisions listed in NS 3032, with EPBD's nine aspects and calculated rating.

NS 3032	EPBD aspects	Calculated rating
1. Space heating	a), b), f)	Heating
2. Ventilation heating	d)	Ventilation
3. Hot tap water	b)	Hot tap water
4. Fans/pumps	d)	Others
5. Lighting	e)	Lighting
6. Various		Others
7. Cooling	c)	Cooling
8. Others		

It is important to keep in mind that a strict division between different end-use categories is almost impossible due to the interaction between the various end-uses. The different loads may influence one another, i.e. the use of electrical appliances and lighting may influence space heating demand and the use of one electrical appliance may lead to the need to use another electrical appliance.

The end-use categorisation in this thesis has been divided into two overarching types, heat load demand and electricity load demand, as illustrated in Table 4.2.

Table 4.2 Overarching types and corresponding end-use categorisations

Purpose	Heat load demand	Electricity load demand
End-use included	Space heating	Pump/fans
	Ventilation heating	Lighting
	Hot tap water	Electrical appliances

Cooling has been disregarded, as will be explained in Chapter 4.2.3. The different end-uses will be described in more detail following.

4.2.2 Heat load demand

Heat load demand is comprised of the load demand for space heating, ventilation heating and hot tap water. Hot tap water is a demand that is year-round and is mostly independent of climatic conditions. Space heating and ventilation heating, on the other hand, are very much dependent on the outdoor temperature, wind velocity, season, sun hours, and more.

Figure 4.3 shows the heat load demand vs. outdoor temperature. The figure gives an idealized view of the temperature ranges in which different end-uses occur.

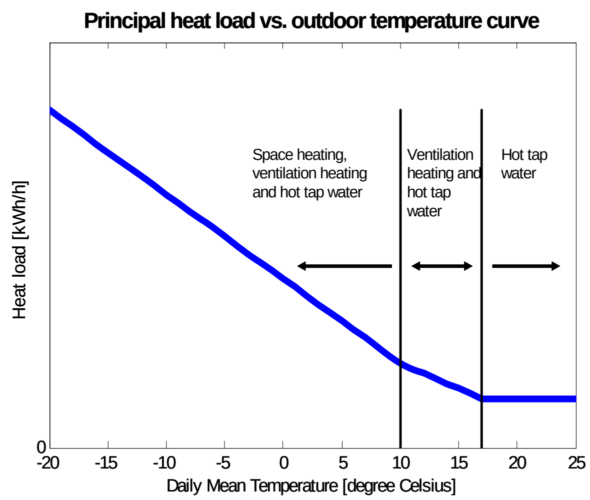

Figure 4.3 Load-temperature curve for hourly heat consumption for a building or an area.

The heating season, as defined in Table 4.3, is shown as occurring at daily mean temperatures until the outdoor temperature reaches 10°C (the average temperature for the start of the temperature dependent season), as shown in Figure 4.3. The inlet air in a ventilation system is usually supplied at a temperature of around 17°C in order to provide an acceptable indoor climate. If a heat recovery system has been installed in the building, the heat load demand will flatten out at a temperature that is lower than the daily mean temperature of 17°C. When the daily mean temperature increases above a certain level, 17°C in Figure 4.3, the only heat load demand will be for hot tap water.

Table 4.3 Definition of the heating season.

Heating season	The duration of time from when the daily mean temperature drops to below 11°C in the fall until the daily mean temperature rises above 9°C in the spring, given in hours [h] (Hanssen et al., 1996)

The design heat load demand for a given building, *i*, is calculated according to the European Standard prEN 12831 (2002):

$$\Phi_{HL} = \sum \Phi_{T,\,i} + \sum \Phi_{V,\,i} + \sum \Phi_{RHT,\,i} \text{ [W]} \tag{4.1}$$

where:

$\sum \Phi_{T,\,i}$ Sum of transmission heat losses of all heated spaces excluding the heat transferred inside the building entity or the building, in [W].

$\sum \Phi_{V,\,i}$ Ventilation heat losses of all heated spaces excluding the heat transferred inside the building entity or the building, in [W].

$\sum \Phi_{RH,\,i}$ Sum of heating-up capacities of all heated spaces required to compensate for the effects of intermittent heating, in [W].

The heating-up capacity needed in buildings with set-back control regimes, i.e. buildings with night set-back or weekend set-back, has not been analysed in detail in this thesis due to the small number of buildings in the sample with this type of control regime.

The different end-uses included in the calculation or measurement of heat load demand are discussed according to their unique characteristics in the following sections.

Space heating

Definition (NS 3031, 1987):

"*Space heating is the load or energy needed to cover transmission and infiltration losses*"

Space heating is the amount of energy deliberately supplied to cover the losses mentioned above. Space heating will also cover some of the energy demand intended for the ventilation heating end-use category.

The demand for space heating can be modelled as proportional to the difference between the indoor and outdoor temperatures. A calculation with greater precision will require consideration of temperature changes over time, internal heat gain, sun hours and wind velocity, among others.

Design transmission heat loss can be calculated for a heated space or building, *i*, according to prEN 12831 (2002):

$$\Phi_{T,i} = (H_{T,ie} + H_{T,iue} + H_{T,ig} + H_{T,ij}) \cdot (\theta_{i,int} - \theta_e) \text{ [W]} \tag{4.2}$$

where:

$H_{T,ie}$	Transmission heat loss coefficient from heated space, *i*, to the exterior, *e*, through the building envelope, in [W/K].
$H_{T,iue}$	Transmission heat loss coefficient from heated space, *i*, to the exterior, *e*, through the unheated space, in [W/K].
$H_{T,ig}$	Steady state ground transmission heat loss coefficient from heated space, *i*, to the ground, *g*, in [W/K].
$H_{T,ij}$	Transmission heat loss coefficient from heated space, *i*, to a neighbouring heated space, *j*, heated at a significantly different temperature, in [W/K].
$(\theta_{i,int} - \theta_e)$	The difference between the indoor temperature and outdoor temperature [°C].

The focus of this thesis has been on the building level. The detailed calculation methods for the transmission heat loss coefficient at the building level can be found in prEN 12831 (2002). A simplification of the four different elements in Equation 4.2 is shown in Equation 4.3:

$$\Phi_T = \sum U_j \cdot A_j \cdot (\theta_{i,int} - \theta_e) \text{ [W]} \tag{4.3}$$

where:

U_j Coefficient of thermal transmittance for every building component, *j*, in [W/($m^2 \cdot K$)].

A_j Area for every building component, *j*, in [m^2].

The effect of thermal bridges and different reduction factors as described in prEN 12831 (2002), have not been discussed. The transmission loss is mainly due to the thermal transmittance of energy through every building component, along with the area of every building component. The guidelines for u-values have changed according to the building codes from different construction and rehabilitation periods, which may have a significant impact on the demand for space heating.

Ventilation heating

Definition (NS 3031, 1987):

"*Ventilation heating is the load or energy needed to heat the supply air, limited by the indoor air temperature, minus the heat given by the fan motor.*"

Ventilation heating is the amount of energy used to heat the supply air until the temperature reaches indoor air temperature. In new ventilation systems, the supply air temperature is slightly lower than the indoor air temperature due to the internal heat gain from lighting, people and appliances. In buildings with low internal heat gain the space heating system will cover the remaining ventilation heat demand. As a consequence, it can be problematic to measure this end-use category without including space heating.

Design ventilation heat loss is calculated for a heated space or building, *i*, according to prEN 12831 (2002):

$$\Phi_{V,i} = H_{V,i} \cdot (\theta_{i,int} - \theta_e) \text{ [W]} \tag{4.4}$$

where:

$H_{V,i}$ Design ventilation heat loss coefficient, in [W/K]

According to prEN 12831 (2002) the design ventilation heat loss coefficient $H_{V,i}$ is calculated as follows:

$$H_{V,i} = \dot{V}_i \cdot \rho \cdot c_p \text{ [W/K]} \tag{4.5}$$

where:

$\dot{V}_i$ Air flow rate of heated space, in [m^3/s]

ρ Air density at $\theta_{i,int}$, in [kg/m^3]

c_p Specific heat capacity of air at $\theta_{i,int}$, in [kJ/kg · K]

This equation may be reduced to:

$$H_{V,i} = 0,34 \cdot \dot{V}_i \text{ [W/K]} \tag{4.6}$$

assuming constant ρ and c_p. $\dot{V}_i$ is given in [m^3/h].

No ventilation system

According to prEN 12831 (2002), infiltration losses are included as a part of ventilation losses, and consequently, the air flow rate in Equation 4.6 is found by Equation 4.7 when there is ***no ventilation system present*** in the building.

$$\dot{V}_i = max(\dot{V}_{i,\,inf}, \dot{V}_{i,\,min}) \text{ [m}^3\text{/h]} \tag{4.7}$$

where:

$\dot{V}_{i,\,inf}$ The maximum of the infiltration air flow rate, in [m^3/h]

$\dot{V}_{i,\,min}$ The minimum air flow rate required for hygienic reasons, in [m^3/h]

Infiltration is the air flow through cracks and joints in the building envelope resulting from a pressure difference between the inside and the outside of a building, with the air flow rate found by Equation 4.8 (prEN 12831, 2002).

$$\dot{V}_{i,\,inf} = 2 \cdot V_i \cdot n_{50} \cdot e_i \cdot \varepsilon_i \text{ [m}^3\text{/h]} \tag{4.8}$$

where:

V_i Volume of heated space, *i*, in [m^3]

n_{50} Air exchange rate occurring at a pressure difference of 50 Pa between the inside and the outside of a building, in [h^{-1}]

e_i Shielding coefficient, [-]

ε_i Height correction factor, [-]

The volume of the heated space is constant, but the pressure difference may change due to the wind speed and direction.

The minimum air flow rate required for hygienic reasons is mainly specified in the regulations to the national building codes. The air flow rate is calculated assuming the maximum number of people in a space, *i*, and emissions from the building materials. However, if the air contaminations from activities and processes are large, the required air flow rate is calculated on this behalf (TEK, 1997).

Balanced ventilation system

Balanced ventilation systems are becoming more common in new and retrofitted buildings. The difference between these buildings and buildings without ventilation systems is that the supply air may not have the same thermal characteristics as the external air. This is mainly due to the heat recovery systems used, but the external air may also be pre-heated centrally or supplied from adjacent spaces.

The design ventilation heat loss coefficient, $H_{V,i}$, is calculated on the basis of infiltration, supply air flow rate, the temperature reduction factor and surplus exhaust air flow rate. See prEN 12831 (2002) for more details.

For most buildings analysed as a part of this project, the ventilation systems include heat recovery systems with temperature efficiencies between 0.5 and 0.8 depending on the type and age of the heat recovery unit. The temperature efficiency of the heat recovery unit is included in Equation 4.9.

$$H_{V,i} = \dot{V}_i \cdot \rho \cdot c_p \cdot (1 - \eta) \text{ [W/K]} \tag{4.9}$$

where:

η The temperature efficiency of the heat recovery unit, [-]

A detailed analyses of the different kinds of ventilation systems is outside the scope of this thesis and thus will not be discussed. The control regime of the ventilation systems, on the other hand, has been analysed in relation to the heat load profiles for the different building categories. The heat capacity is constant, but the air flow rate and the temperature efficiency of the heat recovery unit may change throughout the day and year.

Hot tap water

Definition (NS 3031, 1987):

"*Hot tap water is the amount of load and energy needed for the heating of hot water.*"

Hot tap water is the amount of load and energy needed to heat water for use. It can be measured in electrical distribution systems, but in a district heating network a separate meter is required on the hot tap water side to be able to separate demands for space heating, ventilation heating and hot tap water. This end-use category may vary from being relatively small in office buildings to relatively large in private households. Hot tap water does not include the heating of hot tap water for washing machines and dishwashers.

The heat load demand for hot tap water, Φ_{htw}, is dependent upon the mass flow and the increase in temperature (Fredriksen and Werner, 1993):

$$\Phi_{htw} = \dot{m}_{hw} \cdot c_{p,w} \cdot (\theta_{hw} - \theta_{cw}) \text{ [W]} \tag{4.10}$$

where:

$\dot{m}_{hw}$ Water flow, in [kg/s]

$c_{p,w}$ Specific heat capacity of water, in [J/kg · K]

θ_{hw} Temperature of hot outlet water, in [°C]

θ_{cw} Temperature of cold inlet water, in [°C]

Aronsson (1996) has shown that the hot tap water consumption is slightly dependent upon season, mainly because of the seasonal variations in the cold water inlet temperatures.

The instantaneous heat load for hot tap water may be quite high. Most buildings analysed in this thesis have installed hot tap water containers or accumulator tanks, even though direct hot tap water heating is the most common in district heating systems (Volla, 1996). Buildings supplied by electricity or natural gas for preparation of hot tap water usually have installed accumulator tanks. The time resolution of one hour reduces the measured district heat load for hot tap water preparation in buildings with direct hot tap water heating.

Based on the latter phenomena, the hot tap water demand has not been analysed in detail for the various energy carriers. However, the direct hot tap water preparation in district heating systems is designed on the basis of summer load because of the decrease in primary water temperature and reduced mass flow. As a consequence, the hot tap water heat exchangers will supply sufficient heat load during the winter design load. If the heating system should experience insufficient heat load for a short period of time, the thermal inertia of the buildings will efficiently reduce this effect.

Internal heat gain

The internal heat gain includes excess heat from persons, equipments and lighting, as well as radiant-flux density. The hourly measured district heat consumption included heat gains, and as a result, the internal heat gain has not been discussed separately in this thesis.

4.2.3 Electricity load demand

Electricity load demand consists of the load demand for pumps and fans, lighting and electrical appliances. Pumps and fans may be dependent on climatic conditions as well as daily and seasonal variations. Lighting is mostly dependent on daily and seasonal variations along with behavioural determinants. Electrical appliances are mostly dependent on behavioural determinants. Cooling demand, which is usually covered by electricity in the Norwegian building sector, has not been included in this thesis because of the small number of buildings with cooling units. Additionally, the lack of measurements for this end-use category has also contributed to the decision to omit cooling in this thesis.

The different end-uses that comprise the electricity load demand are discussed according to their unique characteristics in the following sections.

Pumps and fans

Definition (NS 3031, 1987):

"*Pumps and fans comprise the load and energy needed to run the circulation pumps in the heating and cooling systems as well as the fans in the ventilation system.*"

Pumps and fans as a category represents an easily measurable quantity with respect to the running the ventilation, heating and cooling systems in buildings. This end-use is closely related to heat load demand, and therefore, temperature dependent to some extent. Pumps and fans are strongly dependent on the control regime in the building, such as the influence of night or weekend set-backs affecting the pump, or the influence of motion and/or CO_2-sensors influencing the air supply rate.

Hydronic heating systems including pumps may be controlled by mass flow or temperature, or by an interaction between mass flow and temperature. This may result in different utilisation time for the pumps, and consequently, different electricity loads and energy demands.

The ventilation system is based on the air supply and the fan is related to the supply air rate. Electricity loads and energy demands for fans are closely related to the control regime of the ventilation systems. The different buildings analysed in this thesis mainly have two different control regimes (Sørensen, 2001):

- CAV - Constant Air Volume
- VAV - Variable Air Volume

A detailed division of the possible approaches to controlling indoor air quality is given in Table 4.4 (NS-EN 13779, 2004). IDA - C 1 through C 3 may be classified as CAV-systems, while IDA - C 4 through C 6 may be classified as VAV-systems. Several of these types of control systems have been used in buildings that were measured and analysed for the purposes of this thesis. The impact on the ventilation heating and consequently the heat load demand due to the different control regimes is discussed in Chapter 7.

Table 4.4 Indoor air quality control categories as shown in NS-EN 13779 (2004) table 13

Category	**Description**
IDA - C 1	No control The system runs constantly.
IDA - C 2	Manual control The system runs according to a manually controlled switch.
IDA - C 3	Time control The system runs according to a given time schedule.
IDA - C 4	Occupancy control The system runs dependent on the presence of people in the control zone
IDA - C 5	Presence control The system runs dependent on the number of people in the control zone.
IDA - C 6	Direct control The system is controlled by sensors measuring indoor air parameters or adapted criteria (e.g. CO_2, mixed gas, VOC)

Lighting

Definition (NS 3031, 1987):

"*Lighting is the load and energy needed to supply the indoor lighting system.*"

Lighting covers all indoor lights and may be dependent on seasonal variations due to hours of daylight and sun, the building's utilisation time and behavioural determinants, among others. According to NS 3031 (1987), the heat gain from lighting in the household sector is dependent on the month of the year, with a higher heat gain from lighting in January than in May. This implies seasonal variations.

The control, or lack of control, of the lighting system has a direct influence on the load profile and energy demand for this end-use. There are several different ways of controlling lighting, both manually and automatically as well as centrally and/or locally.

Different sensors, such as motion sensors and daylight sensors can be used to automatically control the lighting system in a building and/or building zones. The division of buildings into different zones for control purposes also allows for time control of the lighting systems. This is quite widespread for new buildings with central control and monitoring systems.

All electricity used for lighting purposes will eventually be transformed into heat and used for heat purposes to some extent.

Electrical appliances

Definition (NS 3031, 1987):

"*Various includes load and energy demands not included in any other end-use category.*"

Electrical appliances (included in "Various" in NS 3031 and "Others" in the calculated ratings in Table 4.1) as a category consists of electrical appliances commonly used in the building sector such as TVs, VCRs, DVD-players, stereo systems, computers, white goods, kitchen machines, fax machines, printers, and other related appliances.

The electricity consumption for electrical appliances is strongly dependent on the type of building and the amount of technical equipments. This end-use is mainly affected by behavioural determinants and is thereby governed by cultural influences and habits.

Another important factor when looking at electrical appliances is the amount of electrical standby consumption. One definition of standby was found on the standby home page; http://standby.lbl.gov/index.html, which is based on the IEA Standby Power Initiative:

"*Standby power use depends on the product being analysed. At a minimum, standby power includes power used while the product is performing no function. For many products, standby power is the lowest power used while performing at least one function.*"

These products may include elevators, emergency lighting, computers, fax machines, telephones, remote controls, and many more. In Ross and Meier (2000) standby consumption in the household sector accounts for as much as 10% of the national household electricity consumption in studies conducted in Germany, Japan, the Netherlands and the United States.

4.3 Energy carriers

Energy production may be divided into primary and secondary energy carriers according to Statistics Norway, as shown in Table 4.5.

Table 4.5 Statistics Norway definitions of primary and secondary energy carriers.

Primary energy carrier	Energy carriers produced without raw material from other energy carriers.
Secondary energy carrier	Energy carriers produced with other energy carriers as input.

An energy carrier is a medium in which energy is storable and transportable. Examples of primary energy carriers are natural gas, petroleum, uranium, wood and coal, and examples of secondary energy carriers are electricity, district heating and hydrogen. This thesis focuses on conductor- and pipe-based infrastructure in mixed energy distribution systems, and includes electricity, district heating and natural gas. Hydrogen may be an energy carrier for the future, but this has not been further discussed in this thesis.

Electricity

Electricity is characterized as a high-value energy carrier that may be converted into other energy carriers and used to supply any kind of energy demand, whether electrical, mechanical or thermal. Electricity is the most widespread energy carrier in the Norwegian energy system providing 60.6 TWh/year of the 2005 net domestic stationary consumption in the building sector (SSB, 2006).

District heating

The European Environment Agency defines district heating as "*The supply of heat, either in the form of steam or hot water, from a central source to a group of buildings.*" (EEA, 2006) District heating can supply any kind of heat demand, such as space heating, ventilation heating and hot tap water. In 2005, district heating provided 2.1 TWh/year of stationary heat consumption in the Norwegian building sector (SSB, 2006).

Natural gas

According to the EEA (2006), natural gas is a natural fuel that contains methane and hydrocabons and occurs in certain geologic formations. Natural gas distributed through pipelines to consumers is capable of supplying virtually all heat demand as well as cooking needs, but specific analysis of the latter end-use has been omitted in this thesis. Norway's natural gas net domestic consumption in 2005 accounted for 276 million Sm^3, but only 13% went to the building sector (SSB, 2006). This corresponds to 336 GWh/year for the building sector, with a lower calorific value of 10.4 kWh/Sm^3 and an estimated annual efficiency of gas boilers of 0.9. The amount of methane in the natural gas then lies between 82-93% (ngass, 2007).

Energy carriers used in this thesis

The main focus in this thesis has been on district heating and electricity as energy carriers in order to distinguish between the energy demands for heat and electricity purposes. The energy carriers and different end-uses are shown in Figure 4.4 in relation to the measured and calculated ratings suggested in the mandated standards related to the Energy Performance of Buildings Directive. The red and blue colours correspond to the end-uses supplied by district heating and electricity respectively. The end-uses are shown in a general context and are not related to any specific building category due to the various end-use demands in the different categories.

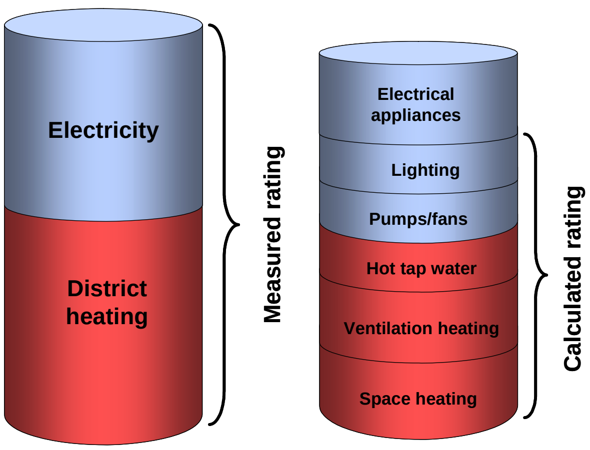

Figure 4.4 The energy carriers and end-uses used in this thesis in relation to measured and calculated ratings from the EPBD. The red and blue colours correspond to heat and electricity loads respectively in relation to supply and demand.

4.4 Building categories

According to EPBD (2002) Article 2, a building is defined as:

"*A roofed construction having walls, for which energy is used to condition the indoor climate; a building may refer to the building as a whole or parts thereof that have been designed or altered to be used separately*"

Maximum load and yearly energy demand in buildings may vary a great deal according to how the building is used. In order to analyse the load profiles and energy demand in buildings, it is important to categorise them in accordance to energy consumption patterns.

Physical and behavioural determinants along with outdoor climate and regulation regimes are often the cause of load variations. Human behaviour is very often characterized by routines; both at home and at work. The working hours for many occupations are strictly regulated, which results in regular load variations in buildings such as office buildings, educational buildings and hospital buildings. The analyses of load measurements have revealed a precise division between day and night hours as well as during weekdays and weekends for the building categories chosen.

Some criteria for the building categories division used in this thesis are listed below:

1. Relatively equal range of use.
2. Relatively equal daily consumption pattern.
3. Relatively equal specific load and energy demand [W/m^2 and kWh/m^2].
4. Limited number of building categories.
5. Adjusted to national, European and international standards and directives.

The first, and most important, criterion has been the relatively equal range of use. In order to compare different buildings in the same building category, it is important that the buildings have been designed and used for the same purposes. Secondly, daily energy consumption patterns within building categories have to be relatively equal. Relatively equal specific load and energy demands within the building categories have been important in order to estimate load and energy indicators. As has been shown by the measures of effectiveness in Chapter 2.4.2, any method used should have a limited number of input variables. As a consequence, the number of building categories analysed have been limited. The last, but also very important, criterion has been the adjustment to national, European and international standards and directives. This is important in relation to consistency, further development and application of the method developed for load modelling of buildings in mixed energy distribution systems.

An investigation done by Pedersen (2006) within standards, regulations, Statistics Norway, different research projects and directives showed that there are no common division of building category division in relation to load and energy demand, as shown in Figure 4.5.

Based on the criteria mentioned above and the summary shown in Figure 4.5, the division of building categories used in the EPBD's Annex has primarily been chosen, as illustrated in the list below (EPBD, 2002). This choice was also due to a desire to allow for analyses that will be consistent with the buildings that will be constructed in the future, because this directive will also affect the energy performance of buildings that have yet to be built.

a) Single family houses of different types
b) Apartment blocks
c) Office buildings
d) Educational buildings
e) Hospital buildings
f) Hotels and restaurants
g) Sports facilities
h) Wholesale and retail trade services buildings
i) Other types of energy-consuming buildings

Buildings from categories a) through f) are analysed in this thesis because hourly measurements of district heat and electricity consumption have been available. The emphasis has been on choosing "clean" buildings, or buildings that fit perfectly within one of the building categories. It was not possible to find sports facilities or wholesale and retail trade services buildings with hourly measurements of district heat and electricity, and therefore, these building categories were omitted from the analyses. The method developed is general in nature, so that the load model should be applicable to all building categories.

EFI ENERGY	NS 3457	NS 3031 / NS 3032	Regulations PBL	GAB	Statistics Norway		Enøk Normtall	EPBD
Single family house	Dwelling	Dwelling	Dwelling	Dwelling	Single family house	Apartment block	Single family house	Single family house
Detached house					Semi-detached house	Buildings for apartment sharing	Detached house	Apartment block
Apartment block					Detached house		Apartment block	
Industry	Industry and warehouse	Workshop	Light industry and warehouse	Industry and warehouse	Industry and warehouse		Warehouse 16°C	
Bank/insurance	Office and commercial building	Office building	Office building	Office and commercial building g	Office and commercial building		Office building	Office building
			Commercial building					
Public administration	Communication building			Communication building	Communication building			
	Hotels and restaurants	Hotels	Hotels and restaurants	Hotels and restaurants	Hotels and restaurants			Hotels and restaurants
Educational building	Culture and research	Educational building	Educational building	Culture and research	Education and culture building		Primary and secondary school	Educational building
			Kindergarten				University and college	
							Kindergarten	
Health care	Health care	Nursing home	Nursing home	Health care	Health care		Nursing home	Hospitals
		Hospital						
		Retirement home	Hospital					
	Prison and preparedness building			Prison and preparedness building	Prison and preparedness building			
		Orphan home						
		Library						

Figure 4.5 Summary of different building category division according to standards, directives, research projects, Statistics Norway, regulations and more.

The different building categories analysed in this thesis are described below, including a presentation of the different buildings within each category.

a) Single family houses (SH) and b) Apartment blocks (AB)

These building categories include both detached and undetached houses as well as apartment blocks. Based on the analyses of single family houses and apartment blocks, it was not found necessary to differentiate between these two building categories. This is mainly due to the fact that most apartment blocks analysed in this thesis are only two story wooden buildings with sizes and shapes that are similar to detached houses.

The buildings within this category may vary a great deal in size, shape, and design, as well as in the number and mixture of people using the building. As a consequence, the load profiles and energy demand in this building category is characterized by large variations that are mainly due to behavioural determinants. As a consequence, this building category has been analysed in relation to clusters, where each cluster consists of approximately 10 separate buildings. This required continuous load measurements from the buildings involved in order to summarize the different clusters' load data.

Hourly measurements of district heat and electricity have been collected from two different residential areas in Bergen in the period from November 2005 until August 2006. Information about the buildings have been collected from several contractors developing these residential areas. All buildings were built in the period from 2001 to 2005 and they were all connected to the newly established district heating network in Bergen. Most of the buildings have only mechanical ventilation with outlet from the kitchen and bathrooms/washing rooms/wc. About half of the buildings have installed chimneys, but not everyone is using the fireplaces. Due to the large amount of buildings analysed, an in depth analysis has not been performed on this building category.

Buildings with continuous measurements during the period of nine months for either district heat or electricity are presented with normalised monthly energy consumption. Figure 4.6 through Figure 4.8 show single family houses (14/10), detached houses (10/20) and apartment blocks (23/8) respectively. The numbers in the parenthesis correspond to number of building types with continuous district heat and electricity measurements respectively. Additionally six buildings with separate continuously hourly district heat and hot tap water measurements were also included in the analyses.

The available areas for the buildings analysed vary between 40 m^2 and 168 m^2 with an average of 120 m^2 for the continuously measured electricity buildings (three buildings lack information about available area) and an average of 95 m^2 for the continuously measured district heat buildings.

15 days of data were missing; January 30 and 31, 2006 and May 1 to 13, 2006. Measurements from the 15 first days of August have been included to make up nine whole months.

Figure 4.6 through Figure 4.8 show the normalised monthly consumption for single family houses, detached houses and apartment blocks respectively. The normalised figures are calculated based on each building's monthly consumption divided on the same buildings average monthly consumption for the period analysed for district heat and electricity respectively. This graphical presentation of energy consumption within different building categories has been applied earlier by Aronsson (1996) for district heat consumption only.

The monthly district heat consumption within these buildings show strong seasonal dependencies, while the monthly electricity consumption show some seasonal dependencies. A few irregularities occur within the different building types which may be caused by a few months of inhabitants' absence or delay in the moving in date among others.

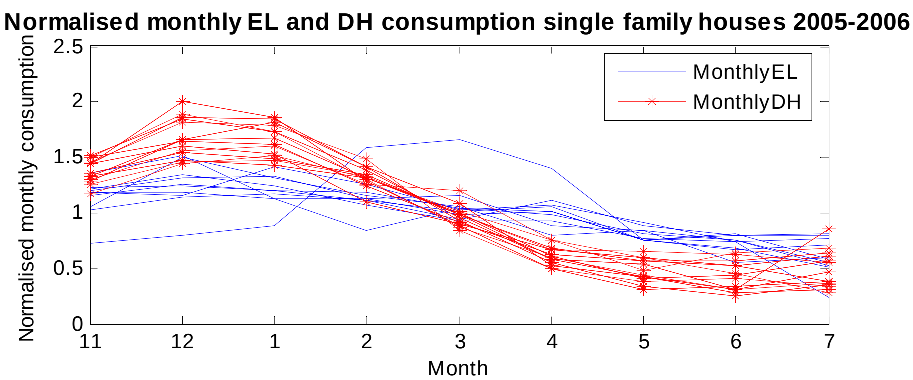

Figure 4.6 Normalised monthly district heat and electricity consumption patterns for selected single family houses from November 2005 to August 2006.

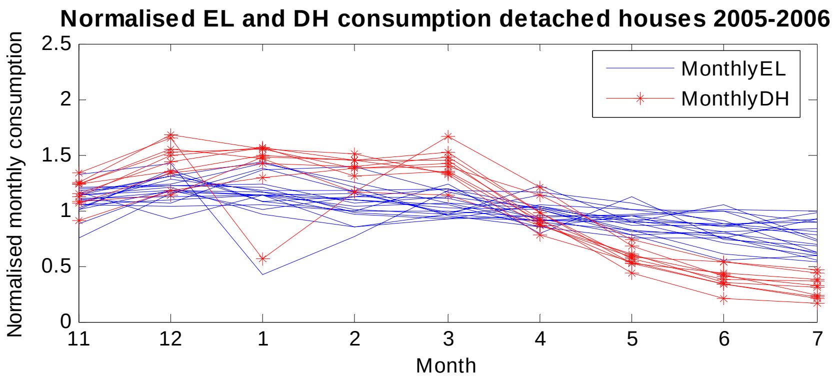

Figure 4.7 Normalised monthly district heat and electricity consumption patterns for selected detached houses from November 2005 to August 2006.

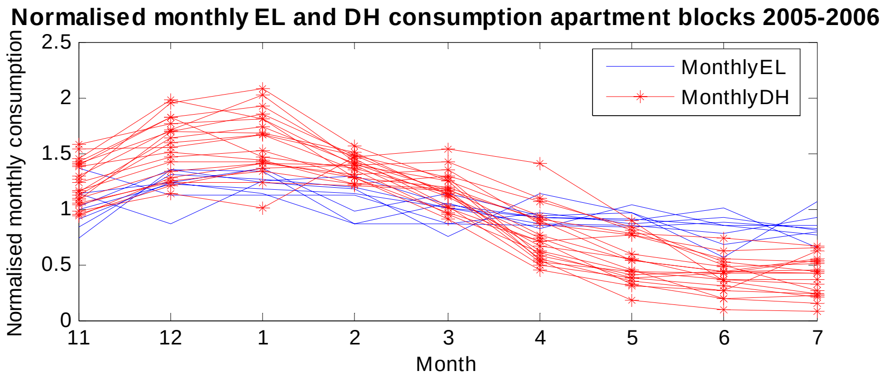

Figure 4.8 Normalised monthly district heat and electricity consumption patterns for selected apartment blocks from November 2005 to August 2006.

It was also interesting to look at the normalised space heating and hot tap water consumption by themselves. Six buildings have continuous hourly district heat measurements for space heating alone, while 17 buildings (including the six previously mentioned) have continuous hourly hot tap water measurements.

Figure 4.9 shows the normalised monthly space heating consumption. The consumption pattern throughout the nine month shows strong seasonal variations due to time of year. The space heating consumption during the summer months June and July is very low for five out of the six buildings analysed. The latter buildings are mainly apartment blocks.

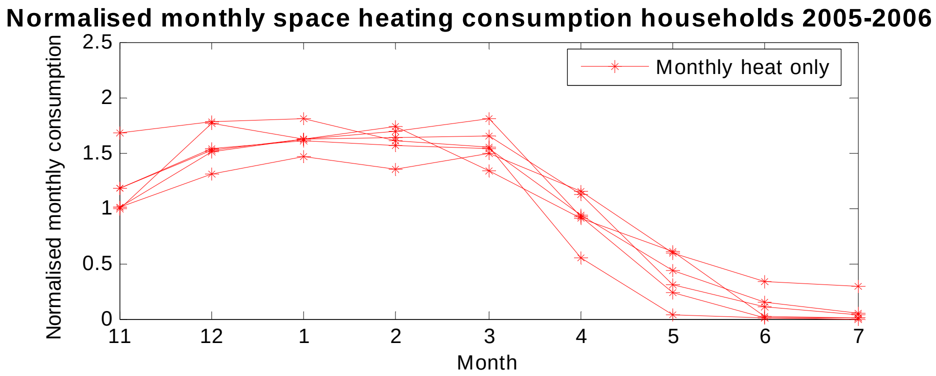

Figure 4.9 Normalised monthly space heating consumption in households with individual hourly measurements of space heating and hot tap water.

Figure 4.10 shows the normalised monthly hot tap water consumption for 17 different buildings; three single family houses and 14 apartment blocks. There are some large monthly hot tap water consumption variations for a few buildings analysed, but the main trend in the plot is that the hot tap water consumption in households indicate a slight seasonal variation.

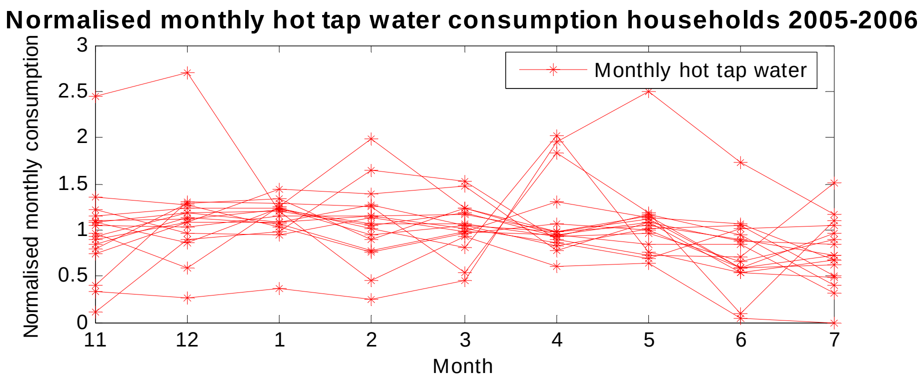

Figure 4.10 Normalised monthly hot tap water consumption in households with individual hourly measurements of space heating and hot tap water.

c) Office buildings (OB)

Office buildings are mainly used as workplaces during weekdays, particularly during the daytime. Some activity may also occur during weekday evenings as well as on weekends. These buildings mainly include individual or landscape office spaces, hallways, meeting rooms and canteens.

Office buildings typically feature large numbers of electrical appliances such as computers, fax machines, printers and more. Most modern office buildings have installed central control and monitoring systems to ensure the most efficient operation of the building's heat and electricity systems. This often includes the operation of the ventilation system, the control of the indoor air temperature and night set-back of radiators, as well as monitoring the lighting system.

For the purpose of this thesis, measurements from nine office buildings were initially collected for analyses, but two buildings were omitted after quality assurance of the measured data. The buildings varied in size and age as shown in Table 4.6. Office buildings 2 and 4 through 7 had four years worth of hourly district heat and electricity measurements, while office buildings 1 and 3 had two years worth of district heat measurements. The electricity measurements for the latter office buildings also included four years of data.

Table 4.6 Selected office buildings that were analysed in this thesis, including available area and construction year.

Office building #	Available area [m^2]	Construction year
1	4 310	Unknown, but before 1983
2	11 739	1972
3	5 645	1980
4	5 341	1998
5	9 109	1998
6	4 984	2000
7	15 405	2000

The monthly consumption patterns for both district heat and electricity for the selected office buildings for January to December 2005 are shown in Figure 4.11. The 2005 calendar year was chosen because all large buildings analysed in this thesis included data for this entire year.

The district heat consumption is very dependent upon seasonal variations, i.e. climatic conditions, while the electricity consumption is rather constant throughout the year.

Although the seasonal variations for district heat consumption are quite evident, the relative monthly amount of district heat consumption varies a great deal from one office building to the next. This is due to the daily load profile variations caused by different control regimes for space heating and ventilation, as well as behavioural determinants.

The increase in electricity consumption in July (month no. 7) for some of the office buildings is due to electrical cooling demand. The decrease in electricity consumption for one office building during the same month is due to the summer holidays and a lack of installed electrical cooling. The slight drop in electricity consumption for some of the office buildings in December may be explained by the Christmas holiday.

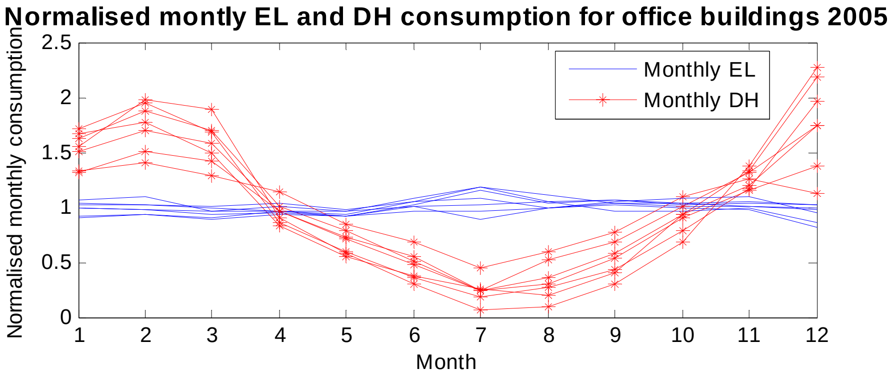

Figure 4.11 Normalised monthly district heat and electricity consumption patterns for selected office buildings from January to December 2005.

d) Educational buildings (EB)

Educational buildings are used as a work space for educational staff as well as a place for educating children and young people during weekdays. These buildings mainly include offices, classrooms, hallways and canteens. Most educational buildings include a gym for physical education, and some schools may also have a swimming pool. Central control and monitoring systems are widespread in this building category.

Educational buildings include primary schools (1st to 7th grade), junior high schools (8th to 10th grade) and colleges (11th to 13th grade), as well as schools that may be comprised of both primary and junior high schools. Measurements from 23 different educational buildings with hourly district heat and electricity data have been investigated, while 15 buildings were used in the analyses after quality assurance of the collected data. The selected educational buildings are listed in Table 4.7 along with available area, construction year and type of school. The data collected represent the hourly district heat consumption for a period of two years for all schools analysed. The hourly electricity consumption collected varied from two to four years of measurements.

Table 4.7 Selected educational buildings that were analysed for the purpose of this thesis, including available area, construction year and type.

Educational building #	**Available area [m^2]**	**Construction year**	**Type (grades included)**
1	6 862	1902/1956	11th - 13th grade
2	8 100	1954	11th - 13th grade
3	4 800	1955/59/71 Rehab 2003	1st - 7th grade
4	9 902	1962	8th - 10th grade
5	7 888	Older than 1980 Rehab 1997/2003	1stt - 7th grade
6	4 063	1982	1st - 7th grade
7	6 199	1987	1st - 10th grade
8	3 396	1989	1st - 10th grade
9	4 000	1980/ Modernized 2000	11th - 13th grade
10	4 276	1997	1st - 7th grade
11	4 083	1997	1st - 7th grade
12	1 785	1997	1st - 7th grade
13	8 808	1999	11th - 13th grade
14	6 083	1969/1997/2000	1st - 7th grade
15	6 439	1880/New 2003	1st - 7th grade

Figure 4.12 shows the monthly consumption patterns for both district heat and electricity for the selected educational buildings from January to December 2005.

The monthly district heat consumption for educational buildings shows a clear seasonal variation due to climatic conditions influencing the space and ventilation heat demand.

The monthly electricity consumption in educational buildings is more likely than office buildings and hospitals to be influenced by special days such as holidays. The monthly consumption of electricity in July (month no. 7) and August (month no. 8) is much lower than the rest of the year. This is especially true for July, when most schools are not in use. March (month no. 3), October (month no. 10) and December (month no. 12) also include one week of holidays, which are the Easter, autumn and Christmas breaks. These special days have a large impact on the electricity load profiles as well as the heat load profiles. As a result, it was very important to identify all special days when analysing educational buildings.

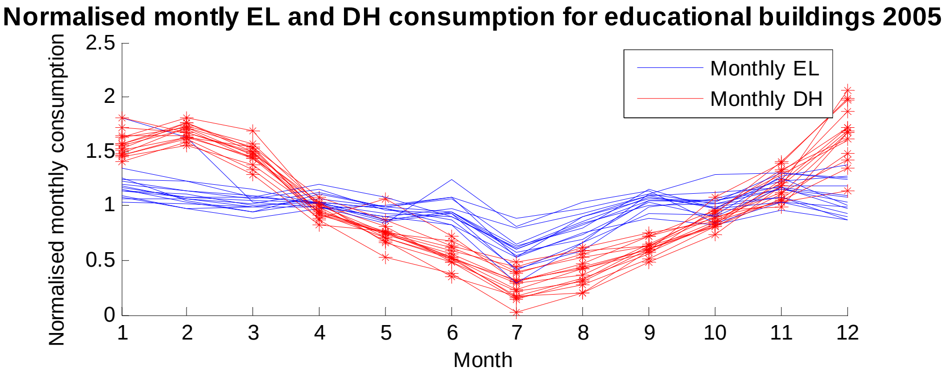

Figure 4.12 Normalised monthly district heat and electricity consumption patterns for selected educational buildings from January to December 2005

e) Hospital buildings (HB)

The hospital building category includes nursing and retirement homes, which have been the focus in this thesis. Nursing and retirement homes are buildings that provide housing for elderly people in need of nursing, as well as a work place for the nursing staff. The heat and electricity load is often controlled by work routines as well as how ambulatory the residents are. The latter may differ between nursing homes and retirement homes as residents of retirement homes often have more control over their movements and behaviour.

Nursing and retirement homes mainly include individual or double rooms with bathrooms, hallways, commercial kitchens and common rooms for social activities, as well as break rooms and offices for the nursing staff. The activity level in nursing and retirement homes tend to be quite equal during weekdays and weekends due to their use.

Measurements from six different nursing and retirement homes have been investigated and data from four buildings' hourly district heat and electricity consumption were acceptable, based on a quality assurance inspection. The buildings selected are shown in Table 4.8 including available area, construction year and type of home. The latter information was not available for hospital building no. 2 (HB2).

Table 4.8 Selected nursing and retirement homes that were analysed for the purpose of this thesis, including available area, construction year and type.

Hospital building #	**Available area [m^2]**	**Construction year**	**Type of home**
1	2 850	1966	Nursing home
2			Nursing home
3	3 412	1985	Retirement home
4	3 804	1987	Nursing home

Figure 4.13 shows the monthly consumption patterns for both district heat and electricity for the selected hospital buildings from January to December 2005.

The monthly district heat consumption shows a distinctive seasonal variation due to the time of year. This variation is caused by temperature dependent space and ventilation heating demands. The hot tap water consumption is also included in the district heat measurements.

As shown in Figure 4.13, the electricity consumption in the selected nursing and retirement homes is quite constant throughout the year. This is the result of strict work routines, which result in homogenous electricity consumption patterns year-round.

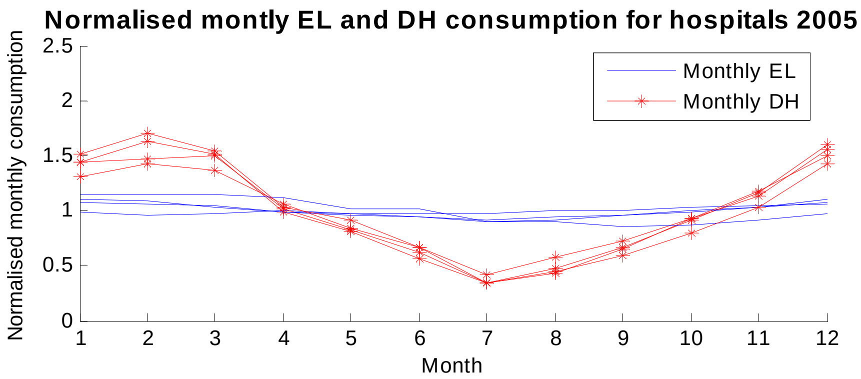

Figure 4.13 Normalised monthly district heat and electricity consumption patterns for selected hospitals from January to December 2005

f) Hotels and restaurants (HR)

The hotels and restaurants building category includes both hotels with and without restaurants as well as separate restaurants. This thesis has only analysed hotels with restaurants. Hotel buildings accommodate people as well as provide a work space for the hotel staff. These buildings mainly include hotel rooms including bathrooms, hallways, reception areas, meeting rooms and restaurants. They may also include saunas and swimming pools as well as exercise rooms. Most hotel buildings analysed in this thesis have installed central control and monitoring systems as well as implemented energy efficiency measures.

Seven hotels including small and large restaurants with hourly measurements of district heat and electricity consumption have been investigated, and after quality assurance, five buildings were selected for the analyses. The district heat measurements included two years of data, while the electricity measurements included more than four years of data. Table 4.9 lists the selected hotels with restaurants including available area and construction year.

Table 4.9 Selected hotels with restaurants that were analysed for the purpose of this thesis, including available area and construction year.

Hotels with restaurants #	Available area [m^2]	Construction year
1	20 000	1897/1917/1952/1980/ 1986/2001
2	4 600	1900/1977
3	6 982	1920, but renovated
4	6 043	1991
5	2 415	1997

The monthly consumption patterns for both district heat and electricity from January to December 2005 for the selected hotels with restaurants are shown in Figure 4.14.

The monthly district heat consumption for hotels shows a distinguished seasonal variation. This variation is caused by the temperature dependent space and ventilation heating consumption. The amount of hot tap water consumption is mostly dependent on the number of visitors, and therefore, dependent on the high and low tourist seasons as well as special events.

The monthly electricity consumption for this building category is almost constant throughout the year, see Figure 4.14.

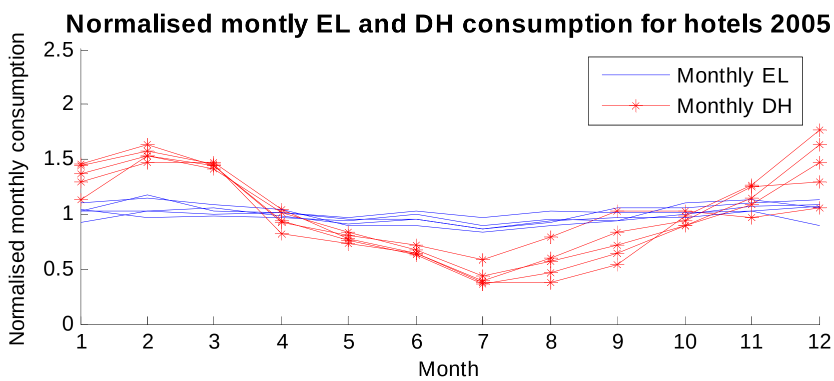

Figure 4.14 Normalised monthly district heat and electricity consumption patterns for selected hotels from January to December 2005

4.5 Archetypes

Archetypes (AT) have been introduced in the IEA Annex 31 (2004); Energy-Related Environmental Impact of Buildings in relation to stock aggregation. An archetype is defined as "...*a statistical composite of the features found within a category of buildings in the stock*." The concept of archetypes has been used in this thesis to categorise primary building categories (Annex 31, 2004), specifically in relation to load profiles for heat and electricity purposes.

Different examples of archetype classification are technology, market, user behaviour, regulations and design, and planning and construction processes (Wachenfeldt and Satori, 2005).

The most important features of the buildings analysed for this thesis have been building age and regulation regime. Building age is especially important in relation to heat load demand because it reflects the ever stricter requirements in the Planning and Building Act concerning insulation standard and ventilation rates. The regulation regime for ventilation systems results in the greatest variations in the heat load profiles, such as running the ventilation system during the daytime only or around the clock.

The archetype division was considered when analysing the daily load profiles for heat and electricity. The main findings of archetype division have been in relation to the operation of the ventilation systems and the ages of the buildings for the development of heat load profiles

5 Background information for load modelling of buildings

5.1 Introduction

The purpose of this chapter is to evaluate and categorise available information with respect to the systems engineering process, as well as to elaborate on the background information collected for load modelling of buildings in mixed energy distribution systems.

Specific background information is required when developing a method that estimates the peak load divided into heat and electricity and the appurtenant load profiles for different building categories. This chapter first assesses the available measured load. Secondly, the climatic parameters that influence the heat load demand are discussed along with a short review of different yearly representations of these parameters. The demand for heat and electricity load in buildings is strongly related to the building's envelope, size and technical installations, as well as social parameters. In view of this, background information for the buildings analysed are discussed in relation to physical determinants, control regimes and behavioural determinants.

5.2 Measured load data

The main parameters for the statistical analyses of load profiles in mixed energy distribution systems have been load data divided into different purposes; heat and electricity demand. One of the three main aspects of the requirement traceability information model shown in Figure 2.8 in Chapter 2.4.3 was to assess available data. This chapter elaborates on the requirements for measurability, availability and verification as part of the collection and quality assurance of measured data.

5.2.1 Collection of data

The measurement of different end-uses for a given period for several buildings was considered outside the scope of this thesis, in accordance with the measurability requirement described in Chapter 2.4.3. This is based on experience showing that traditional methods of collecting end-use measurements for the development of load profiles can be too time consuming, expensive and data intensive (Finleon, 1990). Instead, the focus has been on measurements in buildings with more than one energy carrier, i.e. district heating and electricity. The data collected have been based on hourly simultaneous measurements of district heat and electricity consumption in several buildings, to allow for the analysis of load variations over time.

Available load data

Over the last years, automatic hourly measurements of energy consumption have become more widely available. This is especially true for large buildings. Several district heating companies in Norway have installed hourly measurement equipment, and the electricity consumption for these buildings has also been measured on an hourly basis. These data have been an important input to this thesis.

TEV Fjernvarme, the district heating company in Trondheim, has contributed with measurements for the educational buildings, office buildings, hospital buildings and hotels and restaurants categories. The company has a portal on the Internet called EnergiGuiden (2006) (the Energy Guide) where all hourly district heat and electricity consumption data are updated weekly. Here, it is possible to access the database, choose the different buildings and then download specified load data. This is only possible when the availability requirement is met, i.e. when permission to use the data have been granted by the various building owners. All the buildings used in the analysis have been handled anonymously.

BKK Varme, the district heating company in Bergen, has contributed with measurements for the single family houses and apartment blocks category. Hourly load data divided into district heat and electricity were stored for a three-month period, with the data collected on request every three months.

The building sample analysed for this thesis has not been randomly chosen. The buildings selected have been chosen from among the TEV Fjernvarme and BKK Varme buildings that had hourly measurement data and that could be assigned to unique building categories. This means that the sample is not representative of the entire Norwegian building stock, but the buildings selected do provide the foundation for developing a method for load modelling of heat and electricity demand in buildings.

Measurement uncertainty

The measurement uncertainty is related to the type of measuring instruments installed in the various buildings. According to TEV Fjernvarme the accuracy of the installed heat and electricity measuring instruments are based on the classification of the instruments applied (Lunden, 2007). The heat meters are mainly ultrasound instruments belonging to accuracy class 2 (see Directive 2004/22/EC on measuring instruments for more information) with an initial accuracy of approximately ± 3%. All heat meters in Trondheim are replaced every six years to ensure low measurement uncertainty. The electricity measuring instruments fall within accuracy class 1 with a theoretical accuracy of ± 1%. In reality, the accuracy of the electricity measuring instruments are lower than ± 0.5% (Lunden, 2007).

Both heat and electricity measuring instruments installed in the residential area in Bergen belong to accuracy class 2 according to Paulsen at BKK Varme (2007).

Duration of measurements

The measurement periods in Trondheim and Bergen differed, as did the building-to-building measurement periods. In general, all Trondheim buildings analysed had measurements available from October 1, 2004 for both hourly district heat and electricity consumption. Some buildings had measurements starting on January 1, 2002, but this was more widespread for hourly electricity measurements than hourly district heat measurements. As a consequence, all Trondheim buildings analysed have at least two full years of hourly measurements divided into heat and electricity, i.e. collected load data from October 1, 2004 until October 1, 2006.

The single family houses and apartment blocks measured in the Bergen area only had records from November 1, 2005. This was due to the age of the buildings, and also because the data collected was deleted continuously, with only three months stored at a time.

Time and measurement resolution

Time and measurement resolutions are important aspects when analysing load data. A time resolution of one hour has been used in this thesis in accordance with the measurement interval available for the collected data. This is also the most common time resolution in the field of energy planning. However, load predictions may be more accurate with shorter time periods, such as 5 or 15 minutes measurement intervals. A decrease in the time resolution from 15 minutes to one hour may, for example, result in a decrease in the maximum load by between 20% and 4% for various building categories (Norges Energiverksforbund, 1993).

While the measured load data had a time resolution of one hour, i.e. one kilowatt hour per hour [kWh/h], the measurement equipment recorded the load data with a measurement resolution varying from 0.01, 1, 2, 10 or as high as 20 kWh/h. Low measurement resolution may affect load profiles by shifting the load to a subsequent hour. This was especially true for hourly district heat consumption in small buildings, such as single family houses and apartment blocks. The measurement resolution for hourly electricity consumption in these buildings was 0.01 kWh/h, which is quite good for electricity load modelling. On the other hand, the measurement resolution for hourly district heat consumption for the same building categories was 1 kWh/h, which is not very good for the purpose of heat load modelling.

For commercial and service buildings such as office buildings, hotels and restaurants, educational buildings and hospital buildings, the measurement resolution for electricity was usually 1 or 2 kWh/h, but for district heat it varied from 1 to 20 kWh/h.

Other aspects

Autumnal equinox and vernal equinox, or summer and wintertime, have not caused any problems because the measured load data followed the time change. The climatic data followed the Norwegian Middle Time throughout the year. The 2004 leap year has also been handled appropriately.

5.2.2 Qualitative verification of data by inspection

When the data had met the requirements for measurability and availability, it was important to verify the collected data. One aspect that was very important when working with dividing the load into heat and electricity uses, was to ensure that the data collected covered these purposes only. Parts of the buildings in the initial sample used district heating as well as electricity for heat purposes. Other buildings had installed electrical cooling equipments, which is an end-use that has not been considered in this thesis. The electricity consumption for this thesis has been defined to only include more or less temperature-independent end-uses.

A plot of simultaneous district heat and electricity data has been used in order to identify and remove buildings from the sample with incorrect division of energy carriers supplying different end-uses or purposes, i.e. to detect electricity used for heat purposes. Questionnaires completed by the building owners and/or operation managers could also expose this phenomenon, but this has not been found to be true in all cases.

Figure 5.1 and Figure 5.2 show examples of hourly district heat and electricity consumption plotted for 2005 for educational buildings. The first educational building, EB10, showed temperature-dependent district heat consumption and temperature-independent electricity consumption. The other educational building, EB16, showed both temperature-dependent district heat and electricity consumption. As a consequence, the latter building was omitted from the analysis.

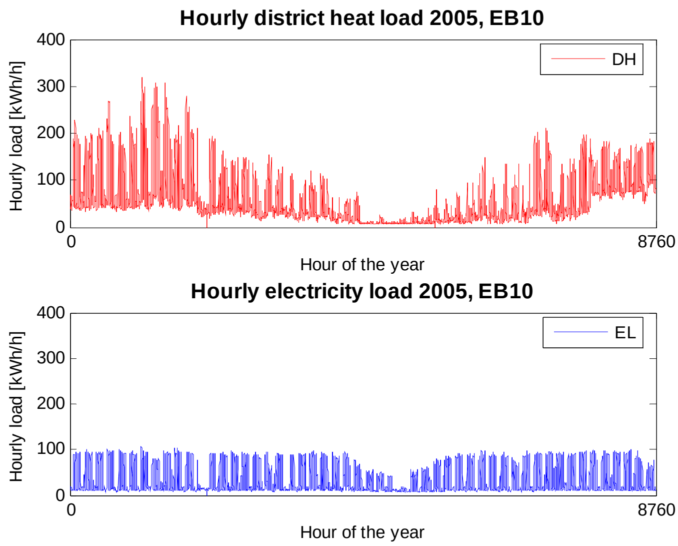

Figure 5.1 Hourly district heat and electricity consumption plotted for educational building EB10 for 2005. EB10 shows temperature-dependent district heat consumption and temperature-independent electricity consumption. Special days such as winter holidays, Easter, summer holidays and Christmas were identified.

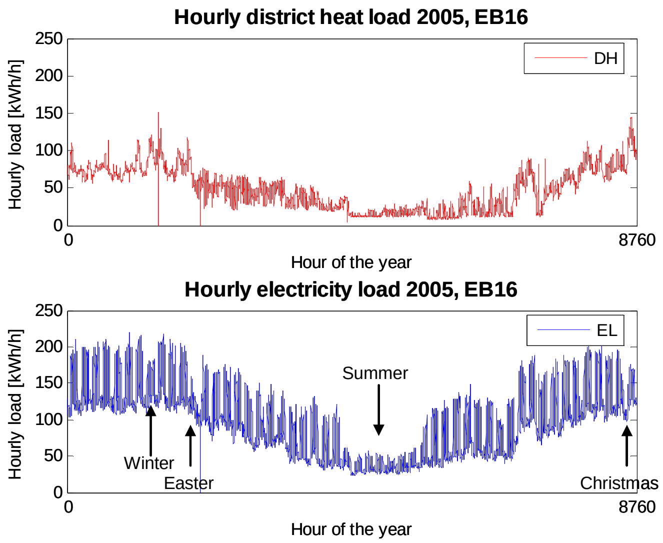

Figure 5.2 Hourly district heat and electricity consumption plotted for educational building EB16 for 2005. EB16 shows both temperature-dependent district heat and electricity consumption, and consequently, EB16 was omitted from the analysis. Special days such as winter holidays, Easter, summer holidays and Christmas were identified.

Both EB10 and EB16 were primary schools, and Figure 5.1 and Figure 5.2 clearly show the consumption pattern for educational buildings. Electricity consumption is especially sensitive to special days such as winter and Easter holidays, as well as summer holidays and Christmas holidays, a phenomenon that is clearly illustrated in the figures. The regulation regimes for space and ventilation heating determine if these holidays are displayed in plots of hourly district heat consumption. For example, it appeared that the ventilation system for EB10 may have been cut back or shut down during the Easter holiday.

Due to their influence on the load demand, these different special days have been taken into consideration when analysing the load variations in the different building categories.

5.2.3 Quality assurance of collected data

The measured data have also been verified in terms of quality assurance. Some data were missing, while other data were incorrect. A procedure for removing corrupt data from the analysis has been established.

It was important to assure that the measured load data was of acceptable quality, because automatically recorded district heat and electricity consumption may be flawed, just like manually read measurements. If all the raw data material had been included in the analyses, it might have provided an incorrect picture of the actual load profiles. It is important to be consistent in handling the data measured. A protocol for quality assurance of the data measured has been developed to handle the hourly load data obtained from the utilities. This protocol mainly deals with:

- Outliers
- Zero values
- Several identical successive values

Outliers

An outlier is an observation that is inconsistent with the rest of the observed data set. The value of the outlier might be much higher or much lower than the rest of the observations (Sheskin, 2000). In this case, the outliers were typically much higher than the other observations. The demand for district heat and electricity may be low or non-existing for certain periods of time, as explained in the next paragraph.

Zero values

The measured load may in some cases have the value of zero because there is no or little load demand during the hour in question. Handling this value in terms of quality assurance has been a complex matter. The zero value might sometimes be of good quality and other times of bad quality. This is especially true for the district heat measurements. During the summer months, the heat demand may in some hours be non-existent, even though there might be a demand for hot tap water. During the winter months, this is not likely to happen due to the cold outdoor temperatures. As a consequence, zero load values in the district heat data set during the winter have been likely to be measurement flaws.

Hourly collected electricity data should never include a zero value because of the electrical standby consumption in almost every building analysed. This standby consumption may be quite high in commercial and service buildings due to elevators, fax machines, computers, emergency lighting, ventilation (electrical fans) and other electrical appliances. Electrical standby consumption also occurs in most single family houses and apartment blocks as well, mostly due to freezers, refrigerators, TVs, stereos, microwave ovens, personal computers and more.

The measurement resolution may also influence zero values when the resolution is low, i.e. when the measurement resolution is 1 kWh/h for district heat in single family houses and apartment blocks and 10 to 20 kWh/h for both district heat and electricity in commercial and service buildings.

Several identical successive values

Several identical successive values occur when the measurement equipment is inoperative for a certain period of time. The load for every hour is then recorded as the average value for that period, i.e. the energy consumption for the period divided by the number of hours the measurement equipment has been down. The load variation throughout the day is then lost, and therefore, these data have been of little interest in load modelling. On the other hand, these values have been included in the yearly energy consumption analysis.

Here, low measurement resolution may have also influenced the load values and resulted in several identical successive values. It was important to keep this in mind when omitting data due to several identical successive values from the load analysis.

Protocol for quality assurance

A quality assurance procedure for outliers, zero values and several identical successive values has been developed to evaluate the collected hourly district heat and electricity consumption in relation to load analysis:

1. First, a data point was removed when it returned true for not-a-number, meaning that the data point was either missing or assigned the letter x.
2. A data point was removed when the investigated electricity data differed more than three standard deviations above the mean value. Outliers were not investigated in relation to hourly district heat consumption.
3. A data point with a zero value was always omitted from the electricity consumption data. A data point with a zero value was omitted from the district heat consumption data when the outdoor temperature dropped below the outdoor temperature defined by the heating season, i.e. daily mean temperature of around 10°C or lower.
4. A data point was removed when it occurred in 24 identical successive values for both district heat and electricity load data.

5.3 Climatic parameters

The main focus of this thesis with respect to heat load profiles has been to investigate the correlation between outdoor temperature and hourly district heat consumption. Other climatic parameters may also influence the heat and electricity load, and these are also discussed in this chapter.

This chapter first addresses outdoor temperature such as daily mean temperature, temperature variations throughout the day, and design temperature for heat load estimations. Other climatic parameters such as hours of sunlight and wind speed and direction may also influence the heat and electricity load to some extent, and are also examined here. Thirdly, different representations of climatic parameters on a yearly and simplified basis are presented. Yearly representations of climatic parameters have been used when estimating yearly heat load profiles and heat load duration profiles.

5.3.1 Outdoor temperature

The Norwegian Meteorological Institute (NMI) is mainly responsible for the measurement of climatic parameters in Norway. The NMI operates manual and automatic weather stations throughout the country, which record information such as daily mean temperature, minimum and maximum daily temperature, hourly outdoor temperature, hours of sunlight, wind speed and direction for each weather station.

The outdoor temperature is recorded at the exact hours 6 a.m., 12 p.m. (noon) and 6 p.m. UTC (Universal Time Coordinated, also known as Greenwich Mean Time - GMT) at manually operated weather stations. The temperature at each hour is, by convention, the average temperature of the minute prior to the hour, i.e. the average outdoor temperature from 05.59 a.m to 06.00 a.m is considered the outdoor temperature at 6 a.m (WMO, 1996). In reality, measurements at manually operated weather stations occur 15 to 25 minutes prior to the hour (NMI, 2006). Minimum and maximum daily temperatures for manual weather stations are also recorded.

Automatically operated weather stations appeared in Norway 15 years ago, and are becoming more common (NMI, 2006). Hourly temperatures are logged for every exact hour of the day based on the same method used at manually operated weather stations. The outdoor temperature is also measured every two minutes throughout the day which results in a unique average hourly temperature in addition to the outdoor temperature at the exact hour. Automatic stations also record minimum and maximum daily temperatures.

Daily mean temperature

There are two different methods that are primarily used for calculating the daily mean temperature, θ_{dmt}:

1. Koeppen's formula.
2. The average of 24 successive exact hourly temperature measurements.

Koeppen's formula is used at manually operated weather stations and has been the most widespread method used during the last century.

The daily mean temperature is expressed as (NMI, 2006):

$$\theta_{dmt} = N - k(N - min) \text{ [°C]} \quad (5.1)$$

$$N = \frac{1}{3} \cdot (t06 + t12 + t18) \text{ [°C]} \quad (5.2)$$

where:

N The average of the outdoor temperature at 6 a.m., 12 p.m. and 6 p.m. UTC, in [°C].

k A factor which changes due to location and month, which compensates for the lack of nightly measurements as well as hours omitted during the daytime.

min The minimum temperature during the temperature day, in [°C].

The average of 24 successive exact hourly temperature measurements is used at automatically operated weather stations. The day follows the temperature day from 6 p.m to 6 p.m UTC. The exact hourly outdoor temperature, and not the average hourly outdoor temperature, is used in calculations of the daily mean temperature.

In October 2006, the Norwegian Meteorological Institute decided to estimate daily mean temperatures based on the Norwegian Middle Time (NMT), and as a result, the 24 hour estimation period is from 12 a.m. to 12 a.m NMT.

The average value of the 24 exact hourly outdoor temperature measurements is a more accurate calculation method for daily mean temperature, and has been used in this thesis. This decision reflects to the increase in the use of automatic weather stations in Norway, and the official decision to adopt this calculation method. The calculation method for daily mean temperatures follows the NMT. Koeppen's formula is still in use to ensure continuity and comparison to previous years.

Figure 5.3 shows the daily mean temperature at Voll weather station in Trondheim based on both Koeppen's formula and the average of 24 successive exact hourly temperature measurements from 12 a.m to 12 a.m NMT. The maximum deviation obtained during a three-year period from January 2002 until December 2004 was 2.0°C. The mean deviation during the three-year period based on the absolute value of the deviation was 0.3°C.

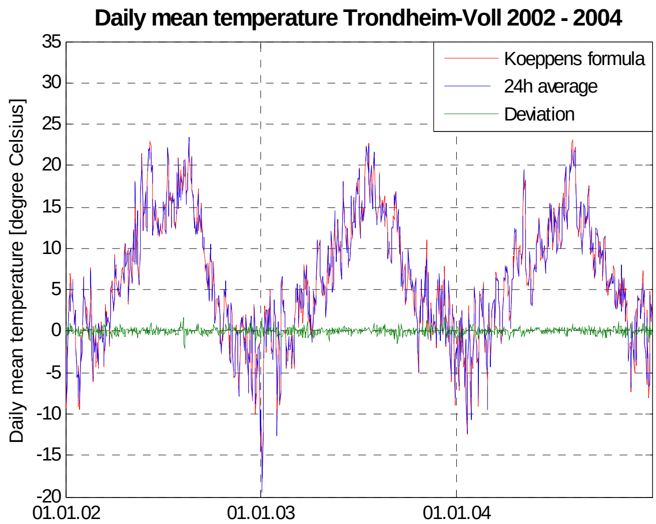

Figure 5.3 Daily mean temperature at Trondheim-Voll 2002-2004 showing the deviation between the 24h average and Koeppen's formula.

The monthly mean temperature is the average of the month's daily mean temperatures, while the yearly mean temperature is the average of the year's monthly mean temperatures (NMI, 2006).

Hourly temperature variations

The daily mean temperature has been used for heat load estimations for every hour throughout the day, in spite of hourly outdoor temperature variations. This is mainly due to the thermal inertia of the different buildings, and consequently, high time constants. In other words, the building's space heat demand does not respond instantaneously to changes in outdoor temperature. This means that thermal energy is accumulated in the building envelope and a drop in the indoor temperature will not occur at the same time as a drop in the outdoor temperature. The buildings' time constants may vary from a few hours to several days depending upon the buildings' envelopes, and may vary just as much within a certain building category as across building categories.

The mean hourly temperature variations for each month are shown in Figure 5.4 for the period January 2002 to October 2006. The outdoor temperature in November, December, January and February show small variations throughout the day, whereas the remaining months show large temperature variations throughout the day. The increase in hours of sunlight and higher sun angle are the main reasons for the temperature variations in the latter months.

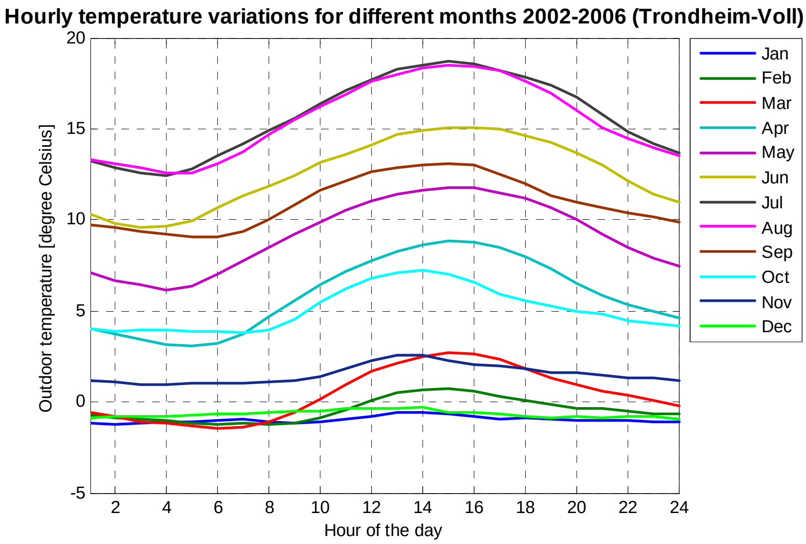

Figure 5.4 Average hourly temperature variations for different months for the Trondheim-Voll measurement station for the period January 2002 to October 2006.

Design temperature

The design temperature has been used for the estimation of maximum heat load demand, or design heat load. The design heat load is defined in ISO 15927-5 (2004) as the "*...maximum heat output required from the heating system of a building, in order to maintain required internal temperatures without supplementary heating*." According to ISO 15927-5 (2004), "*...the practical solution is to choose an infrequent, but not extreme, climatological value as the basis for the design load.*" The most extreme outdoor temperatures are not used for design heat load calculations due to the buildings' thermal inertia.

Design temperature is very dependent on location because of the vast difference in climatic conditions in Norway. Lately, there has been a discussion about changing the estimation period for the design temperature due to possible effects from climate change. Today, the design temperature in Norway is the average outdoor temperature during the three coldest successive days in a 30-year period: from 1961 to 1990. The ISO 15927-5 (2004) suggests that the n-day mean design temperature should be calculated based on 20 successive years of meteorological data, where n is one, two, three or four days.

The n-day mean design temperatures for various locations in Norway have not yet been calculated, but they may be available in the future. Hence, the design temperature for the 30-year period from 1961 to 1990 has been used for design heat load calculations in this thesis.

5.3.2 Other climatic parameters

Other climatic parameters aside from the outdoor temperature may influence the heat and electricity load demand in buildings. These parameters have not been included in the load modelling of buildings, but a brief summary of two important climatic parameters, the influence of sun and wind, is provided in the paragraphs below.

Werner (1984) found that the influence of solar gain and wind infiltration was significant, but small, in large district heating systems. Ericsson (2006a and 2006b) applied multiple regression analysis incorporating both hours of daylight and wind speed in his model regarding electricity load in all-electric households.

Hours of sunlight

Sunny days, especially during spring and fall, will decrease the heat load demand due to heat gain through the windows. The heat gain from sun radiation is a result of the radiant-flux density, the window pane’s sun factor and area, as well as the shielding coefficients (NS 3031, 1987). The radiant-flux density, in [W/m^2], varies according to month, solar altitude and building orientation. Specific values have been tabulated in Table 6 in NS 3031 (1987) for various Norwegian locations.

There is a correlation between outdoor temperature and sun radiation, as can be seen in Figure 5.4.

Wind speed and direction

The wind speed and direction both influence the infiltration rate, resulting in increased heat load demand during windy days. The infiltration loss is dependent upon thermal capacity of the air, the building volume, the number of air changes, and the outdoor temperature (NS 3031, 1987). The number of air changes in buildings is influenced by the wind speed, topography, and degree of shielding, with values provided for various Norwegian locations in Table 2 in NS 3031 (1987).

Concluding comments

Palsson et al. (2004) have developed an equivalent outdoor temperature that incorporates the average wind speed and the number of sunshine hours each day for weather-dependent district heat consumption. The dynamic behaviour of the district heating system was also included in the model. This approach might have been used to allow for the influence of sun and wind in the heat load modelling of buildings.

On the other hand, the use of outdoor temperature as the single independent variable reduces the problems of multicollinearity caused by the use of other climatic parameters in the statistical analyses. The time spent on data collection is reduced because the daily mean temperature is a widely available parameter (Kissock et al., 1998).

Another factor that has played a part in the decision to omit the influence of sun and wind in the heat load model has been the lack of satisfactory data, such as hours of sunlight, and windspeed and direction, from the selected buildings' locations. As a consequence, these climatic parameters were not investigated further.

5.3.3 Different representations of climatic parameters

Some paragraphs in this chapter have been taken from Pedersen (2007).

Different climatic parameters influence the load and energy demand, such as temperature level vs. space heating, ventilation and cooling; wind speed and direction vs. space heating and ventilation; solar irradiance vs. cooling and lighting; hours of daylight vs. lighting; and cloud layer vs. space heating. The climate changes from place to place as well as from year to year, making the generation of a normal representation of the average climate a challenging task at any given location.

In order to estimate load profiles and duration profiles on a yearly basis, it was necessary to use a representation of the normal climate. Several different representations have been investigated, which are presented in Table 5.1.

Table 5.1 Overview of different climatic representations introduced in Chapter 5.3.3.

Yearly representation	**Simplified representation**
Test Reference Year (TRY)	Simplified weather file
Design Reference Year (DRY)	Design day
Typical Meteorological Year (TMY)	
Weather Year for Energy Calculations (WYEC)	
Reference year (ISO 15927-4:2005(E))	

The representation of weather data can be divided into yearly weather files and simplified weather files. The most important yearly representations are Test Reference Year (TRY), Design Reference Year (DRY), Typical Meteorological Year (TMY) and Weather Year for Energy Calculations (WYEC) (Said and Kadry, 1994; Moeller Jensen and Lund, 1995). A reference year calculated according to ISO 15927-4 (2005) has also been included in the list, but the latter yearly representation is not yet available for use in annual energy estimations.

TRY consists of one year of actual weather data chosen from the available annual weather years recorded. The specific year is selected based on certain criteria. Years that include months with extremely low or high daily mean temperatures are eliminated. This process is continued until one year remains, which then represents the test reference year. TRY is not sufficiently accurate for the purpose of load modelling and therefore cannot be used in energy requirements calculations exceeding several years. However, the TRY may be applied when comparing different designs in retrofit options (Said and Kadry, 1994).

A Design Reference Year (DRY) is a further development of the TRY. The DRY consists of 8760 sets of hourly weather data – which represents the number of hours that constitutes a normal year – for a given location. The DRY is mostly used for annual energy simulations where the computer programs can handle more than one climatic parameter, and includes hourly climatic parameters such as global, diffuse and direct normal irradiance, dry bulb and dew point temperature, cloud information, wind speed and direction. Like the TRY, the DRY is compiled from measured data at a certain location during a 12-month period. Twelve representative months are selected from among at least 10 years of measurements and are adjusted with each month given a true mean value along with the variance for the main climatic parameters (Moeller Jensen and Lund, 1995; Skartveit et al., 1994). Figure 5.5 shows an example of hourly outdoor temperatures from a DRY developed for Oslo, Norway.

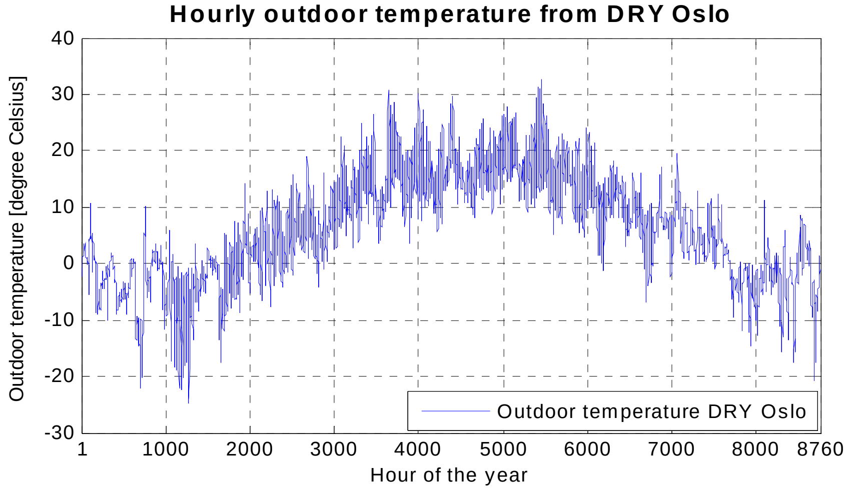

Figure 5.5 Hourly outdoor temperature from DRY Oslo.

The typical Meteorological Year (TMY), on the other hand, represents a constructed weather data year based on actual meteorological data. Each month consists of typical or average months from annual measured data over several years. The months selected approximate the long-term average conditions. Therefore, TMY is a compilation of twelve months that might have occurred in different years. Consequently, two adjacent months may have a “jump” in weather conditions in the transitional period. This data is smoothed using a curve fitting technique (Said and Kadry, 1994).

The Weather Year for Energy Calculations (WYEC) data file is constructed using months that show the closest proximity to the 30-year normal, where both temperature and solar radiation are taken into consideration. Some days and hours are replaced by corresponding data from the same month, but from a different year, to bring the weather file closer to the published 30-year normal for that month (Said and Kadry, 1994). This representation is mainly used in long-term load and energy predictions due to the similarity to the 30-year normal.

The document "Hourly data for assessing the annual energy use for heating and cooling", ISO 15927-4 (2005), presents a calculation procedure for a climatic reference year. The calculation procedure includes meteorological parameters such as dry-bulb temperature, solar irradiance, humidity and wind speed. However, this ISO reference year is not yet available from the Norwegian Meteorological Institute.

Different representations of climatic parameters are most interesting in relation to simulation programs and intelligent computer systems, but yearly representations are also used to some extent in statistical analyses in general, and in regression analyses in particular. The Test Reference Year is most suitable for short-term predictions of load and energy demand because of its real representation of weather characteristics. The Design Reference Year also employs real data and may be used in both short-term and long-term predictions. The Typical Meteorological Year and the Weather Year for Energy Calculations consist of constructed data representing long-term average climatic parameters. As a consequence, the DRY, the TMY and the WYEC are most suited for long-term load and energy predictions.

Yearly representations of weather parameters require a large amount of data. The accuracy level of the climatic representation must correlate with the load and energy estimation method used by the energy planner. For example, a large amount of weather data will increase the simulation time. One possibility for reducing the simulation time might be to use simplified weather data and a corresponding method.

Westphal and Lamberts (2004) presented a simplified weather file with 21, 14 or only 7 days per month of data. They found in a case study in Brazil that the difference in energy estimation between simulations using the TRY and a simplified weather data file was as high as 18%. The simulation time using the simplified data was reduced by as much as 50%. The simplified weather data file gave satisfactory results for buildings with low thermal mass, but the methodology presented in Westphal and Lamberts (2004) revealed weaknesses when the simulation involved buildings with high thermal mass. The main weakness is that the simplified method did not take into account the influence of thermal inertia in buildings with a large thermal mass.

In some cases, it is also possible to use simplified weather data such as a design day. Chou et al. (1999) present a methodology for the selection of a design day weather file for energy simulations based on the TMY. The selected design day is not based on the most adverse set of weather conditions, but rather on weather conditions that give a low peak as well as few hours of load not met. Simplified weather data offers the advantage of allowing the use of less complex simulation programs. The disadvantage lies in the accuracy of the output from the corresponding simulation program.

In this thesis, the Design Reference Year has been chosen for the calculation of yearly heat load profiles and heat load duration profiles. The Design Reference Year has only been developed for the Norwegian locales of Oslo, Bergen and Andøya. The outdoor temperatures from the DRY for Oslo have been used in this thesis because the Oslo climate is very close to both the average Norwegian climate, and the Trondheim climate (BNES, 2005).

5.4 Other factors influencing load modelling in buildings

In addition to climatic parameters, three main factors influence the load and energy demand in buildings:

1. Physical determinants
2. Control regimes
3. Behavioural determinants

Physical and behavioural determinants have been highlighted in Yao and Steemers (2005) in relation to domestic buildings. Control regime parameters have also been included in this thesis due to their strong influence on large buildings in general and educational buildings, hotels and restaurants, hospital buildings and office buildings in particular.

Figure 5.6 shows a sketch of some of the different factors that influence the heat and electricity load demand in a building. The physical determinants are exemplified through the building envelope, the control regime is exemplified by the operation of the space heating, the ventilation and the lighting system, whereas the behavioural determinants are exemplified by the presence of people and their use of electrical appliances.

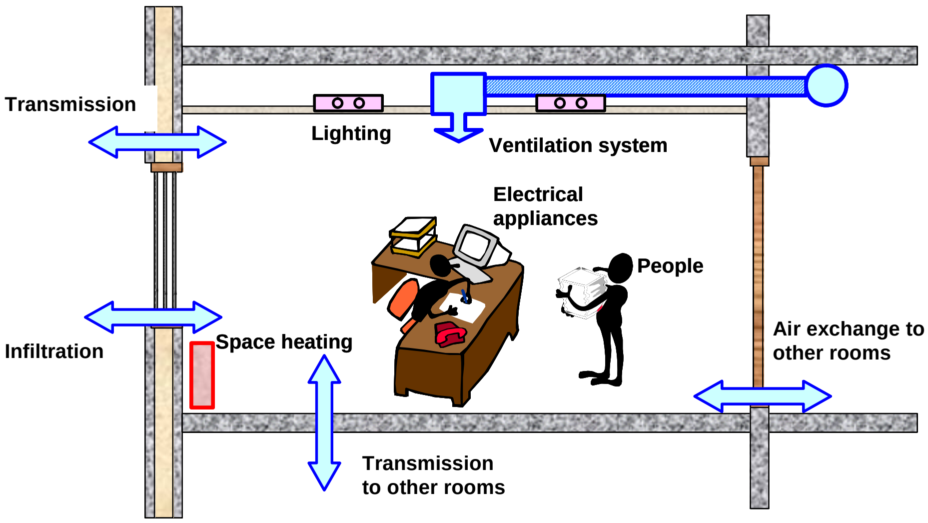

Figure 5.6 Sketch of a room showing some of the different factors, aside from climate, that influence the heat and electricity load demand in a building. These are physical determinants, control regime and behavioural determinants (Novakovic, 2000).

5.4.1 Physical determinants

According to Yao and Steemers (2005), physical determinants are relatively fixed decisions, and the correlations between energy and climate and between energy and building design are significant. In order to analyse the correlation between energy and building design, a number of physical background parameters concerning the building sample were collected.

The physical determinants collected for the different buildings are shown in Table 5.2. The building owners and/or operational managers completed questionnaires concerning the buildings' physical determinants and control regimes.

Table 5.2 Physical parameters collected for the building sample

Physical parameters	**Comment**
Building year	The year the construction of the building started.
Rehabilitation	Large scale rehabilitation of the building envelope or the building's installations.
Available area	Available area of the building according to NS 3940.
Number of buildings	One or more buildings included in the electricity and district heat measurements.
Shape	Square, rectangular etc.
Building material	Brick, glass, wood, etc. influencing the buildings' time constants.
Insulation standard	External walls, floor and roof, as well as windows and doors.
Number of free facades	External walls not connected to another building.
Floor heating	Electrical or hydronic heating system in the floor.
Radiators	Wall mounted hydronic heaters.
Heater battery	Electrical or hydronic heater battery in the ventilation system.
Temperature efficiency	Efficiency of the heat recovery unit in the ventilation system.
Hot tap water heating	Direct heating or accumulator tank for hot tap water heating.
Shading devices	Venetian blinds, marquises, curtains etc.
Cooling system present	Electrical or hydronic cooling.

Additional information concerning the most important physical input parameters is synthesized in the following paragraphs.

Construction year, rehabilitation and insulation standards have been found to be important input parameters in relation to load modelling of buildings, especially for heat purposes. This is a result of the changes in the building codes from 1928 and to the present day (2007). A historical review of the Norwegian building regulations was presented by Thyholt (2006). Quantified requirements for heat transmission coefficients for various building components were not introduced until 1949. Stricter regulations regarding heat transmission coefficients were also introduced in 1969, 1980, 1987 and 1997 (Thyholt, 2006). The last revision of the building code regulations came into force on February 1, 2007 with a transition period of two-and-a-half years for full implementation (TEK, 2007).

The heat transmission coefficients for external walls, windows, roofs and ground floors influence the space heating demand, as shown in Equation 4.3 in Chapter 4.2.2. The building codes and the technical regulations that are current during a building's construction and possible rehabilitation have a direct impact on the building's transmission losses, and thereby, the heat load demand.

Available area was defined in NS 3940 (1986) as the area of the occupied unit(s) and shared unit(s) that lie within the surrounding walls, with certain deductions specified in the standard. It has been very important to collect information about the available area for all the buildings analysed in this thesis because of the model's use of specific load demand and specific energy consumption. Also, the specific energy consumption in the buildings analysed has been compared to the collected total specific energy consumption for several building categories in the Building Network's Energy Statistics (BNES, 2005).

Questions in the questionnaire filled out by the building owners or managers about the buildings' various technical installations, such as floor heating, radiators, and heater batteries, easily identified buildings that used electricity for heat purposes.

Future developments in building code regulations, and the introduction of new technology regarding energy distribution and consumption, will influence the heat and electricity load profiles for new and rehabilitated buildings. New heat and electricity load profiles for buildings should be developed after occurrence of major changes, as described above.

5.4.2 Control regimes

Central control and monitoring systems are becoming more widespread in buildings, which has a direct influence on load profiles. Collected input parameters that can be related to control regimes are presented in Table 5.3, along with brief comments regarding the various control regime parameters.

Table 5.3 Control regime parameters collected for the building sample.

Control regime parameter	**Comment**
Indoor temperature	Set point temperature that meets the thermal comfort of the building users.
Night set-back	Shut-down or reduction of the space-heating system during the night, and also during the weekends for some buildings.
Ventilation rate	Amount of inlet air at full capacity.
Operation of the ventilation system	Continuous operation, or during daytime only.
Reduced fanspeed	Set-back of the ventilation system reducing the amount of inlet air during the afternoon/night and weekends.
Lighting control	Manual or automatic control. If the latter, motion and/or daylight sensors.

The indoor air temperature for most buildings analysed has been in the range of 20°C to 22°C, mainly controlled by thermostats. Buildings with night set-back for the space heating system have not been included in the analyses due to the small number of buildings in this category.

The ventilation rate is strongly related to the building's construction year or major rehabilitation of the ventilation system. Building code regulations specify the minimum amount of air needed for hygienic reasons and also emissions from building materials. An evaluation of the requirements to air flow rates in the regulations to the building codes was given by Blom (2006). In 1969, the required air flow rate was based on the building area only. In the TEK from 1987, the requirement changed for both inlet air which reduced the body odours [l/s pr. person] and reduced the emissions from building materials [l/s pr. m^2]. Even stricter requirements were placed on the amount of air to reduce the emissions from building materials in TEK 1997 (Blom, 2006).

Control regimes for the ventilation systems are strongly related to the building's usage time, as well as the indoor air quality control categories that have been applied to the ventilation systems. The type of air quality control influences both the ventilation heating demand and the electricity demand to the fans. For more information regarding control categories, see Table 4.4 in Chapter 4.2.

Most ventilation systems in the buildings analysed for the purpose of this thesis ran during the buildings' usage times and were otherwise strongly reduced or shut down, i.e. mainly using time control. A few office buildings also featured occupancy control of the ventilation system.

Most lighting systems in the buildings analysed were manually controlled.

There has been, and still is, a great deal of technological development in the central control and monitoring systems field. Future trends, such as continuous commissioning, demand-side management with possible load control, and smart house technology, will influence the heat and electricity load profiles in new and rehabilitated buildings. Introduction of new control technology must be allowed for in energy planning projects.

5.4.3 Behavioural determinants

Some paragraphs in this chapter have been taken from Pedersen (2007).

Yao and Steemers (2005) defined behavioural determinants as strongly related to households human factor with a high correlation to people's habits.

The amount of energy consumed is very dependent upon the attitude and the awareness of energy customers. The consumption patterns in different building types, especially in households, are unique for that particular building. Therefore, customer influence differs depending on what kind of buildings they spend their time in. Consumers have less influence in a building with automatic control than in a manually operated building. Awareness and attitudes towards energy consumption are more evident in household consumption than in buildings where many people may simultaneously have an influence on energy use, such as in office buildings.

Aune (1998) has performed several field surveys and in-depth interviews with several people in different Norwegian households in order to characterize different consumer groups. She has learned that attitude and consumption do not necessarily coincide, and that the way consumers think they use energy might not be reflected in their actual consumption.

The actual energy consumption also depends upon the culture. Wilhite et al. (1996) found that the Norwegian culture is intensive in its energy use in relation to space heating and lighting, while the Japanese people use less energy for space heating and lighting. As a result, Norwegian households have higher energy bills in terms of space heating and lighting consumption. The Japanese, on the other hand, have a very energy intensive and extremely important bathing culture, which means that hot tap water use accounts for a large part of their energy bill.

Differences in culture, attitudes and building practices are important and should be considered when estimating load profiles and energy demand. Some methods, such as the energy-signature method (Aronsson, 1996), take this into consideration, while some building simulation programs concentrate mainly on the building's physical behaviour. According to Richalet et al. (2001), a method developed for load and energy estimations should be based on measured energy data, because the real behaviour of the building can differ significantly from its design due to the operation of the building's energy system.

The price sensitivity of energy consumers regarding time-differentiated tariffs and the customers' response to strongly increased tariffs have not been investigated in this thesis. Ericsson (2006a) found that residential electricity consumers in his sample were not very price responsive. However, the response rate was based on the average of all the customers within defined categories, excluding the possible identification of customers who were motivated to respond to time-differentiated tariffs.

6 Method developed for load modelling of buildings

6.1 Introduction

The purpose of this chapter is to present the method developed for heat and electricity load modelling of buildings, as well as the procedure for load profile aggregation for a specified planning area.

The methods developed for heat and electricity load modelling have been based on the processing of data from the requirement traceability information model. This chapter focuses on computer program requirements and calculus of probability, as well as uncertainty analyses and robustness. First of all, the computer programs applied in this thesis are presented. Secondly, the method developed for heat load demand based on regression analysis is elaborated. Thirdly, the method developed for statistical analysis of electricity load demand is presented. And last, the method for aggregation of load profiles is introduced.

6.2 Computer program

The requirements for one or more computer programs have been essential for this thesis due to the amount of data collected. It was important to handle the data in a structured and orderly manner as well as to have the ability to process the data in every way desired. The computer program had to be adjusted to the file format of the data collected. Excel was used for the purpose of data collection. The solution algorithm for load modelling in mixed energy distribution systems was developed in Matlab.

6.2.1 Excel

Hourly measured district heat and electricity consumption numbers are available on the Internet. The TEV energy utility has a database called the Energy Guide on the Internet. Once permission to use the energy data had been granted, the specified data was automatically downloaded to Excel. Climatic parameters concerning hourly and daily mean temperatures received from the Norwegian Meteorological Institute or downloaded from Internet (eklima, 2007), have also mainly been collated in Excel worksheets. For this reason, and also because of its user-friendliness, Excel was used to collect and organize data concerning load measurements, climatic parameters and time.

The hourly district heat and electricity measurements were organized in a 2 by n matrix (# measurements) for each building analysed. The matrix was called **Measurements** and consisted of hourly electricity consumption (EL) in the first column and hourly district heat consumption (DH) in the second column.

$$\textbf{Measurements} = \begin{bmatrix} EL_1 & DH_1 \\ \dots & \dots \\ EL_n & DH_n \end{bmatrix} \tag{6.1}$$

The climatic parameters were organized in a 2 by m matrix called **Climate** with hourly temperatures (HT) in the first column and daily mean temperatures (DMT) in the second column. The daily mean temperature was equal for each of the 24 rows corresponding to one day. The row number in the **Climate** matrix corresponded to the **Measurements** matrix and the **Time** matrix as explained in the paragraphs above and below respectively.

$$\textbf{Climate} = \begin{bmatrix} HT_1 & DMT_1 \\ \dots & \dots \\ HT_m & DMT_m \end{bmatrix} \tag{6.2}$$

The 6 by m **Time** matrix was organized with year (Y), month (M), date (D), days (Day), hour (H) and special days (SD), all as variables. The days were presented as Mondays = 1, Tuesdays = 2, ..., and Sundays = 7. The special days corresponded mainly to the educational buildings category due to the number of special days concerning holidays, see Table 6.1. This column was also used to indicate Christmas and Easter in all building categories analysed.

$$\textbf{Time} = \begin{bmatrix} Y_1 & M_1 & D_1 & Day_1 & H_1 & SD_1 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ Y_m & M_m & D_m & Day_m & H_m & SD_m \end{bmatrix} \tag{6.3}$$

For all matrices; **Measurements**, **Climate** and **Time**, $m \geq n$.

Table 6.1 Classification of special days mainly related to the educational buildings category.

Name	**Number**
Regular day	0
Summer holiday	1
Fall break	2
Christmas holiday	3
Winter break	4
Easter (the whole week)	5
Others	6

In the early stages of the thesis work, some analyses of load profiles were performed by Pivot tables in Excel. This was a helpful tool in order to get an overview of the relation between **Measurements**, **Climate** and **Time**. But this tool had its limitations, and the decision fell on the computer program Matlab in order to develop the solution algorithms based on functions and scripts.

6.2.2 Matlab

The computer program Matlab has been used as the analysis tool in order to handle and process large amounts of data. The **Measurements**, **Climate** and **Time** matrices were all imported from Excel and processed in Matlab using specially developed functions and scripts, as well as built in toolboxes.

In addition to numerous built-in functions, Matlab also has various toolboxes such as Neural Networks, Partial Differential Equations and Statistics. These toolboxes may all be applied in load modelling and energy estimations in relation to intelligent computer systems, simulations programs and statistical analyses. The latter methodology has been the basis for this thesis, with the Statistics toolbox the tool of choice in the analyses, in particularly the Polynomial Fitting Tool for regression analyses and the Distribution Fitting Tool for probability distributions.

The solution algorithm is tripartite; one procedure has been developed for analysing relative heat and electricity load profiles for each building, a second procedure has been developed for comparison and generalisation of the different load profiles for the selected building categories, and a third procedure has been developed for the aggregation of load profiles for a specified planning area with a given mixture of buildings.

Algorithm for one building

The procedure for the solution algorithm for one building is given in the list below:

1. Load specific building file and perform quality assurance on the data.
2. Calculate the change-point temperature dividing the temperature-dependent and temperature-independent heat consumption. Calculate relative design load profile for heat load demand, including relative regression coefficients, as well as temperature-independent heat load profile.
3. Calculate relative design load profile for electricity load demand as well as seasonal electricity load profiles.

The solution algorithm for the calculation of relative load profiles for heat and electricity has been shown in Figure 2.9 in Chapter 2.4.4 in relation to feasible solutions in the systems engineering process.

Algorithm for generalisation

The procedure for the solution algorithm for generalised load profiles for different building categories is listed below:

1. Load relative heat and electricity load profiles for all buildings analysed.
2. Sort load profiles by building category and archetype.
3. Calculate expected value and standard deviation for all archetypes.

The solution algorithm for calculation of generalised load profiles for heat and electricity has been shown in Figure 2.10 in Chapter 2.4.4 in relation to feasible solutions in the systems engineering process. The generalised load profiles are presented in Chapter 7: Analyses and results.

Algorithm for aggregation

The procedure for the solution algorithm for aggregation of load profiles for a specified planning area with a given mixture of buildings is listed below:

1. Select a specified planning area with a defined mixture of buildings.
2. Apply generalised heat and electricity load profiles for building b based on the building category.
3. Use specific load indicators to construct real heat and electricity load profiles as well as standard deviations for design day.
4. Apply design reference year (DRY) for calculating relative yearly load profiles. Use specific energy indicators to calculate real yearly heat and electricity load profiles.
5. Add real design heat and electricity load profiles at node connection points as well as standard deviations. Add yearly load profiles at the same node.
6. Add all design and yearly load profiles at the energy distribution/transformer unit, including the 95% quantile for peak load estimations.
7. Calculate coincidence factors for heat and electricity for design load profiles.
8. Choose energy carriers and include distribution losses for load and energy accordingly.

The solution algorithm for load profile aggregation of heat and electricity has been shown in Figure 2.11 in Chapter 2.4.4 in relation to feasible solutions in the systems engineering process. The aggregation method is explained in detail in Chapter 6.5 and a theoretical case study is performed in Chapter 8 to illustrate the aggregation procedure.

6.3 Heat load model based on regression analysis

The method developed for the estimation of heat load profiles for this thesis is based on simple linear regression. The daily mean temperature and the heat load have been investigated in relation to linear correlation. The method developed for heat load model are examined in this chapter.

6.3.1 Background for the heat load model

The objective of the heat load model was to find the linear equation for every hour of the day for each building category, i.e. to find the values of α and β in Equation 3.8. When analysing the district heat consumption, it has been important to divide the temperature-dependent and temperature-independent consumption. The base load for heat load demand is the hot tap water consumption. The space heating and ventilation heating demand are temperature-dependent and occur only during the temperature-dependent season.

The steady state temperature-dependent load has been defined in Equation 4.1 in Chapter 4.2.2 by the demand to cover the total heat loss, Φ_{HL}, caused by transmission, infiltration and ventilation losses (prEN 12831, 2002). Intermittent heating was excluded, see Chapter 4.2.2. The heat load model is based on actual measurements of district heating, which covers the demand for space heating, ventilation heating and hot tap water. The latter end-use has also been included in the calculations. The heat load demand is given in Equation 6.4:

$$\Phi_{HL} = \sum \Phi_{T,i} + \sum \Phi_{V,i} + \Phi_{htw} \text{ [W]} \tag{6.4}$$

where:

$\sum \Phi_{T,i}$ Sum of transmission heat losses of all heated spaces excluding the heat transferred inside the building entity or the building

$\sum \Phi_{V,i}$ Ventilation heat losses of all heated spaces excluding the heat transferred inside the building entity or the buildings

Φ_{htw} Heat load demand to satisfy the demand for hot tap water

As Equation 4.3 and Equation 4.4 in Chapter 4.2.2 have shown, the heat load demand is dependent on the difference between the indoor and outdoor temperature. The reason why heat is supplied to a building is to achieve thermal comfort, i.e. a state of mind where people experience absolute satisfaction with the thermal surroundings (Hanssen et al., 1996). The ability to achieve such a state of mind is mainly dependent on the indoor temperature, the air velocity and the air humidity. More specifically, the indoor temperature demand is dependent on the type of building and people's activity level. In most building categories, the indoor temperature is set to 20°C for heat load calculations. Since the indoor temperature, θ_i, is set to a certain temperature, the variables in the heat load demand equation are the outdoor temperature, θ_e, the transmission heat loss coefficient, H_T, the ventilation heat loss coefficient, H_V and the hot tap water demand, Φ_{htw}.

The heat load demand has been shown to be dependent on outdoor temperature in Equation 4.3 and Equation 4.4. For the purpose of this thesis, the daily mean temperature was chosen as the unit to work with instead of the hourly outdoor temperature. See Chapter 5.3.1 for more information about the outdoor temperature.

There are also several other climatic parameters which may influence the heat load demand, as described in Chapter 5.3.2. These have been omitted from the analyses due to the scope of this thesis, which was to develop a model that is good enough for the stakeholders for the purpose of planning for mixed energy distribution systems, without requiring too many input variables.

6.3.2 Linear equation for every hour of the day

It is possible to solve for linear equation for every hour of the day for a given building when the heat load demand is assumed to be dependent only on the daily mean temperature, θ_{dmt}. The transmission heat loss coefficient, H_T, and the ventilation heat loss coefficient, H_V can be assumed to be constant within each hour of the day. The heat load demand for hot tap water, Φ_{htw}, is assumed to be relatively constant within each hour due to the measurement resolution of one hour. All buildings analysed for this thesis, except for most of the single family houses and apartment blocks, have balanced ventilation systems.

Consequently, Equation 6.5 is derived from the insertion of Equation 4.3 and Equation 4.9 in Chapter 4.2.2 into Equation 6.4.

$$\Phi_{HL} = (\sum U \cdot A + \dot{V}_i \cdot \rho \cdot c_p \cdot (1 - \eta)) \cdot \Delta\theta + \Phi_{htw} \text{ [W]} \tag{6.5}$$

where:

$\Delta\theta$ $(\theta_{i,\,int} - \theta_{mdt})$, in [K]

$\theta_{i,int}$ Indoor temperature, 20°C for load estimations

θ_{dmt} Daily mean temperature, in [°C]

Equation 6.5 expressed in the same form as Equation 3.7, i.e. the regression equation, gives:

$$\Phi_{HL} = \alpha + \beta \cdot \theta_{dmt} + e \text{ [W]} \tag{6.6}$$

where:

α $(\sum U \cdot A + \dot{V}_i \cdot \rho \cdot c_p \cdot (1 - \eta)) \cdot \theta_{i,\,int} + \Phi_{htw}$ [W]

β $-(\sum U \cdot A + \dot{V}_i \cdot \rho \cdot c_p \cdot (1 - \eta))$ [W/K]

e residual, the error in the fit

For every building category, the district heat and electricity consumption have been divided into 24 different equations, with each equation representing the hour of the day. The general Equation 6.6 for heat load demand is derived for every hour, j, of the day for a given building category. Every variable has been assumed to have a constant value within the specified hour, i.e. static conditions, with the daily mean temperature as the only exception:

$$\Phi_{HL,\,j} = \alpha_j + \beta_j \cdot \theta_{dmt} + e_j \text{ [W]} \tag{6.7}$$

where:

j 1, 2, 3,..., 24 where 1 = 12 a.m. to 1 a.m., 2 = 1 a.m. to 2 a.m., ..., 24 = 11 p.m. to 12 a.m.

α_j The specific regression coefficient for a given hour j

β_j The specific regression coefficient for a given hour j

ej Residuals for a given hour j

As a result, every building category defined in Chapter 4.4 has been assigned its unique α_j and β_j for hours j = 1, 2, ..., 24. As a consequence, two vectors, **A** and **B**, of length 24 have been calculated for every building category:

$$\mathbf{A} = [\alpha_1\ \alpha_2\ \alpha_3\ ...\ \alpha_{23}\ \alpha_{24}]$$

$$\mathbf{B} = [\beta_1\ \beta_2\ \beta_3\ ...\ \beta_{23}\ \beta_{24}]$$

A and **B** inserted into Equation 6.8 gives the heat load vector, Φ_{HL} :

$$\Phi_{HL} = \mathbf{A} + \mathbf{B} \cdot \theta_{dmt} \tag{6.8}$$

Here, the residuals have been omitted from Equation 6.8. The standard deviation is discussed in Chapter 7 in the analyses of load profiles for different building categories.

The unique classification of the α and β variables have been conducted according to the first letters of the different building categories, see Table 6.2. The building category division have been selected according to the EPBD, and the underlined building categories are those that have been analysed in this thesis in relation to the heat load model.

Table 6.2 Unique classification of α and β values according to the different building categories

Building category	α	β
<u>Single family Houses of different types</u>	α_{SH}	β_{SH}
<u>Apartment Blocks</u>	α_{AB}	β_{AB}
<u>Office Buildings</u>	α_{OB}	β_{OB}
<u>Educational Buildings</u>	α_{EB}	β_{EB}
<u>Hospital Buildings</u>	α_{HB}	β_{HB}
<u>Hotels and Restaurants</u>	α_{HR}	β_{HR}
Sports Facilities	α_{SF}	β_{SF}
Wholesale and Retail trade services buildings	α_{WR}	β_{WR}
Other types of energy-consuming buildings		

A regression analysis for heat load demand is illustrated using the example of an office building in Trondheim, called OB2. Figure 6.1 shows an example of daily mean temperature plotted against hourly district heat measurements for OB2. The heat load is the average load from 11 a.m. to 12 p.m. during a period from January 2002 until October 2006. The figure shows that the heat load is temperature-dependent below a certain daily mean temperature, also referred to as the temperature-dependent season. For daily mean temperatures above a certain value, the heat load is temperature-independent, meaning that the only heat load demand is hot tap water. The scatter plots indicated that a piece-wise linear regression model would be a good approach to model the heat load demand. The temperature that separates the temperature-dependent and temperature-independent season is called the change-point temperature.

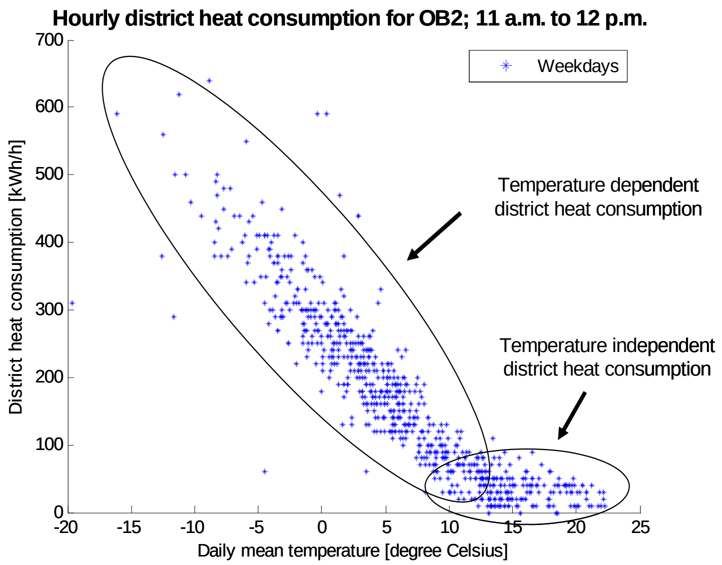

Figure 6.1 Scatter plot of daily mean temperature vs. hourly district heat consumption for OB2 in Trondheim for weekdays hour 12, i.e. district heat consumption from 11 a.m. to 12 p.m. for nearly five years (January 2002 - October 2006).

Alpha and beta values

The hourly district heat consumption can be divided between temperature-dependent and temperature-independent consumption, as shown in Figure 6.1. The temperature-dependent season in this thesis has been defined to be the number of days when the daily mean temperature drops below the temperature that gives relatively equal beta values, i.e. when the influence of the temperature-independent season no longer is present. This is illustrated in the next paragraphs along with the beta band, the temperature band and the temperature range defined in this thesis. The temperature-dependent season may not be equal to the heating season defined in Chapter 4.

The temperature-dependent season for a given building is strongly related to the building material, the insulation thickness, the control system and the people using the building, among others. As a consequence, the temperature-dependent season may vary from one building to another within the same building category, as well as variations between the hours of the day for the same building due to the use.

It was important to find the temperature-dependent season for every building and every hour of the day, because the regression analysis is performed on this consumption only. The scatter plot in Figure 6.1 indicates that the temperature-dependent season starts somewhere from 15°C down to 9°C. It was necessary to develop a mathematical approach to find the correct temperature-dependent season.

The beta value in Equation 6.7 gives the slope of the regression equation and indicates how much the heat load decreases with increasing daily mean temperature. The alpha and beta values have been found using the method of least squares, see Chapter 3.3.2.

For a given hour, in this illustration hour 11 a.m. to 12 p.m., the calculated beta values for the temperature-dependent season are plotted in steps of 0.1°C, see Figure 6.2. The temperature-dependent season is set to vary from 17°C down to 0°C.

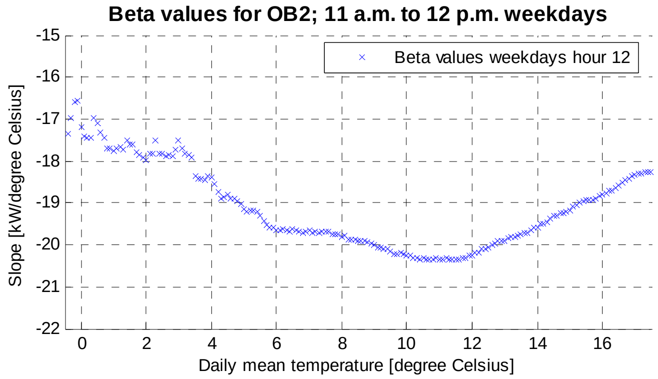

Figure 6.2 Beta values plotted for the temperature-dependent season, assuming the temperature-dependent season starts at 17°C and decreases to 0°C with a temperature step of 0.1°C.

An approximately constant beta value indicates that the influence of the temperature-independent heat consumption is neglectable. The variation of the beta values at low daily mean temperatures in Figure 6.2 is due to the fact that many data points within the actual temperature-dependent season have been left out of the regression analysis.

The idea was to find a temperature band of $\Delta\theta$ equal 1°C, where the beta value is approximately constant, i.e. where the total sum of squares was minimum. The variation of the beta value is defined to be the beta band. The temperature-dependent season is defined to start at the daily mean temperature corresponding to the average temperature within the temperature band.

Total sum of squares (SST) (Walpole et al., 1998):

$$\text{SST} = \sum_{i=1}^{n} (x_i - \bar{x})^2 \tag{6.9}$$

where:

x_i Beta values calculated for every temperature step within each temperature band.

$\bar{x}$ Average beta value within the given temperature band.

Before the temperature band is found on the basis of the minimum total sum of squares of beta values, the alpha values are investigated. Figure 6.3 shows the alpha values for OB2 weekdays hour 11 a.m. to 12 p.m. The alpha value indicates the point of intersection at 0°C daily mean temperature, i.e. the heat load demand at a daily mean temperature of 0°C.

Figure 6.3 shows that the alpha values increase slightly from 15°C and down to 6°C and increase more from 17°C to 15°C and from 6°C and down to 0°C.

The alpha values during the temperature-dependent season should be relatively constant. As a result, the temperature-dependent season is found in the temperature range where both the intersection of the regression line at 0°C and the slope have the smallest variations.

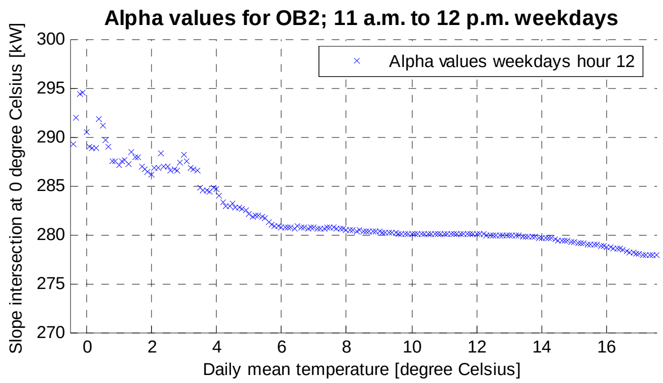

Figure 6.3 Alpha values plotted for the temperature-dependent season, assuming the temperature-dependent season starts at 17°C and decreases to 0°C with a temperature step of 0.1°C.

The mathematical procedure developed to find the change-point temperature for a given building at a given hour is based on alpha and beta values in the following way:

1. Calculate the temperature range of $\Delta\theta$ = 5°C in which the total sum of squares of the alpha values is smallest. The alpha values slide from 17°C and down to 0°C with a temperature step of 0.1°C.

2. Calculate the temperature band of $\Delta\theta$ = 1°C where the minimum total sum of squares of the beta values occur within the temperature range of $\Delta\theta$ = 5°C found in # 1. The beta values slide from the highest temperature in the temperature range to the lowest with a temperature step of 0.1°C.
3. The temperature-dependent season is then found within the temperature band given by # 2. The change-point temperature starts at the average temperature within the temperature band.
4. When the temperature-dependent season is found in # 3, the alpha and beta values are calculated using the method of least squares for the temperature-dependent consumption only.

The minimum total sum of squares for alpha values for OB2 weekdays between 11 a.m. and 12 p.m. occurred at the temperature range from 8.9°C to 13.9°C. The corresponding minimum total sum of squares for beta values within the temperature range occurred within the temperature steps from 10.2°C to 11.1°C, see Figure 6.4. This is defined to be the temperature band for the given hour and the temperature-dependent season is defined to begin at the mean temperature step, here 10.6°C.

The beta value calculated within the temperature-dependent season gave a slope of -20.29 kW/°C and the corresponding alpha value was calculated to be 282.56 kW.

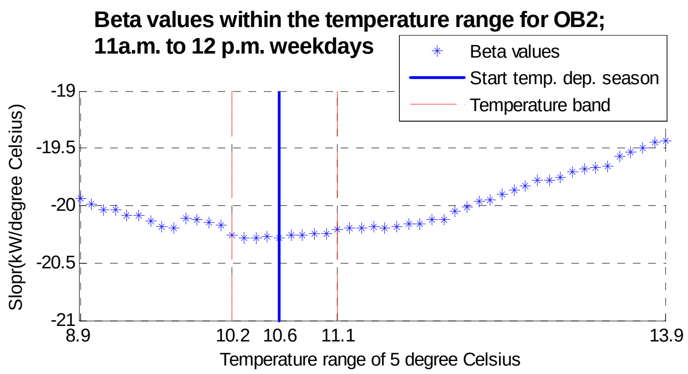

Figure 6.4 Beta values plotted within the 5°C temperature range found by the minimum total sum of squares of alpha values. The temperature band is given by the dotted lines and the start of the temperature-dependent season is given by the solid line.

Correlation coefficient

The alpha and beta values were not found based on the temperature band alone. The correlation coefficient has also been an important indicator for the mathematical correlation between the daily mean temperature and the heat load. Figure 6.5 shows the absolute value of the correlation coefficient, *R*, for the various temperature-dependent seasons. The real r-value within the temperature band for the specified hour, 11 a.m. to 12 p.m., vary from -0.8905 to -0.8828. This indicates a correlation, r^2, between the daily mean temperature and the heat load of somewhere from 79,3% down to 77,9%. The negative sign of the r-value indicates that the slope is decreasing with increasing daily mean temperature.

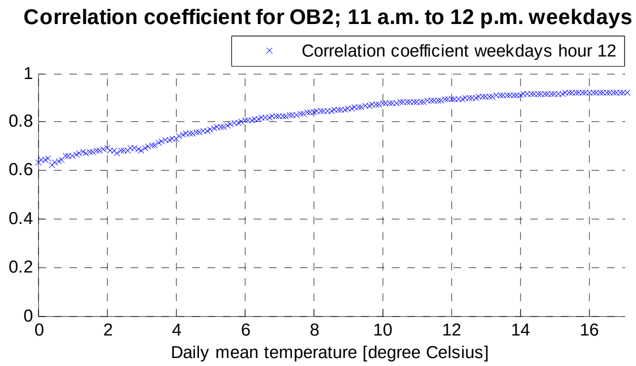

Figure 6.5 The absolute value of the correlation coefficient for the data points are plotted for the temperature-dependent season assuming the temperature-dependent season starts at 17°C and decreases to 0°C with a temperature step of 0.1°C.

The linear heat load equation from 11 a.m. to 12 p.m. for OB2 is given in Equation 6.7:

$$\Phi_{OB2,\,12} = \alpha_{OB2,\,12} + \beta_{OB2,\,12} \cdot \theta_{dmt} \tag{6.10}$$

where:

$\alpha_{OB2,12}$ = 282.56 kW

$\beta_{OB2,12}$ = -20.29 kW/°C

Sensitivity analysis of the alpha and beta values

The sensitivity analysis of the alpha and beta values have been based on the following three parameters:

1. Temperature range $\Delta\theta$ for relatively constant alpha values.
2. Temperature band $\Delta\theta$ within the temperature range for relatively constant beta values.
3. Temperature step $\Delta\theta$.

The sensitivity analysis has been performed on several buildings by investigating the calculated change-point temperature based on various temperature ranges, temperature bands and temperature steps respectively.

<u>Temperature range</u>

Sensitivity analysis of the temperature range revealed that the temperature range should not be too wide. This was due to the fact that the minimum total sum of squares of beta values may occur at high outdoor temperatures such as 17°C or above. This was caused by the large number of measurements in the real temperature-independent season. Large temperature ranges may also result in estimations of very low temperature-dependent seasons in buildings with large variations within the alpha band.

Temperature ranges that are too narrow are disadvantageous because the minimum total sum of squares of beta values may occur outside the calculated temperature range.

Based on these assumptions, a temperature range of 5°C was chosen for all buildings analysed in this thesis. This was also due to a graphical analysis of the calculated alpha values for different temperature-dependent seasons.

Figure 6.6 shows a sensitivity analysis of the temperature range for OB2 weekdays, including a constant temperature band of 1°C and a temperature step of 0.1°C. The temperature range varies between 3°C, 5°C, 7°C and 10°C. There were only small variations between the temperature ranges, which showed that this parameter was not very sensitive for OB2. Different temperature ranges have shown to be more sensitive for other buildings analysed.

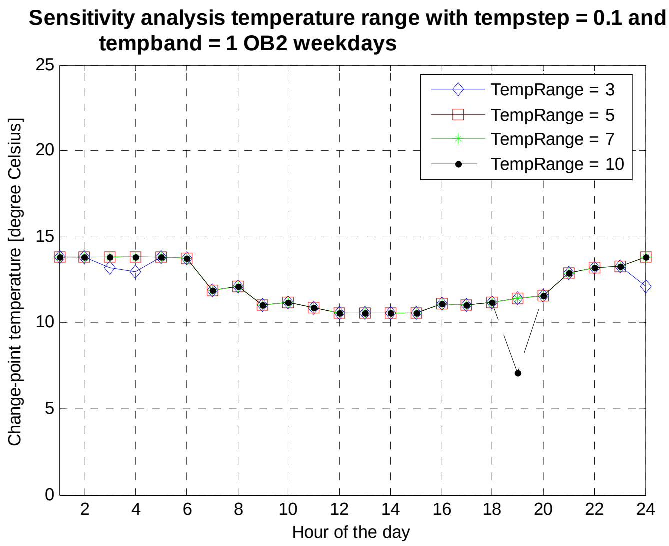

Figure 6.6 Calculated temperature-dependent season for different temperature ranges with a constant temperature step and temperature band for OB2 weekdays.

Temperature band

The temperature band has proven to be the most sensitive parameter in the sensitivity analysis, because the temperature-dependent season is calculated based on the mean temperature within the temperature band. This suggested that the temperature band had to be narrow, but at the same time it had to be in proportion with the temperature step.

The temperature band has been set to 1°C for all temperature-dependent season calculations. An accuracy of 0.5°C, i.e. finding the mean temperature within the temperature band, has been a specific enough estimate of the temperature-dependent season for heat load estimations.

Figure 6.7 shows a sensitivity analysis of the temperature band for OB2 weekdays, including a constant temperature range of 5°C and a temperature step of 0.1°C. The temperature band varies between 0.5°C, 1°C, 2°C and 3°C. The temperature band of 0.5°C may be too narrow, but the other temperature bands gave almost the same temperature-dependent season.

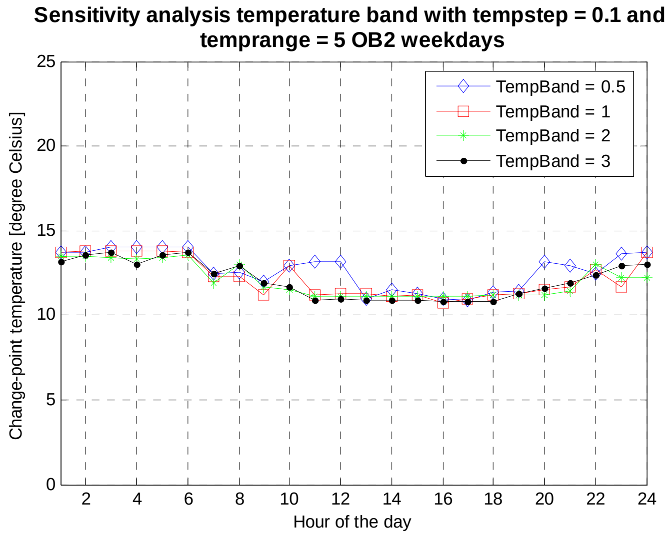

Figure 6.7 Calculated temperature-dependent season for different temperature bands with constant temperature step and temperature range for OB2 weekdays.

Temperature step

The temperature step is dependent on the size of the temperature band and the temperature range, and it had to be adjusted accordingly. Large temperature steps could give different temperature-dependent seasons than smaller temperature steps. Due to the variation of the beta values within the temperature range, too high temperature steps could give incorrect values for the temperature-dependent season. On the other hand, temperature steps that were too small did not increase the accuracy of the estimate and it did increase the calculation time.

Based on these criteria, a temperature step of 0.1°C was chosen. Figure 6.8 shows a sensitivity analysis of the temperature step for OB2 weekdays, including a constant temperature range of 5°C and a temperature band of 1°C. The temperature step varies between 0.05°C, 0.1°C, 0.2°C and 0.5°C. Large temperature steps in relation to a narrow temperature band gave more fluctuations in the change-point temperature throughout the day.

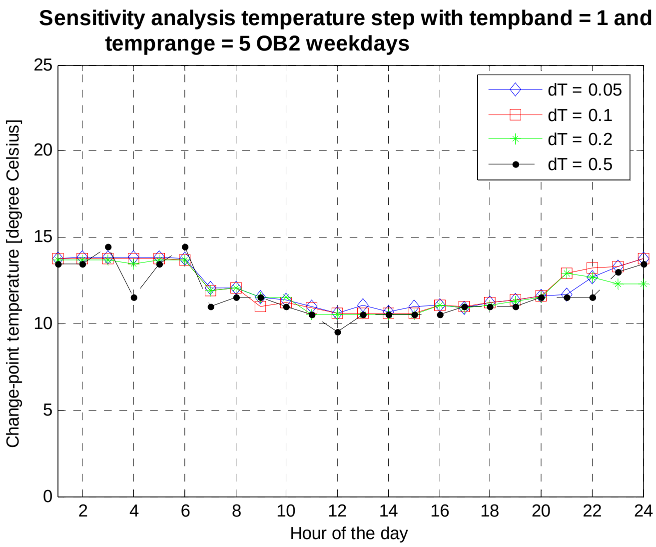

Figure 6.8 Calculated temperature-dependent season for different temperature steps with a constant temperature range and temperature band for OB2 weekdays.

Other steps for the temperature range, the temperature band and the temperature step have also been investigated, but they have not been presented in this thesis.

None of the parameters in the sensitivity analysis have shown to influence the heat load profile significantly. Even though the different parameters varied, the change-point temperature did not vary very much, and as a result, the method developed for the heat load model is robust.

Confidence interval

The confidence interval for a regression analysis using a linear equation has been defined in Chapter 3.3.2. The change-point temperature has been used when performing a confidence interval analysis on the data material from the different buildings.

Figure 6.9 shows the regression analysis for OB2 from 11 a.m to 12 p.m. The regression line, 95% confidence interval lines and standard deviation lines are plotted. The temperature-dependent season has been defined to begin at 10.6°C. The method of least squares has been used as the curve fitting technique, i.e. the first degree equation. The two red curves indicate the 100(1-α)% confidence interval calculated using Equation 3.11, while the two green curves represent the standard deviations.

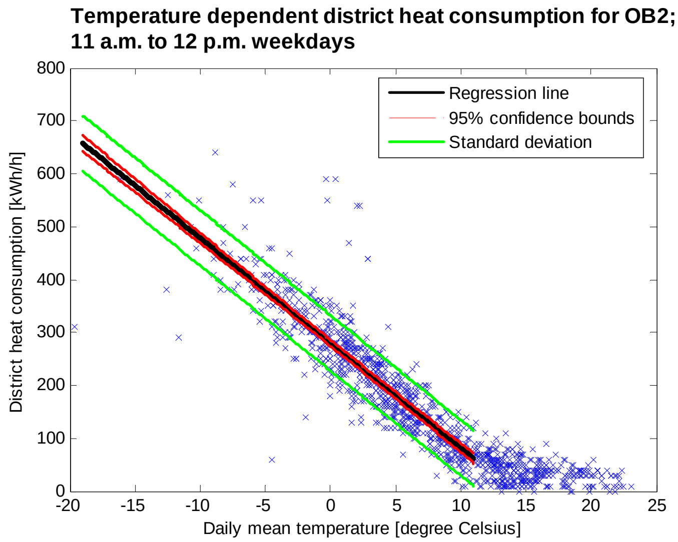

Figure 6.9 Regression line, 95% confidence interval and standard deviation plots for temperature-dependent heat consumption OB2 from hour 11 a.m. to 12 p.m. weekdays.

The residuals, which are the error of the fit for every data point, are plotted for OB2 hour 12 weekdays in Figure 6.10. The residuals must be independent of each other and have a normal distribution. According to Figure 6.10 the residuals are shown to be independent. A bar plot of the residuals also revealed an approximately normal distribution.

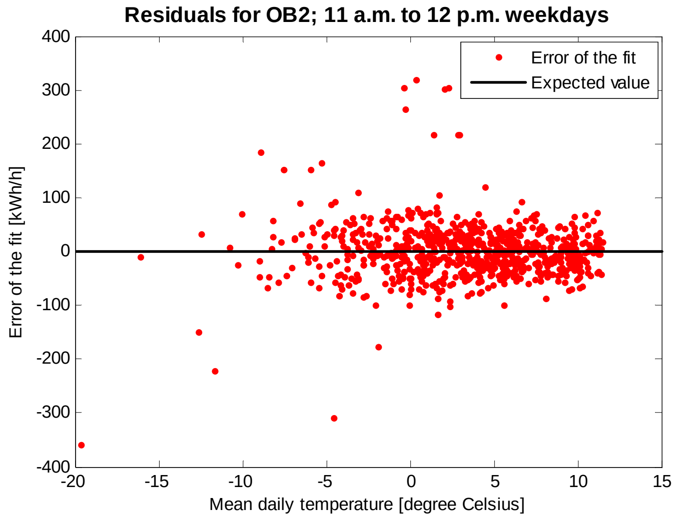

Figure 6.10 Residuals for OB2 weekdays from 11 a.m. to 12 p.m.

6.3.3 Division of day types; weekdays and weekends

The heat load pattern may change from day to day, from weekdays to weekends, as well as from season to season and year to year. Some changes are due to outdoor temperature, while others are due to control regime, type of building, consumer behaviour, and more.

Weekdays are defined to be Mondays, Tuesdays, Wednesdays, Thursdays and Fridays, while weekends include Saturdays and Sundays as well as holidays.

The heat load patterns for weekdays and weekends are often very different within the various building categories. This is especially true for service buildings such as office buildings and educational buildings. Consequently, 24 different equations have been derived for both weekdays and weekends for every building category in order to analyse the difference, if in fact there is one.

To illustrate the difference in district heat consumption between weekdays and weekends for a building category, a scatter plot of hour 10 for OB7 is shown in Figure 6.11 for both weekdays and weekends. OB7 has a very distinct division between weekdays and weekends and hour 10 was chosen because the maximum hourly heat load throughout the day for this building occurs in this hour. The blue asterisks show the hourly heat load for weekdays, whereas the red circles indicate weekends. The heat load is plotted for a period of almost five years, from January 2002 to October 2006.

OB7 shows various heat consumption patterns for weekdays and weekends. Consequently, the heat load profiles for weekdays and weekends were significantly different. For some buildings and even building categories the differences may be more specific, i.e. Mondays and Fridays may differ from the other weekdays in regards to heat load demand and Saturdays and Sundays likewise. Figure 6.11 shows that OB7 consumed heat at a very high level on some Saturdays and/or Sundays. One explanatory factor is that OB7 hosted some events during the weekends, especially on Saturdays.

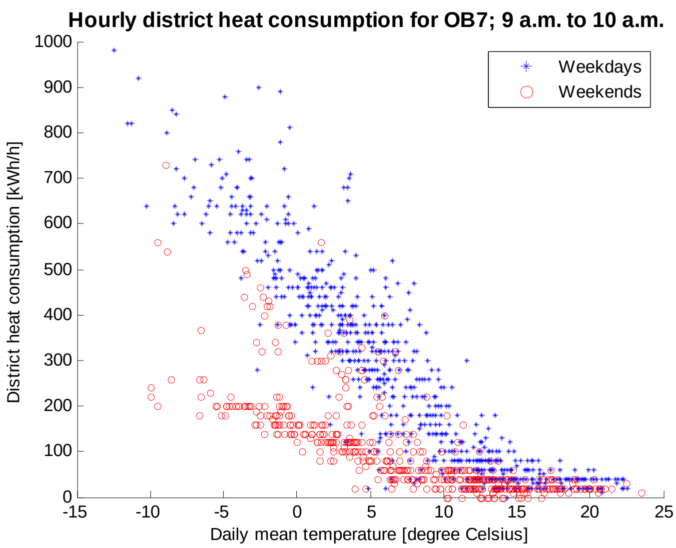

Figure 6.11 Scatter plot of hourly district heat consumption for OB7 hour 10; 9 a.m. to 10 a.m., for both weekdays and weekends.

6.3.4 Design conditions for heat load estimations

In order to estimate the maximum load profile for a specific building or a mixture of buildings, it was important to determine the design conditions. This differs between heat and electricity load due to the difference in temperature-dependency. Design conditions for heat load have been defined to be the required load to satisfy the heat load demand when the outdoor temperature reaches design temperature. For more information about design conditions, see Chapter 5.3.1.

The maximum heat load profile for a building has been found by using the 24 unique equations for weekdays and weekends respectively, and by inserting the design temperature for the given location of the building into the 48 equations.

The design heat load profile for OB7 is shown in Figure 6.12. The heat load profile is plotted for weekdays, which are defined as Mondays through Fridays.

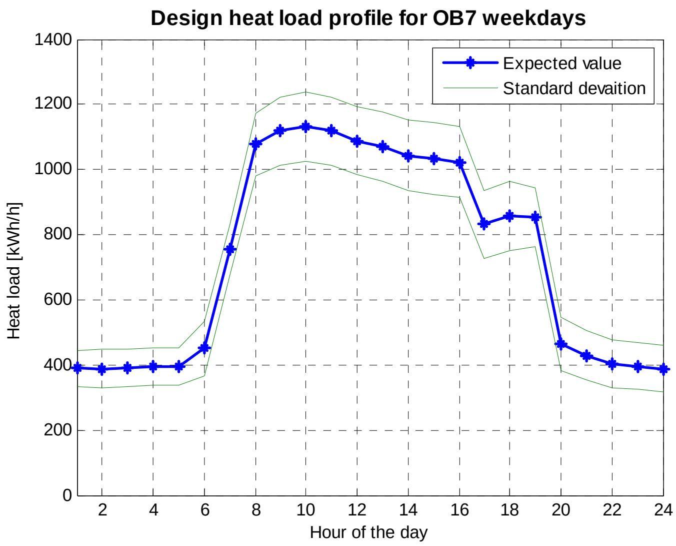

Figure 6.12 Design heat load profile for OB7 in Trondheim for weekdays, including standard deviation bounds.

The design temperature for Trondheim is -19°C, which gives a maximum expected heat load demand for hour 9 a.m. to 10 a.m. for OB7 of 1131 kWh/h for weekdays.

The expected heat value and the standard deviation for the design temperature together give an indication of the likelihood of the maximum heat load demand for one hour occurring inside a given quantile. The quantile analysis is presented in Chapter 6.5 in regards to aggregation of both heat and electricity load profiles for a specified planning area. The standard deviation is a very important input parameter and has been calculated for every building analysed.

For the actual analyses of office buildings and other building categories, see Chapter 7.

6.3.5 Relative values

It was desirable to make the load profiles compatible with a possible grouping, i.e. by building category or archetypes. For this reason, it was important to produce generalised load profiles (Jardini et al., 2000). A baseload, Φ_B, was chosen according to Equation 6.11:

$$\Phi_B = \frac{1}{24}\sum_{j=1}^{24} \Phi_{M,j} = \frac{\text{Daily consumptin (kWh)}}{24} \tag{6.11}$$

where:

$\Phi_{M,j}$ Maximum load for hour j during weekdays, in [kWh/h]

The maximum daily consumption was found by Equation 6.12:

$$\text{Daily consumption} = \sum_{j=1}^{24} (\alpha_j + \beta_j \cdot \theta_{dut}) \tag{6.12}$$

Relative design heat load profiles for several buildings within a certain building category were derived in order to compare and generalise the heat load profiles. The relative load profiles were found by dividing the maximum heat load within a given hour, j, by the baseload, see Equation 6.13:

$$\Phi_{R,j} = \frac{\Phi_{M,j}}{\Phi_B} \tag{6.13}$$

where:

$\Phi_{R,j}$ The relative load for hour *j* of the day

j 1, 2, ..., 24 where 1 = 12 a.m. to 1 a.m., 2 = 1 a.m. to 2 a.m., ..., 24 = 11 p.m. to 12 a.m.

Figure 6.13 shows the relative heat load profile for OB7. When the heat load profiles were presented in this form, it allowed for comparisons despite the difference in maximum heat load. The y-axis are given in P.U.; meaning per unit or relative to one.

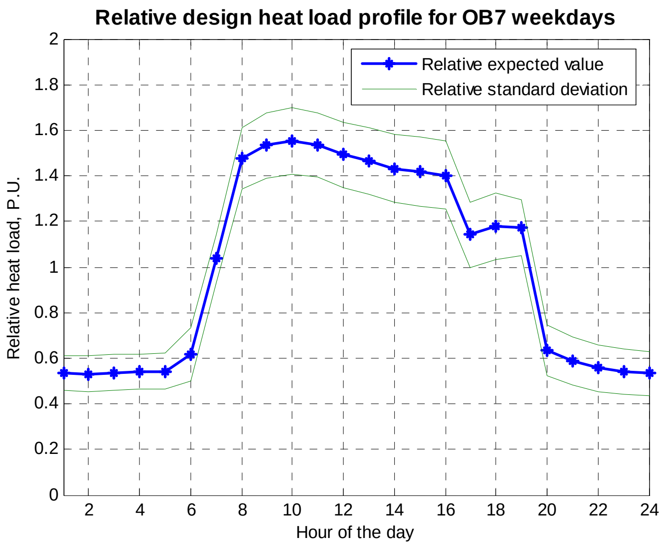

Figure 6.13 Relative design heat load profile for OB7 in Trondheim for weekdays, including relative standard deviation bounds.

The vectors **A** and **B** are also derived in relative form; $\mathbf{A}_R$ and $\mathbf{B}_R$, as given in Equation 6.14. Here, Equation 6.7 is inserted into Equation 6.13.

$$\Phi_{HL,R,j} = \frac{\alpha_j + \beta_j \cdot \theta_e}{\Phi_B} = \frac{\alpha_j}{\Phi_B} + \frac{\beta_j}{\Phi_B} \cdot \theta_{mdt} = \alpha_{R,j} + \beta_{R,j} \cdot \theta_{dmt} \qquad (6.14)$$

where:

$\alpha_{R,j}$ The relative specific regression coefficient for a given hour *j*

$\beta_{R,j}$ The relative specific regression coefficient for a given hour *j*

θ_{dmt} Daily mean temperature [°C]

and in vector form:

$$\Phi_{HL,R} = \boldsymbol{A}_R + \boldsymbol{B}_R \cdot \theta_{dmt} \qquad (6.15)$$

where:

$\mathbf{A_R}$ = $[\alpha_{R,1}\ \alpha_{R,2}\ \alpha_{R,3} \cdots \alpha_{R,23}\ \alpha_{R,24}]$

$\mathbf{B_R}$ = $[\beta_{R,1}\ \beta_{R,2}\ \beta_{R,3} \cdots \beta_{R,23}\ \beta_{R,24}]$

6.3.6 Temperature-independent heat load model

The temperature-independent heat load model is based on the hourly district heat consumptions during the temperature-independent season, which mainly represents hot tap water consumption. This model has not been used in relation to design heat load, but it was important to estimate this consumption in relation to yearly heat load profiles and consequently heat load duration profiles.

This model is based on the assumption that the heat load above the change-point temperature is independent of outdoor temperature. Hot tap water consumption fluctuates throughout the day and is also very dependent upon the building’s use and category.

The temperature-independent heat load model is based on probability distributions, and the relative expected values and the relative standard deviations for every hour and day type for all building categories analysed have been calculated. The baseload for the temperature-dependent heat load model was applied.

Figure 6.14 shows a probability plot for OB2 weekdays during hour 11 a.m. to 12 p.m. including fitted normal and Student's t distributions. Both distributions show a good fit for all buildings, and as a consequence, the normal distribution was applied for all hours for the temperature-independent heat load model. This implies that all buildings have more than 30 measurements for all hours during the temperature-independent season; the explanation of the theory behind the Student's t distribution has been presented in Chapter 3.3.3.

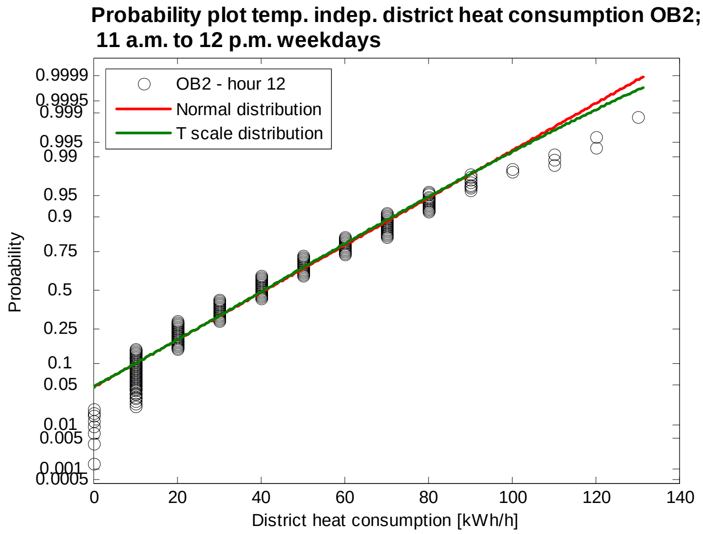

Figure 6.14 Probability plot of temperature-independent district heat consumption for OB2 during hour 11 a.m. to 12 p.m. weekdays, including fitted normal and Student's t distribution.

The temperature-dependent season, as shown in Figure 6.6, is not constant throughout the day. The total expected heat load should never decrease below the expected value for hot tap water for any hour. As a result, the heat load for the yearly load profile calculations was always higher or set equal to the heat load for the temperature-independent season.

6.3.7 Representative sample

To be able to find a statistically significant heat load profile for a specific building category, the sample have to include measurements of several buildings in the various building categories. When Statistics Norway carried out energy user surveys in the household sector in 1990 and 2001, the representative sample was around 2200 for the latter survey with a response rate of 48% (SSB, 2003). This resulted in a final sample of a little more that 1000 households, which gave a good indication of energy consumption in the household sector.

A large representative sample will lead to less uncertainty, so that it was desirable to collect as many hourly measurements within the different building categories as possible. The Finnish load model is based on measurements from several buildings with electricity as the only energy carrier within 46 very specific selected building categories (Seppälä, 1996). A sample of at least 30 buildings in the same building category with hourly measurements over several years would be sufficient to produce good generalised load profiles (Løvås, 2004).

In the SEDS project, it was desirable to look at mixed energy distribution systems, i.e. energy distribution systems with multiple energy carriers. It has been difficult to collect as many as 30 unique measurements samples within a certain building category from buildings with simultaneous hourly measurements of both district heat and electricity. As a result, the method developed in this thesis will probably give more accurate load profiles in the future when the representative samples grow larger.

The objective of the thesis has been to perform a qualitative analysis of heat and electricity load profiles based on buildings for which there have been background information available for the analysis, and for which there have been hourly district heat and electricity measurements of high quality. The various buildings have been examined in relation to the method developed and the background information collected in order to define archetypes that give a good approach to the generalised heat load profile(s) for the specified building category.

6.3.8 Generalisation of heat load profiles

In order to generalise heat load profiles for different building categories, it was very important to sort the buildings into different archetypes regarding building type and regulation regime.

The sample size, *N*, within each building category should be larger than 30 in order to use the normal distribution when generalising heat load profiles, but it has not been possible to meet this criteria. However, the principal method for generalisation of heat load profiles is developed based on this distribution. This implies that the alpha and beta coefficients will improve for a given building category when more input data concerning hourly district heat and electricity consumption become available for more buildings.

It is possible to calculate the expected value for every building category based on the expected relative heat load profiles for the buildings within each category.

If X_1, X_2, ..., X_n are independent variables from the same probability distribution with mean value, μ, and standard deviation, σ, then the central limit theorem states that (Løvås, 2004):

$$\bar{X} = \frac{1}{n}(X_1 + X_2 + \ldots + X_n) \tag{6.16}$$

is approximately Normal(μ, $\frac{\sigma}{\sqrt{n}}$).

Equation 6.16 implies that the mean value for every hour and day type for a given building category can be expressed as:

$$\bar{\mu} = \frac{1}{n}(\mu_1 + \mu_2 + \ldots + \mu_n) \tag{6.17}$$

Substitute α and β into Equation 6.17 for every building at a given hour and day type:

$$\bar{\alpha} + \bar{\beta}\theta = \frac{1}{n}(\alpha_1 + \alpha_2 + \ldots + \alpha_n + (\beta_1 + \beta_2 + \ldots + \beta_n) \cdot \theta) \tag{6.18}$$

The relative α-value and β-value are consequently expressed by Equation 6.19 and Equation 6.20 respectively:

$$\bar{\alpha} = \frac{1}{n}(\alpha_1 + \alpha_2 + \ldots + \alpha_n) \tag{6.19}$$

$$\bar{\beta} = \frac{1}{n}(\beta_1 + \beta_2 + \ldots + \beta_n) \tag{6.20}$$

The standard deviation can be found by first calculating the variance for the sample *N*, and then calculating the standard deviation as the positive square root of the variance:

$$\overline{\sigma^2} = \frac{1}{n}(\sigma_1^2 + \sigma_2^2 + \ldots + \sigma_n^2) \tag{6.21}$$

$$\bar{\sigma} = \sqrt{\overline{\sigma^2}} \tag{6.22}$$

The generalisation of heat load profiles is illustrated through the office building category. The relative design heat load profiles and relative standard deviations for weekdays for selected office buildings are shown in Figure 6.15 along with the estimated generalised heat load profile for this building category.

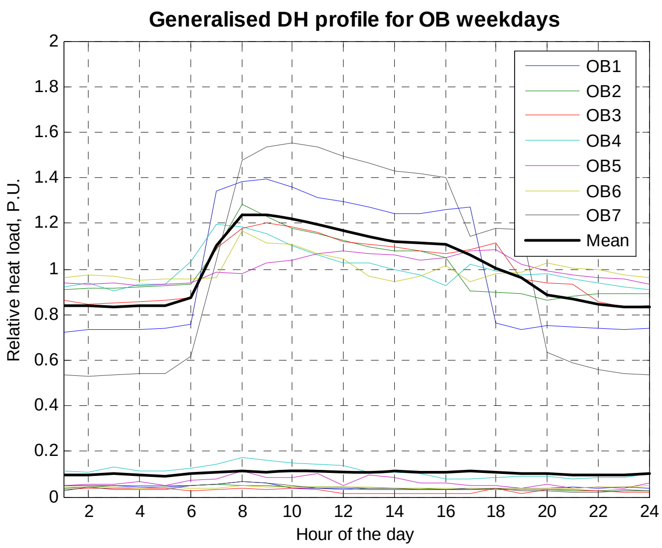

Figure 6.15 Relative design heat load profiles for office buildings, including the generalised heat load profile and relative standard deviation.

The calculated change-point temperatures, which determine the temperature-dependent season, are shown in Figure 6.16 for every office building during the weekdays, along with the mean change-point temperature for this building category. The average mean temperature is applied for yearly heat load calculations for all hours, see Chapter 7.3.2. For office buildings during weekdays, this temperature was estimated to 11.0°C.

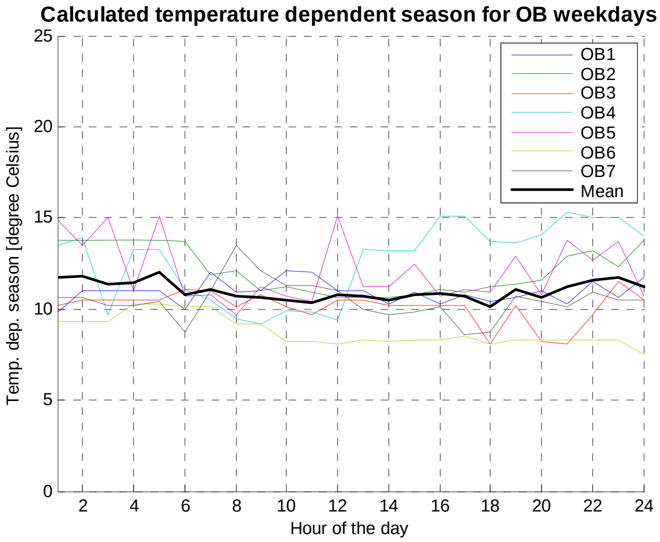

Figure 6.16 The calculated temperature-dependent season for all office buildings during weekdays.

Comment

The model developed for estimating heat load profiles can also be applied for estimating cooling load demand when hourly measurements of this type is available. The change-point temperature for the cooling season has to be estimated, and the design temperature has to be determined. If the cooling is supplied by electricity, the coefficient of performance for the cooling unit has to be included in order to estimate the actual cooling demand.

6.4 Electricity load model based on probability distributions

Different probability distributions have been applied by researchers when analysing energy consumption in buildings, most frequently for electricity load in all electric buildings. The electricity load model developed for mixed energy distribution systems is based on probability distributions. The method employed is presented in this chapter.

6.4.1 Background for the electricity load model

The hourly electricity consumption for one hour for a given day type has been found to be more or less independent of outdoor temperature based on graphical representation of daily mean temperature vs. hourly electricity consumption. Figure 6.17 shows a scatter plot of hourly electricity consumption for OB2 weekdays hour 12; 11 a.m. to 12 p.m. for a period of four years (2002 to 2005).

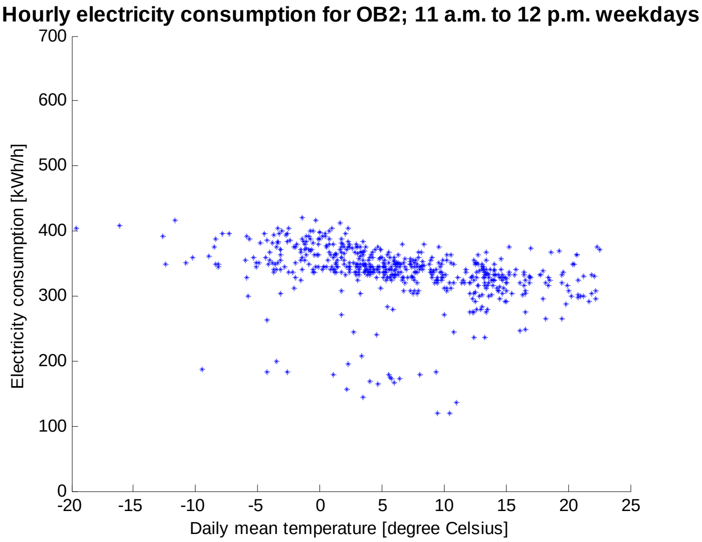

Figure 6.17 Scatter plot of daily mean temperature vs. hourly electricity consumption for OB2 in Trondheim for weekdays during hour 12, i.e. electricity consumption from 11 a.m. to 12 p.m. over a four-year period (2002-2005).

Probability distributions have been used in order to analyse the electricity load demand for buildings with mixed energy distribution systems. The electricity load model is based on continuous probability distributions;

Chapter 3.3.3 can be consulted for examples. The hourly electricity consumption data have mainly been examined in relation to normal, lognormal and Student's t distributions. Weibull distribution did also show some promising results, but this distribution was disregarded after more in-depth analyses. The remaining distributions in Chapter 3.3.3 showed poor results regarding goodness of fit to hourly electricity consumption.

Figure 6.18 shows a bar distribution plot of electricity consumption for OB2 for weekdays during hour 12 along with the fitted normal, lognormal and Student's t (or t scale) distributions.

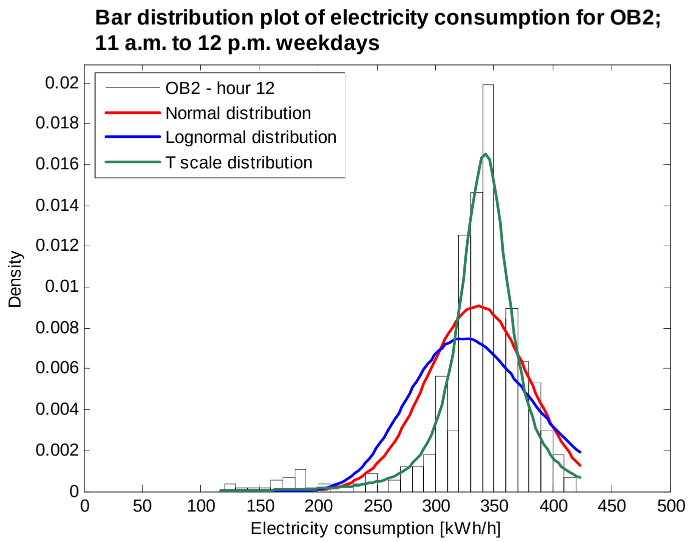

Figure 6.18 Bar distribution plot of hourly electricity consumption for OB2 weekdays between 11 a.m and 12 p.m. Normal, lognormal and Student's t distributions have been fitted to the data set.

The probability distributions' goodness of fit have been provided in Matlab as graphical representations of probability plots for any kind of distribution chosen, as illustrated in Figure 6.19. Due to the large amount of data, it was not possible to apply different kinds of hypothesis tests, such as the Jarque-Bera test or Lilliefors tests (Matlab, 2004) to obtain a number representing the goodness of fit. A data set of this size would never fit a distribution perfectly, but the graphical goodness of fits have been acceptable.

The probability plot in Figure 6.19 shows that the Student's t distribution gives a fairly good fit, while the normal distribution does not fit as well. The lognormal distribution does not fit for this particular high load hour. For other hours, especially for low load hours, the normal distribution and also the lognormal distribution may give a good fit.

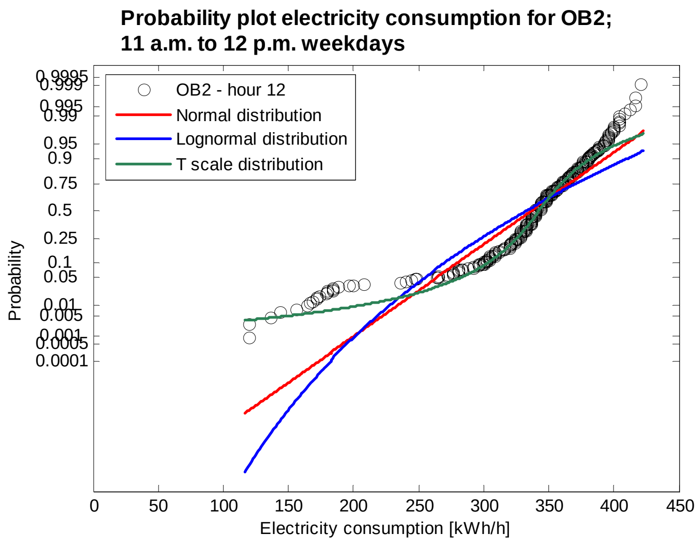

Figure 6.19 Probability plot of hourly electricity consumption for OB2 weekdays between 11 a.m and 12 p.m. The goodness of fit are shown for normal, lognormal and Student's t distributions.

Based on the graphical representations of goodness of fit, the Student's t distribution appeared in most cases to give the best distribution in relation to the hourly electricity measurements for high load hours. Normal distribution also showed a good fit for some buildings during high load hours. For low load hours both Student's t and lognormal distributions showed good fits, depending on the building.

The background theory for the normal, lognormal and Student's t distributions have been presented in Chapter 3.3.3.

6.4.2 Expected values and standard deviation

The expected values and variances of the normal and lognormal distributions have been given in Chapter 3.3.3, but a short summary is provided in Table 6.3. The standard deviation related to a distribution is given by the positive square root of the variance.

Table 6.3 Expected values and variances for the normal distribution and the lognormal distribution.

	Expected value E(x)	Variance Var(x)
Normal distribution	μ	σ^2
Lognormal distribution	$e^{\mu + \frac{\sigma^2}{2}}$	$e^{2\mu + \sigma^2} \cdot (e^{\sigma^2} - 1)$

The electricity consumption in the buildings analysed in this thesis have mainly shown temperature independencies, and the electricity load profiles have been based on the expected values for each hour and day type along with the standard deviations.

The unique classification of the variables for the expected value, *E,* and standard deviation, σ, have been assigned according to the first letters of the different building categories, as is shown in Table 6.4. As has already been shown for the heat load model, the building category division are based on the EPBD. The building categories underlined in Table 6.4 are the ones that have been analysed in relation to the electricity load model.

Table 6.4 Unique classification of expected value, E, and standard deviation, σ, according to the different building categories

Building category	E	σ
Single family Houses of different types	E_{SH}	σ_{SH}
Apartment Blocks	E_{AB}	σ_{AB}
Office Buildings	E_{OB}	σ_{OB}
Educational Buildings	E_{EB}	σ_{EB}
Hospital Buildings	E_{HB}	σ_{HB}
Hotels and Restaurants	E_{HR}	σ_{HR}
Sports Facilities	E_{SF}	σ_{SF}
Wholesale and Retail trade services buildings	E_{WR}	σ_{WR}
Other types of energy-consuming buildings		

The load profiles for electricity have been expressed in two vectors, expected value (**E**) and standard deviation (σ), for every day type including 24 values for each hour:

$$\mathbf{E} = [E_1\ E_2\ E_3\ ...\ E_{23}\ E_{24}]$$

$$\sigma = [\sigma_1\ \sigma_2\ \sigma_3\ ...\ \sigma_{23}\ \sigma_{24}]$$

6.4.3 Division of day types; weekdays and weekends

The consumption pattern for electricity load also differs according to day types. This is especially true for service buildings, such as office buildings, educational buildings and retail stores. The electricity consumption pattern in single family houses and apartment blocks also differs according to work hours and leisure time.

The difference in electricity consumption between weekdays and weekends for a building category is illustrated with a scatter plot of hour 12 in Figure 6.20 for OB2. The blue asterisks show the hourly electricity load for weekdays, whereas the red circles indicate weekends. The electricity load is plotted for a period of four years; from 2002 to 2005.

The selected office building, OB2, have different work hours for weekdays and weekends. Consequently, the electricity load profiles for weekdays and weekends are significantly different.

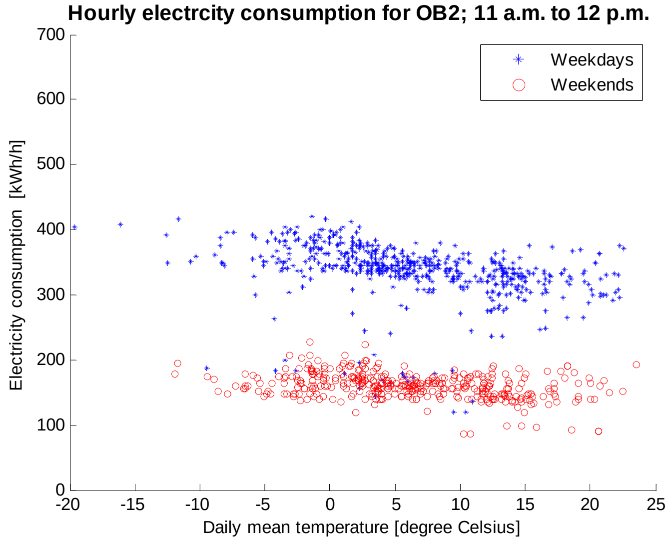

Figure 6.20 Scatter plot of hourly electricity consumption for OB2 hour 12, 11 a.m. to 12 p.m., for both weekdays and weekends.

6.4.4 Division of seasons; winter, spring/fall and summer

The qualitative verification of hourly electricity data by inspection revealed that most buildings analysed showed some seasonal variations. The t-test was applied to the hourly electricity consumption in relationship to outdoor temperature. The test showed a relation between outdoor temperature and hourly electricity consumption for some hours and no correlation for other hours. This may be due to the fact that very few buildings had an entirely strict division of energy carriers supplying the different purposes, i.e. electricity may have been used for some heating and/or cooling purposes.

Lighting as an end-use is related to seasonal changes in hours of daylight and sun. It has not been possible to determine the correlation between temperature and hourly electricity consumption because outdoor temperature is not independent of hours of daylight and sun.

Pumps and fans as end-uses are related to space heating and ventilation heating systems respectively. The space heating systems within a building are mainly regulated by temperature, resulting in a constant mass flow throughout most of the year. The amount of electricity for the pumps is decreased during the temperature-independent season, only circulating hot tap water. The supply air rate in the ventilation system is independent of climatic conditions and strongly related to the building's utilisation time.

Based on this information, the electricity consumption was investigated in relation to seasonal variations, and the day types were divided into winter, spring/fall and summer days. The winter season included December, January and February, the summer season included June, July and August, while the spring/fall season included the remaining months.

Verification of this method and other approaches are discussed in Chapter 7: Analyses and results.

6.4.5 Design conditions for electricity load estimations

The design conditions for electricity load estimations differs from the design conditions for heat load estimations due to the temperature independence of the electricity load. Design conditions for electricity consumption occurs during the winter season in buildings with no or little cooling demand throughout the year. The expected value and the standard deviation for the winter season give an indication of the likelihood of the electricity load for one hour occurring inside a given quantile. The quantile analysis is presented in Chapter 6.5 concerning load aggregation.

Figure 6.21 shows the expected design electricity load profile for OB2 weekdays, including standard deviation bounds. The winter electricity load profile for OB2 is based on a normal distribution for all hours due to the Student's t distribution showing the best fit for all hours and day types.

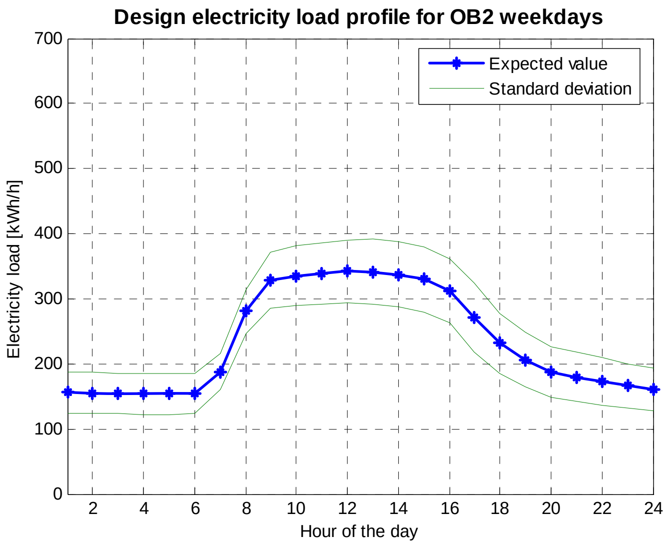

Figure 6.21 Design electricity load profile for OB2 weekdays. The electricity load profile is represented by the expected value, including standard deviation bounds.

6.4.6 Relative values

It was also desirable to produce generalised load profiles for electricity load demand. The baseload for electricity, Φ_B, is calculated based on the average daily electricity load for winter season weekdays.

Relative electricity load profiles for several buildings within a certain building category have been derived in order to compare and generalise the electricity load profiles. The relative load profiles have been found by Equation 6.13. The relative electricity load for every hour, *j*, is expressed in vector form:

$$\mathbf{E}_R = \quad [E_{R,1}\ E_{R,2}\ E_{R,3}\ \ldots\ E_{R,23}\ E_{R,24}]$$

$$\sigma_R = \quad [\sigma_{R,1}\ \sigma_{R,2}\ \sigma_{R,3}\ \ldots\ \sigma_{R,23}\ \sigma_{R,24}]$$

The relative design electricity load profile for OB2 weekdays, i.e. the winter season, is plotted in Figure 6.22 including relative standard deviation bounds.

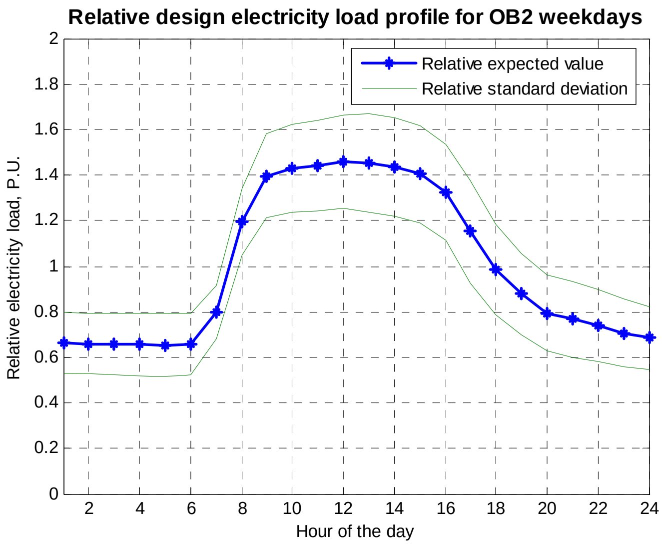

Figure 6.22 Relative design electricity load profile for OB2 weekdays. The relative electricity load profile has been represented by the relative expected value and the relative standard deviation bounds.

6.4.7 Generalisation of electricity load profiles

The same generalisation strategy applied to heat load profiles has also been applied to the generalisation of electricity load profiles for every season. This produced three relative electricity load profiles for each day type. Equation 6.17 and Equation 6.22 have been used to calculate expected values and standard deviations respectively.

Figure 6.23 shows the relative electricity load profiles for all office buildings weekdays, including the standard deviations for the winter season. The generalised winter electricity load profile for this building category is plotted along with the accompanying standard deviation, and is shown as bold lines in Figure 6.23.

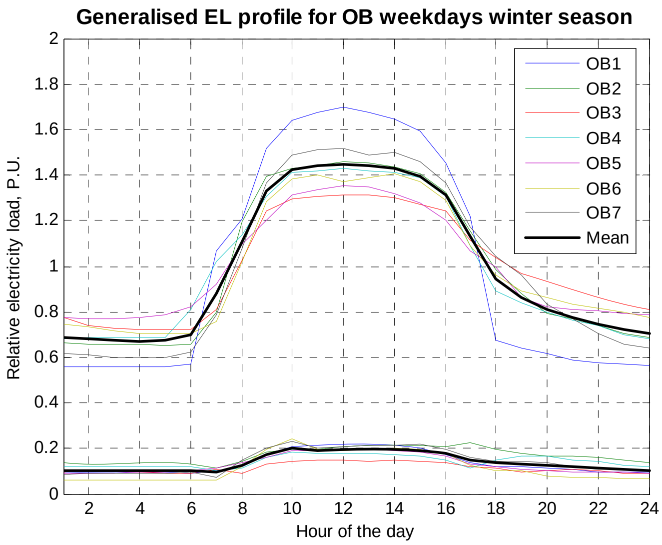

Figure 6.23 Generalised electricity load profile, including standard deviation for weekdays during the winter season for the office buildings category.

6.5 Aggregation of load profiles

The method for estimating relative design load profiles divided into heat and electricity demand has been thoroughly discussed in the previous chapters. The challenge of using these profiles in order to estimate the maximum load, the annual energy demand and load duration profiles for a specified planning area is discussed below.

Figure 6.24 shows an example of a distributed energy system that includes several customers at different load connection points or nodes. The energy distribution infrastructure includes both electrical cables/wires and pipelines for district heating or natural gas. Both maximum load and annual energy losses through the distribution systems as well as the coincidence factor are explored in relation to the aggregated load profile. The solution algorithm for load aggregation has already been shown in Figure 2.11 in Chapter 2.4.4.

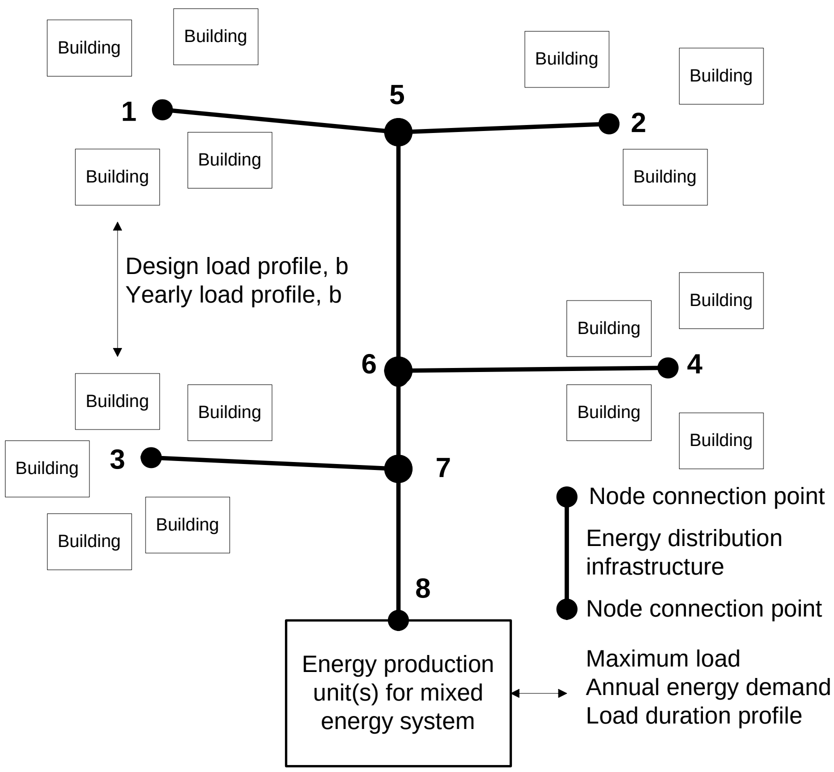

Figure 6.24 An example of an energy distribution system for a specified planning area including energy production unit(s), distribution system(s), node connection points and various energy consuming units or buildings.

6.5.1 Background for the aggregation model

A bottom-up approach is applied for the aggregation of individual building load profiles to derive the load profile for a specified planning area.

The method for aggregating load profiles is based on the sum of normal distributions. It has been assumed that the load profiles developed for heat and electricity for different building categories are independent and normally distributed.

If X_1, X_2, ..., X_n are independent variables from same distribution with means μ_1, μ_2, ..., μ_n and variance σ_1^2, σ_2^2, ... , σ_n^2 respectively, then the sum of the independent variables can be calculated according to Equation 6.23 (Løvås,2004):

$$Y = X_1 + X_2 + \ldots + X_n \tag{6.23}$$

The sum of the variables has an approximately normal distribution with Normal($n\mu$, $\sqrt{n}\sigma$).

The variance for Y is the sum of the variances for X:

$$\sigma_Y^2 = \sigma_1^2 + \sigma_2^2 + \ldots + \sigma_n^2 \tag{6.24}$$

The standard deviation of Y, which is the more interesting variable in this thesis, is the positive square root of the variance for Y.

The assumption that the individual loads for the different buildings are independent is a simplification. The correlation between each building's load demand throughout the day should be calculated and the variance should be found according to Equation 6.25. (Sintef Energy Research, 1993):

$$\sigma^2 = \sum_{\gamma} \sigma_{\gamma}^{2} + 2\sum_{\gamma}\sum_{\xi} \rho_{\gamma,\xi}\sigma_{\gamma}\sigma_{\xi} \tag{6.25}$$

This correlation, and consequently the influence of calculating the variance according to Equation 6.25 instead of Equation 6.24, has shown to have little influence on the resulting load (Feilberg, 2002). As a consequence, the variance, and thereby the standard deviation, are calculated using Equation 6.24 for the purpose of aggregating the load.

6.5.2 Aggregated design load

The distribution intervals for a normally distributed variable X can be written as follows (Løvås, 2005):

1. It is a 100(1-α)% certainty that the X value occurs within the interval $\mu \pm (z_{\alpha/2} \cdot \sigma)$
2. It is a 100(1-α)% certainty that the X value will be less than $\mu + (z_{\alpha} \cdot \sigma)$
3. It is a 100(1-α)% certainty that the X value will be greater than $\mu - (z_{\alpha} \cdot \sigma)$

The value z_{α} is called the α-quantile. There are different statistical tables tabulating α-quantiles for different distributions, for example standard normal distribution, Student's t distribution and kji quadrate distribution.

Since the standard deviations were unknown and had to be calculated based on the hourly load measurements, the α-quantiles from the Student's t distribution have been applied. α-values and corresponding α-quantiles for the Student's t distribution are tabulated for n-1 degrees of freedom in most books about statistics. The values for the t-quantiles are slightly higher than the corresponding z_{α}-values, which reflects the uncertainty of calculating the standard deviation.

The most important distribution interval in relation to maximum heat and electricity load profiles for a specified planning area has been expressed in bullet number two. As an example, based on t_{α}-values, there is a 95% probability that the load demand will be less than 1.66 standard deviations above the expected value with n-1 = 100 degrees of freedom. The design conditions for the maximum heat and electricity load profiles are dependent on the accuracy level, but in general terms the maximum load may be expressed as Equation 6.26. This approach has also been applied by Jardini et al. (2000) and in USELOAD (Feilberg, 2002) for all electric buildings.

$$\Phi_{MaxLoad} = \mu_{MaxLoad} + t_{\alpha} \cdot \sigma_{MaxLoad} \text{ [W]} \quad (6.26)$$

A probability of the maximum load occurring inside a given interval with a 95% likelihood is a good estimate for load modelling in mixed energy distribution systems, and consequently the α-quantile of 95%-interval has been chosen for design conditions.

6.5.3 Indicators

In order to convert the relative generalised load profiles into real design load profiles and yearly load profiles for a selected building, specific heat and electricity load indicators as well as specific heat and electricity consumption indicators are applied.

Specific heat and electricity loads, given in [W/m^2], have been estimated for every building category based on the method developed for calculating heat and electricity load. The baseload was omitted and expected design heat and electricity load for each building analysed within each building category have been calculated. The standard deviation for design conditions for every building category has also been estimated based on each building's variance. Specific heat and electricity loads have been used to restore the design load profiles developed for each building category.

An Energy Consumption Indicator (ECI), given in [$kWh/m^2 \cdot yr$], is a well-known term in the field of energy planning. Most ECIs are presented based on total energy consumption in a building and are not divided into different purposes such as heat and electricity.

Heat Consumption Indicators (HCI) and Electricity Consumption Indicators (ELCI) have been calculated for every building category analysed. The temperature-dependent part of the HCI has been normalised using the degree days method. The HCIs and ELCIs have been used to restore the yearly load profiles for heat and electricity purposes respectively.

Another important aspect concerning Energy Consumption Indicators are their ability to incorporate changes in building design and the introduction of new technology. The ECIs have to be adjusted to future development in order to allow for an increase or a decrease in energy consumption in the various building categories.

The specific load and energy indicators do not allow for all nuances concerning the building's behaviour in relation to heat and electricity consumption. Other indicators identifying the core activities in the various building categories and archetypes could also provide important input.

Example of core activity indicators:

- Number of residents in single family houses and apartment blocks [kWh/person · yr].
- Number of employees in office buildings [kWh/person · yr].
- Number of students and teachers in educational buildings [kWh/person · yr r].
- Number of visitors in hotels and restaurants [kWh/ sleepover · yr].
- Number of residents in retirement homes [kWh/ person · yr].

These indicators have not been analysed in relation to load modelling of buildings.

6.5.4 Coincidence factor

The coincidence factor is a term that is used when estimating the maximum load for a specified planning area. The maximum load for all customers do not coincide, i.e. the sum of each customer's maximum load is not equal to the maximum load for the specified planning area. This means that (Fredriksen and Werner, 1993):

$$(\Phi_1 + \Phi_2)_{maximum} < \Phi_{1,\,maximum} + \Phi_{2,\,maximum} \tag{6.27}$$

where:

Φ_1, Φ_2 Daily load for each building when design conditions occur.

The coincidence factor for *n* buildings has been defined by Fredriksen and Werner (1993) among others:

$$\text{Coincidence factor} = \frac{\Phi_{maximum(total)}}{\sum_{i=1}^{n} \Phi_{i,\, maximum}} \tag{6.28}$$

The coincidence factor is important when making load estimations in order to reduce the installed capacity and thereby investment cost. An over-estimation of an energy production unit reduces the annual efficiency, and as a consequence, increases the operational costs.

The coincidence factor is dependent on the number of customers served by a node or an energy production unit. The nature of the customers, i.e. whether they represent a homogeneous group or a heterogeneous group, will influence the coincidence factor level.

The peak load demands for each building analysed within the building categories are not shown in the generalised load profiles. As a consequence, the generalised load profiles incorporate the coincidence factor for each building category due to the average expected value. The remaining coincidence factors for heat and electricity demand are given by the design load profiles' shapes.

The total coincidence factors for heat and electricity demand for an area will not be discussed in detail in this thesis.

6.5.5 Distribution losses

Maximum load and annual energy distribution losses are important parts of energy planning. Based on the methods developed in this thesis, the load level and the yearly energy demand have been estimated at the customer level. The losses in the distribution system(s) have to be included in order to estimate the maximum load level and the yearly energy demand at the production unit(s).

The distribution losses are strongly dependent upon the energy carriers, and electricity, district heating and natural gas have different characteristics in relation to distribution losses. This is a study of its own: only a brief overview of the various energy carriers in relation to distribution losses is given in this chapter.

Electricity

The losses in each level of the electricity grid, ΔP_i, may be written as shown in Equation 6.29 through Equation 6.31 (Feilberg, 2002):

$$\Delta P_i = \frac{R_i}{U_i^2} \cdot (P_i^2 + Q_i^2) \tag{6.29}$$

$$= \frac{R_i}{U_i^2} \cdot (1 + tg\ \varphi_i^2) \cdot P_i^2 \tag{6.30}$$

$$= k_i \cdot P_i^2 \text{ [W]} \tag{6.31}$$

where:

R_i Resistance in grid level *i*, in [Ω].

U_i Voltage level on grid level *i*, in [kV].

P_i Maximum local active power withdrawn on grid level *i*, in [kW].

Q_i Appurtenant reactive power on grid level *i*, in [kvar].

The k-value must be calculated for every level of the grid depending mainly on the resistance losses and the voltage level as well as cable/wire thickness.

The equations above show that the power or load losses in the grid are dependent on the load level at each time interval. This implies that the losses in the grid are dependent on seasons as well as day type and time of day. The annual electricity loss is the sum of the active load losses for every time interval throughout the year.

A simplified analysis of the maximum and annual electricity losses has been performed in a case study. For this purpose, actual distribution losses have been collected from TEV Nett, which is the grid company for Trondheim, Norway. The maximum load loss has been estimated to be 7.7%, based on empirical data. The annual electricity losses in the grid have been based on real measurements at the customer level divided on the outlet at the central grid. The latter values have varied between 4.75 and 6% in recent years (Sylte, 2007).

The distribution grid in Trondheim mainly consists of cables which may have higher cross-sections than transmission lines. As a result, the decreased resistance in the grid reduces the electricity losses. The high electricity density in the concessionary area also reduces the losses (Sylte, 2007).

District heating

The maximum load and annual energy losses in a district heating distribution system are mainly dependent upon the following criteria:

- High or low heat density in the distributed area.
- Forward flow temperature and flow rates in the primary distribution system.
- Insulation standard and design of pipelines.
- Temperature efficiencies of the heat exchangers.

These are very complex matters that have to be considered for every development project individually.

A project report carried out at NTNU about annual heat losses from district heating systems in low heat density areas showed that the annual heat loss from 6 Norwegian district heating systems varied from 7 to 22%. For 68 low heat density district heating systems in Denmark, the numbers varied from 18 to 48% due to long pipe sections. The average value is 32%. In Sweden, the annual heat loss based on measurements in 29 district heating systems varied from 10 to 45% with an average value of 21%. The differences in the annual heat losses may be due to the difference in insulation class (Hoftvedt, 2004), the age of the system, single pipes vs. twin pipes, as well as correct or oversized design.

It is important to keep in mind that the above mentioned district heating systems represent low heat density areas and that these systems have already been built. When planning for new mixed energy distribution systems, the infrastructure will be up to date concerning new technology and insulation standards. New district heating distribution systems using single pipes systems may have an annual heat loss of approximately 10 to 15% and a heat loss of about 2 to 3% at maximum load (Ulseth, 2006). Twin pipes distribution systems will reduce the annual heat losses even more (Hoftvedt, 2004).

The heat losses in each customer's substation may be omitted due to their placing. The substations are mainly located in heated areas in most buildings, and as a consequence, the heat losses from the substations are exploited.

Natural gas

Natural gas is distributed to customers through gas pipelines from the landing or the energy production unit. The maximum load and annual energy losses in natural gas distribution systems are mainly caused by pressure reduction due to safety measures and the types of energy conversion and distribution systems within the buildings.

Most buildings supplied by natural gas for heat purposes have installed a condensing gas boiler connected to a hydronic heating system. The maximum load and annual energy losses are dependent on the maximum efficiency of the condensing gas boiler and the annual efficiency respectively. Some buildings may also have installed gas stoves and surface mounted gas heaters. Various suppliers of gas stoves report an annual efficiency of 70 to 80%, while surface mounted gas heaters have an annual efficiency of about 95% (Stene, 2006).

Efficiency requirements for condensing gas boilers ranging from 4 to 400 kW have been given in article 5 in The Council Directive 92/42/EEC on efficiency requirements for new hot-water boilers fired with liquid or gaseous fuels (1992). The efficiency at rated output should be more than or equal to 91 + 1 log(Pn)%, where Pn is the maximum load. The efficiency at part load should be more than or equal to 97 + 1 log(Pn)%.

Based on the requirements above, the annual efficiency of condensing gas boilers varies from 97.6 to 99.6%, while the efficiency at rated output or maximum load varies from 91.6 to 93.6%. The annual energy losses due to flue gas and radiation from the condensing gas boilers are in the order of 1 - 3% (Stene, 2006). Most condensing boilers are situated in separate rooms, such as basements or technical rooms, and the radiation will not be exploited.

In this thesis, the maximum and annual efficiencies of condensing gas boilers have been applied when analysing maximum load and annual energy losses in energy distribution systems based on natural gas as the sole energy carrier for heat purposes. The distribution losses due to pressure reduction in the pipelines vary from 1 to 2% in the natural gas distribution system in Stavanger (Idsø, 2007).

The maximum load and annual energy losses in a natural gas distribution system based on condensing gas boilers' efficiencies vary from 6.8 to 9.2% and from 0.4 to 2.5% respectively, from the customers point of view.

7 Analyses and results

7.1 Introduction

This chapter presents the main analyses and results based on the methods developed for heat and electricity load modelling in buildings for mixed energy distribution systems. A verification of feasible solutions according to the systems engineering process is also presented.

One of the main objectives of the SEDS project was to develop an energy planning tool for mixed energy distribution systems. Specific peak load and energy consumption indicators are presented in this chapter. These indicators are needed to estimate maximum load demands and yearly energy consumption. The maximum load level determines the capacity that needs to be installed, and thereby the investment costs for the energy production unit(s) and distribution system(s). Yearly energy consumption and load duration profiles provide the operational costs as well as the optimal operation of the mixed energy distribution system.

The design load profiles for heat and the seasonal load profiles for electricity, including standard deviations, are presented for every building category analysed. The various load profiles estimated along with the specific yearly energy consumption indicators have been employed to estimate annual heat and electricity load profiles and load duration profiles.

Finally, a verification of the methods chosen for the development of heat and electricity load profiles is presented. Various methods developed throughout the thesis work are also presented and compared to the selected methods.

7.2 Specific peak load and energy consumption

The specific peak load demand for every building category has been estimated based on the methods developed for heat and electricity load demand. This value is needed to restore the design load profiles from relative to real values in order to find the maximum heat and electricity demand for a specified planning area. The design daily consumption can also be used for restoring relative load profiles, but the hourly specific maximum load is the most widely used term. The maximum heat and electricity demand is needed to calculate investment costs in distributed energy systems in relation to energy production unit(s) and distribution systems.

The specific energy consumption has been calculated for every building category based on the real hourly measurements for a period of one year. The district heat consumption was temperature-corrected based on the degree day method. The specific energy consumption is needed to convert the normalised yearly load profiles and consequently the normalised load duration profiles into real values. The annual load duration profiles for heat and electricity based on a reference year is needed to calculate annual operational costs for distributed energy systems.

7.2.1 Maximum estimated specific heat and electricity load

The coincidence factors for all building categories or archetypes have first been calculated based on all the hourly district heat and electricity measurements respectively and each building's maximum load. The different coincidence factors are presented in Table 7.1. The individual heat load profiles for the educational building category indicated two different heat load profiles; buildings built before and after 1997, as will be described in Chapter 7.3.1.

The coincidence factor for the single family houses and apartment blocks category was very low. Based on this finding and the large load variations within this building category, the category has been analysed using cluster analysis. The relative standard deviation for the latter building category was then reduced by more than 50%.

Table 7.1 DH and EL coincidence factors based on actual measurements for all building categories/archetypes analysed in this thesis.

<table>
<tr><th>Building category</th><th>DH coincidence factor</th><th>EL coincidence factor</th></tr>
<tr><td>Single family houses and apartment blocks (SH and AB)</td><td>0.264[1]</td><td>0.387</td></tr>
<tr><td>Clusters (ap. 10 buildings) single family houses and apartment blocks</td><td>0.711</td><td>0.844</td></tr>
<tr><td>Office building (OB)</td><td>0.836</td><td>0.811</td></tr>
<tr><td>Hospital building (HB)</td><td>0.945</td><td>0.763</td></tr>
<tr><td>Hotel and restaurants (HR)</td><td>0.867</td><td>0.969</td></tr>
<tr><td>Educational buildings (EB) - AT1</td><td>0.768</td><td rowspan="2">0.649</td></tr>
<tr><td>Educational buildings (EB) - AT2</td><td>0.816</td></tr>
</table>

1. The measurement resolution for district heating in single family houses and apartments blocks is very low causing the heat load to be registered at a different hour and at a different value than what was the actual physical heat load. This caused the DH coincidence factor to be very low.

The focus in this chapter is on the maximum specific heat and electricity load demand for each building category.

The maximum specific heat load demand is based on the heat load model developed, and the heat load has been estimated for the design temperature for one given location for all building categories. The design temperature for Trondheim is -19°C, which has been used in the calculation of the maximum heat load demand.

The maximum specific electricity load demand is based on the electricity load model developed, and the electricity load has been estimated based on the winter seasonal load profile. The latter profile included the relative electricity peak load for all buildings analysed.

The specific load profiles varied more in size than the relative load profiles, due to the limitations of the indicator (given in [W/m^2]). Large buildings have been compared with smaller buildings with different shape coefficients, i.e. size of surface area in relation to size of available area. This may cause the maximum load for one building to occur at a different hour than what has been estimated by the generalised load profiles. As a consequence, the variation in sizes for the maximum electricity load profiles presented in Figure 7.1 are larger than the variations in the relative load profiles shown in Figure 6.23 in the previous Chapter.

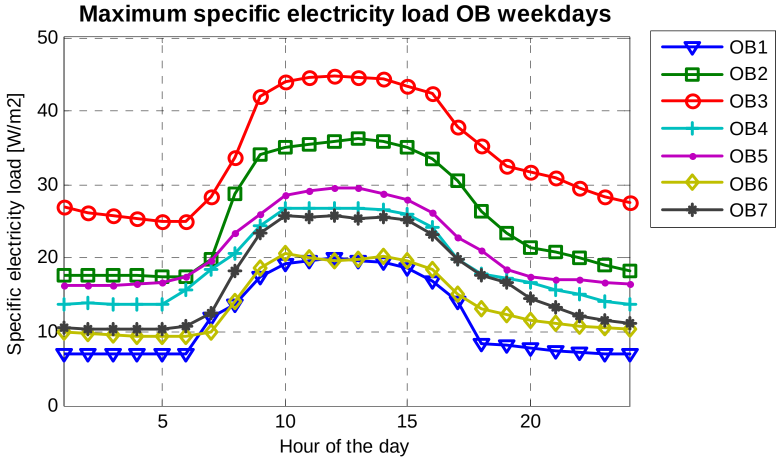

Figure 7.1 Maximum specific electricity load for office buildings during weekdays.

Even though the maximum specific load may occur at different hours for the various buildings within each building category, this value has been used to determine the category's expected specific load. As a result, the maximum specific heat and electricity loads for every day type have both been calculated for every building category/archetype according to Equation 7.1:

$$\bar{\Phi}_{specific} = \frac{1}{n}\sum_{b=1}^{n} \frac{\Phi_{b,\,max}}{A_b} \quad [\mathrm{W/m^2}] \tag{7.1}$$

where:

Φ_b	The maximum estimated load for the building b, in [W].
b	The various buildings/clusters within a building category.
n	Number of buildings/clusters within each building category.
A	Available area for each building/cluster, in [m^2].

The specific standard deviation for each building that has been analysed was also calculated to determine the specific standard deviation for the entire building category or archetype. First, the variance for the building category or archetype was calculated from Equation 6.21 and then the standard deviation was calculated according to Equation 6.22. This value is needed for the aggregation of load profiles for design conditions using the 95% quantile.

The specific loads for heat and electricity are presented in Table 7.2 and Table 7.3 respectively for all building categories and archetypes analysed. Both day types are included in the tables along with the specific standard deviation. The peak load hours are identified based on the generalised heat load profiles for a design temperature of -19°C and the generalised winter load profiles. The peak load hours are also tabulated.

The peak loads for heat and electricity for the selected buildings were always higher for weekdays than weekends. However, the maximum specific load demand for single family houses and apartment blocks, hospital buildings and hotels and restaurants was quite similar for both day types. Office buildings and educational buildings, on the other hand, had very different peak load demands for weekdays and weekends due to the reduced use of these building categories during weekends.

The ratio between the specific standard deviation and the specific heat or electricity load is always higher for weekends than weekdays. This is due to larger variations in load demand during the weekends and the greater degree of scattering of load data.

Table 7.2 Specific heat loads and specific standard deviations for both weekdays and weekends for all building categories/archetypes analysed.

	DH weekdays	**DH weekdays**	**DH weekends**	**DH weekends**
Building category	**Specific load [W/m^2] (hour)**	**Specific STD [W/m^2]**	**Specific load [W/m^2] (hour)**	**Specific STD [W/m^2]**
SH and AB (clusters)	46.0 (7 a.m.)	5.2	44.7 (10 a.m.)	7.4
OB	55.6 (8 a.m.)	5.0	44.5 (10 a.m.)	7.0
EB - AT1	61.3 (9 a.m.)	6.0	34.0 (7 a.m.)	5.9
EB - AT2	81.3 (8 a.m.)	8.5	29.2 (7 a.m.)	6.5
HB	64.0 (10 a.m.)	4.2	59.4 (9 a.m.)	5.1
HR	42.6 (8 a.m.)	5.3	41.1 (10 a.m.)	7.0

The ratio between the specific standard deviation and the specific electricity load for educational buildings for both day types is much higher than for any other building category. This building category includes many special days that were not always possible to identify.

Table 7.3 Specific electricity loads and specific standard deviations for both weekdays and weekends for all building categories analysed.

	EL weekdays	**EL weekdays**	**EL weekends**	**EL weekends**
Building category	**Specific load [W/ m2] (hour)**	**Standard deviation**	**Specific load [W/ m2] (hour)**	**Standard deviation**
SH and AB (clusters)	10.5 (9 p.m.)	1.7	10.3 (8 p.m.)	2.1
OB	23.8 (12 a.m.)	3.2	13.0 (5 p.m.)	1.9
EB	19.6 (11 a.m.)	5.9	6.3 (6 p.m.)	2.9
HB	23.1 (1 p.m)	1.6	20.2 (1 p.m.)	1.4
HR	16.3 (9 a.m.)	2.3	15.9 (10 a.m.)	2.7

Each building's and cluster's maximum specific load, including specific standard deviation intervals, are presented in the following figures.

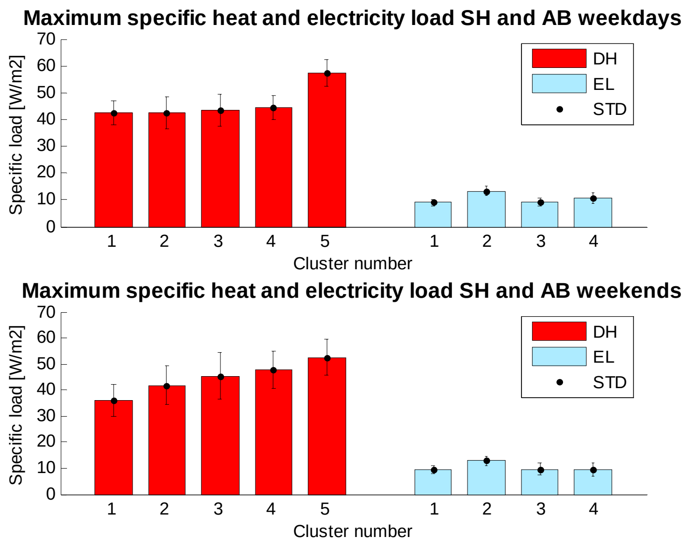

Figure 7.2 Maximum specific heat and electricity load including specific standard deviation intervals for each single family house and apartment block cluster analysed for both day types.

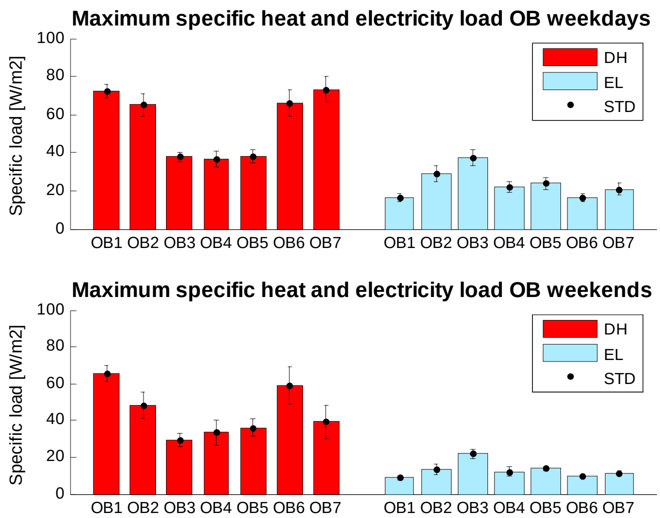

Figure 7.3 Maximum specific heat and electricity load including specific standard deviation intervals for each office building analysed for both day types.

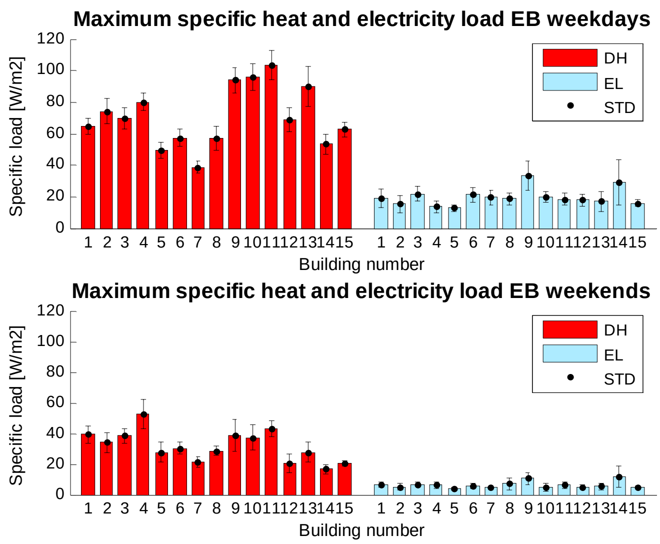

Figure 7.4 Maximum specific heat and electricity load including specific standard deviation intervals for each educational building analysed for both day types.

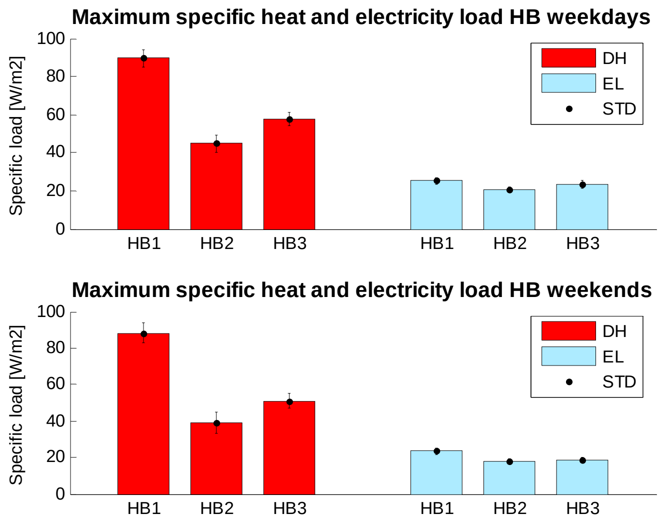

Figure 7.5 Maximum specific heat and electricity load including specific standard deviation intervals for each hospital building analysed for both day types.

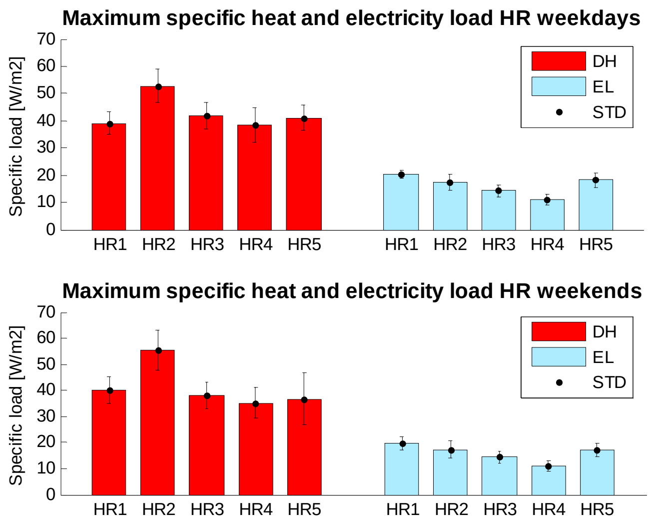

Figure 7.6 Maximum specific heat and electricity load including specific standard deviation intervals for each hotel and restaurant building analysed for both day types.

7.2.2 Yearly specific district heat and electricity consumption

Yearly specific district heat and electricity consumption are based on real measurements from the different buildings analysed. The district heat consumption was normalised using the degree day method, which involves comparing the normal degree days to the actual degree days. In this case, the normal degree days are the climatological degree days, while the actual degree days are the meteorological degree days (Werner, 1984).

The data collected from the Bergen residential area buildings consist of nine months of measurements; from November 1, 2005 until August 13, 2006 including two gaps of 15 days altogether.

As a consequence, the specific district heat and electricity consumption missing for these buildings have been calculated for each building using the individual estimated load profiles for the period between January 30th and January 31st, May 1st and May 13th as well as August 15th to November 1st. This resulted in an artificial year from November 1, 2005 until November 1, 2006. As a result, the specific district heat and electricity consumption is presented for one time period for the Bergen buildings:

1. November 1, 2005 - October 31, 2006

Bergen normally has 3597 degree days based on the climatic period from 1961 to 1990. The degree days used in this thesis are calculated as the sum of the difference between 17°C and the daily mean temperature, when the daily mean temperature is less than 17°C, according to Equation 7.2 (BNES, 2005). There are also other definitions of the degree days which allow for the heating season defined in Table 4.3, see for example Fredriksen and Werner (1993) and Hanssen et al. (1996).

$$G_a = \sum_{d=1}^{365} (17°C - \theta_{dmt}) \text{ for } \theta_{\mathrm{dmt,d}} < 17°C \qquad (7.2)$$

where G_a is the annual number of degree days for the specified period of 365 days given in $[\text{days} \cdot °\text{C}]$.

The degree day calculated for the period November 1, 2005 to October 31, 2006 for Bergen is 3043. The average specific district heat consumption in the buildings from Bergen has eventually been corrected to Trondheim climate in order to compare the various building categories.

For the buildings located in Trondheim, the specific district heat and electricity consumption are presented for three different time periods:

1. October 1, 2004 - September 30, 2005
2. January 1, 2005 - December 31, 2005
3. October 1, 2005 - September 30, 2006

The first and third grouping do not follow the calendar year because the energy consumption data period was measured from October 1, 2004 until October 1, 2006 for the different building categories.

The degree days for Trondheim listed above are shown in Figure 7.7, along with the normal degree days for Trondheim based on the climatic period from 1961 until 1990. The latter degree day number is 4441 (BNES, 2005).

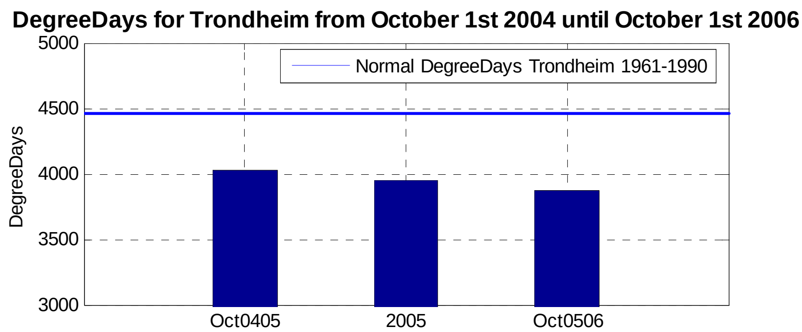

Figure 7.7 Number of degree days for Trondheim for the periods from October 1, 2004 until October 1, 2005; January 1, 2005 until January 1, 2006; and October 1, 2005 until October 1, 2006. The normal degree days for Trondheim based on the climatic period from 1961 until 1990 is also shown.

Only the temperature-dependent district heat consumption (the space heating and ventilation heating) has been corrected for climate. The temperature-independent district heat consumption for each building category has been estimated. Consequently, the hot tap water consumption for each building category and construction period was used in order to find the specific district heat consumption. The numbers in Table 7.4 were calculated based on Enøk Normtall (Enøk Normtall, 2004) for the mid-Norway coast (Trondheim) for office buildings, educational buildings, hospital buildings, and hotels and restaurants, while the numbers for single family houses and apartment blocks were calculated based on the southern Norway coast (Bergen).

Enøk Normtall consists of Energy Consumption Indicators (ECI), calculated for seven of Norway's climates divided into the end-uses presented by NS 3032 in Chapter 4.2.1. These factors have been calculated for retrofit buildings, and therefore, are not fully representative for all the buildings analysed in this thesis. However, these data have been used because of the lack of measurements for different end-uses.

Table 7.4 Amount of temperature-independent annual heat consumption based on the hot tap water consumption from Enøk Normtall (2004)

	Temperature-independent amount of annual heat consumption		
From PBL	**Older**	**1987**	**1997**
Office buildings	0.093	0.120	0.175
Educational buildings	0.119	0.153	0.224
Hospitals	0.234	0.253	0.328
Hotels and restaurants[1]	0.259	0.294	0.455
Single family houses[2]	0.173	0.211	0.359
Apartment blocks	0.280	0.319	0.484

1. There are no numbers for this building category, but the numbers for apartment blocks have been used because they show a similar consumption pattern.
2. Average of the temperature-independent consumption for single family houses and detached houses.

The district heat consumption for the six apartment blocks with hourly individual space heating and hot tap water measurements is shown in Figure 7.8. Over the measurement period of nine months for these buildings, the average amount of hot tap water consumption constituted 16% of the total district heat consumption. This result is much lower than the number provided by Enøk Normtall for apartment blocks for 1997 for the southern coast of Norway. But the sample is too small and the measurement period too short to draw any conclusions based on Figure

7.8. However, this may indicate that there is a need for more measurements divided into temperature-dependent and temperature-independent heat consumption.

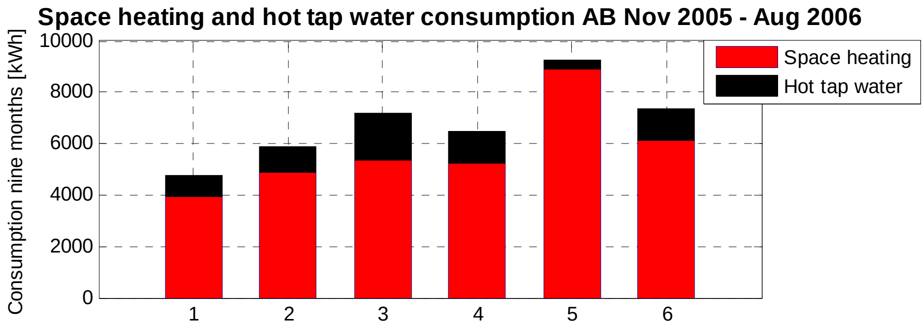

Figure 7.8 Heat and hot tap water consumption for six apartment blocks in Bergen measured over a nine-month period.

The normalised total heat consumption is calculated according to Equation 7.3 (Aronsson, 1996):

$$Q_{\text{tot, norm}} = Q_{tot} \cdot p_{htw} + Q_{tot} \cdot (1 - p_{htw}) \cdot \frac{G_n}{G_a} \tag{7.3}$$

where:

$Q_{tot,norm}$ Normalised total yearly district heat consumption for the building, in [kWh/yr].

Q_{tot} Total measured yearly district heat consumption for the building, in [kWh/yr].

p_{htw} Amount of temperature-independent district heat consumption, i.e. amount of hot tap water consumption.

G_n Normal degree day for the specified location based on the climatic period from 1961 to 1990, in [days · °C].

G_a Actual number of degree days for the specified period of 365 days, in [days · °C].

The total specific energy consumption has been compared to the Building Network's Energy Statistics (BNES) for the large buildings including office buildings, educational buildings, hospital buildings, and hotels and restaurants.

The Building Network was established in 1996, with the purpose of promoting energy savings in large buildings. The buildings that participate in this network report annual energy consumption to Enova, which in turn publishes this information as annual statistics (BNES, 2005).

The average specific energy consumption or ECI for the various building categories and archetypes are summarised in Table 7.5. There are already a number of ECIs for total energy consumption, but the main findings here are the specific energy consumption divided into heat and electricity purposes, defined as HCI and ELCI respectively. The latter indicators are essential when planning for mixed energy distribution systems.

Table 7.5 Average specific total, district heat and electricity consumption for the different building categories/archetypes analysed.

Building category	Specific energy consumption $[kWh/m^2 \cdot yr]$		
	ECI	**HCI**	**ELCI**
SH and AB[1]	142/166[2]	92/116[3]	49
OB	235	100	135
EB - AT1	175	109	69 (66)[4]
EB - AT2	174	103	69 (72)
HB	284	152	132
HR	233	113	120

1. The total number does not add up with the numbers for district heat and electricity due to different buildings analysed for district heat and electricity consumptio.n
2. Corrected to Trondheim climate.
3. Corrected to Trondheim climate.
4. The numbers in the parenthesis correspond to a similar division of archetypes in educational buildings for electricity purposes as was applied for heat purposes.

The different building categories are presented in their entirety in the paragraphs below in relation to yearly specific energy, district heat and electricity consumption respectively. Each building category has been compared to the BNES.

Single family houses and Apartment blocks

The total specific energy consumption for single family houses, detached houses and apartment blocks that have both continuous district heat and electricity measurements are plotted in Figure 7.17. The numbers are based on nine months of real measurements and calculated expected consumption for the last three months based on appurtenant real daily mean temperatures. The average specific energy consumption for the period was 142 $kWh/m^2 \cdot yr$, as shown by the black solid line in Figure 7.9. The specific energy consumption varies from 104 to 184 $kWh/m^2 \cdot yr$. The average ECI was 166 $kWh/m^2 \cdot yr$ if corrected to Trondheim climate.

The buildings in Figure 7.9 are sorted by building type starting with apartment blocks, detached houses and single family houses with 1, 8 and 3 buildings respectively. The average amount of energy consumption for heat purposes was estimated to 65%, with a variation from 44 to 82%. If corrected to Trondheim climate, the same numbers were 70%, 49% and 85% respectively.

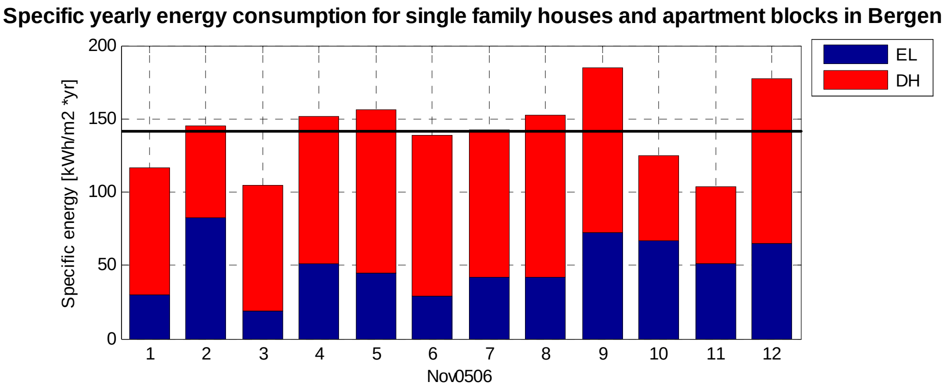

Figure 7.9 Specific yearly energy consumption for single family houses and apartment blocks plotted for the period from November 1, 2005 until November 1, 2006.

The specific district heat and electricity consumption for single family houses, detached houses and apartment blocks are plotted in Figure 7.10. The average temperature-corrected district heat consumption for the period was 92 $kWh/m^2 \cdot yr$, with a variation from 35 to 193 $kWh/m^2 \cdot yr$. If corrected to Trondheim climate, the HCI was 116 $kWh/m^2 \cdot yr$. The average electricity consumption for the same period was 49 $kWh/m^2 \cdot yr$, with a variation from 19 to 83 $kWh/m^2 \cdot yr$. The black lines in Figure 7.10 illustrate the average specific district heat and electricity consumption respectively.

The numbers in Figure 7.10 for district heat and electricity consumption do not correspond to the same buildings. The buildings are also sorted by type starting with 29 apartment blocks, 10 detached houses and 14 single family houses for district heat consumption. For electricity consumption, the numbers are 8, 20 and 10 respectively.

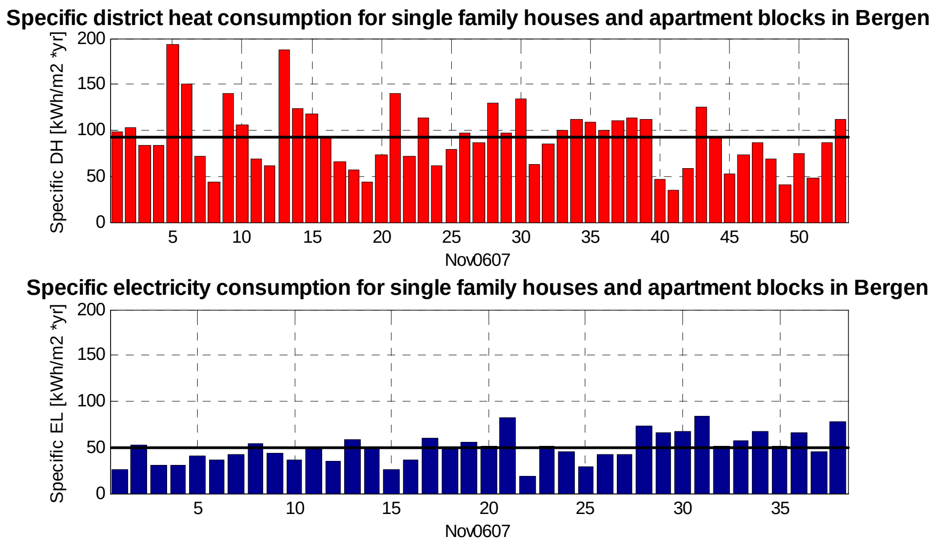

Figure 7.10 Specific yearly district heat and electricity consumption for single family houses and apartment blocks plotted for the period from November 1, 2005 until November 1, 2006. The figure includes 53 buildings with continuous district heat measurements and 38 buildings with continuous electricity measurements.

Office buildings

The total specific energy consumption for selected office buildings are plotted in Figure 7.11. The average specific energy consumption for the period was 235 $kWh/m^2 \cdot yr$, with a variation from 193 to 318 $kWh/m^2 \cdot yr$, as shown by the black solid line in Figure 7.11. The Building Network has collected total specific energy consumption for 228 office buildings, with an average yearly temperature-corrected energy consumption for these buildings of 234 $kWh/m^2 \cdot yr$. Here, the specific energy consumption varied from approximately 90 to 660 $kWh/m^2 \cdot yr$

(BNES, 2005). The selected office buildings in this thesis lie well within the bounds published in the Building Network's Energy Statistics with an almost identical average value.

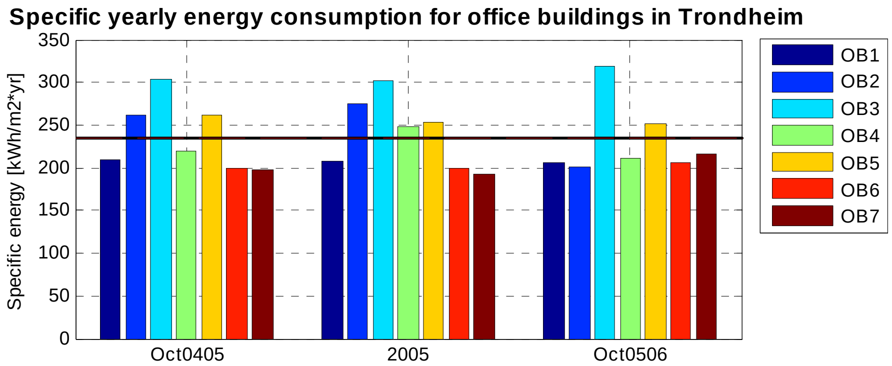

Figure 7.11 Specific yearly energy consumption for office buildings plotted for the periods from October 1, 2004 until October 1, 2005, January 1, 2005 until January 1, 2006 and October 1, 2005 until October 1, 2006.

The specific district heat and electricity consumption for office buildings are plotted in Figure 7.12. The average temperature-corrected district heat consumption for the period was 100 $\mathrm{kWh/m^2 \cdot yr}$, with a variation from 52 to 132 $\mathrm{kWh/m^2 \cdot yr}$. The average electricity consumption for the same period was 135 $\mathrm{kWh/m^2 \cdot yr}$, with a variation from 76 to 260 $\mathrm{kWh/m^2 \cdot yr}$. The black lines in Figure 7.12 illustrate the average specific district heat and electricity consumption respectively.

From Figure 7.12 it is clear that office building 3 (OB3) stands out with respect to yearly specific district heat and electricity consumption, but the total consumption still lies within the bounds published in the Building Network's Energy Statistics.

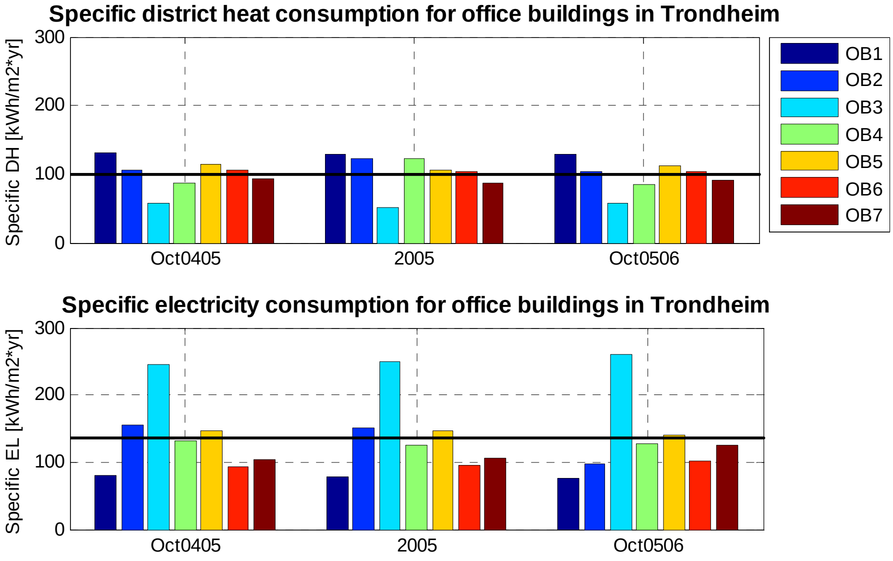

Figure 7.12 Specific yearly district heat and electricity consumption for office buildings plotted for the periods from October 1, 2004 until October 1, 2005, January 1, 2005 until January 1, 2006 and October 1, 2005 until October 1, 2006.

Educational buildings

The total specific energy consumption for selected educational buildings are plotted in Figure 7.13. The average specific energy consumption for the period was 175 $kWh/m^2 \cdot yr$, with a variation from 123 to 246 $kWh/m^2 \cdot yr$, as shown by the black solid line in Figure 7.13. The Building Network has collected total specific energy consumption for 72 high schools along with 412 primary schools without swimming pools. They found that the average yearly temperature-corrected energy consumption was 170 and 172 $kWh/m^2 \cdot yr$ respectively (see the dotted line in Figure 7.13). The Building Networks' specific energy consumption varied between 80 and 370 $kWh/m^2 \cdot yr$ for this building category (BNES, 2005). The educational buildings analysed lie within the bounds published in the BNES, with a slightly higher yearly average specific energy consumption.

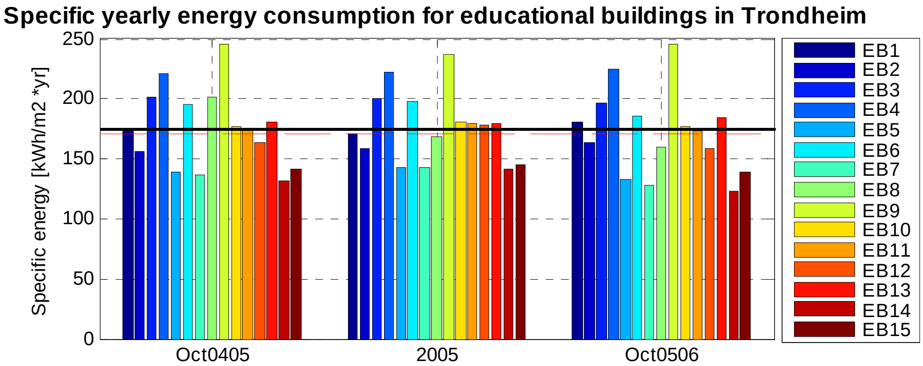

Figure 7.13 Specific total energy consumption for educational buildings plotted for the periods from October 1, 2004 until October 1, 2005, January 1, 2005 until January 1, 2006 and October 1, 2005 until October 1, 2006.

The specific district heat and electricity consumption for educational buildings are plotted in Figure 7.14. The average temperature-corrected district heat consumption for the period was 106 $\text{kWh/m}^2 \cdot \text{yr}$, with a variation from 66 to 170 $\text{kWh/m}^2 \cdot \text{yr}$. The average electricity consumption for the same period was 69 $\text{kWh/m}^2 \cdot \text{yr}$, with a variation from 49 to 118 $\text{kWh/m}^2 \cdot \text{yr}$. The black lines in Figure 7.14 illustrate the average specific district heat and electricity consumption respectively.

The average specific district heat consumption for the two educational building archetypes defined for heat purposes differ only slightly. Buildings built before 1997, AT1, have an average specific heat consumption of 109 $\text{kWh/m}^2 \cdot \text{yr}$, while buildings built in 1997 or after, AT2, have an average specific heat consumption of 103 $\text{kWh/m}^2 \cdot \text{yr}$.

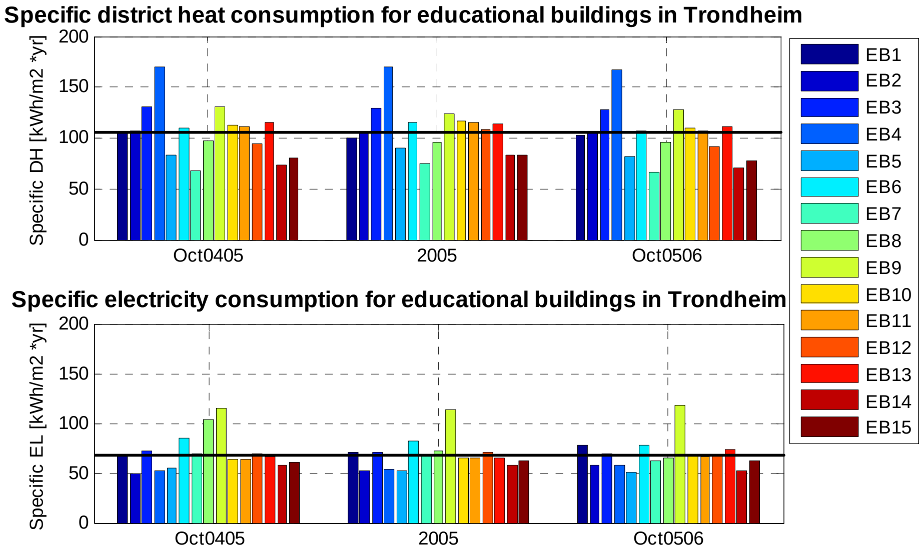

Figure 7.14 Specific yearly district heat and electricity consumption for educational buildings plotted for the periods from October 1, 2004 until October 1, 2005, January 1, 2005 until January 1, 2006 and October 1, 2005 until October 1, 2006.

Hospital buildings

The total specific energy consumption for the selected hospital buildings, i.e. nursing and retirement homes, are plotted in Figure 7.15. HB2 has been excluded from the specific energy analysis due to a missing data point (available area).

The average specific energy consumption for the period was 284 $kWh/m^2 \cdot yr$, with a variation from 224 to 358 $kWh/m^2 \cdot yr$, as shown by the black solid line in Figure 7.15. The Building Network has collected total specific energy consumption for 172 retirement and nursing homes, with the average yearly temperature-corrected energy consumption at 265 $kWh/m^2 \cdot yr$ (see the dotted line in Figure 7.15). The Building Networks' specific energy consumption varied between 70 and 900 $kWh/m^2 \cdot yr$ for this building category (BNES, 2005). The selected hospital buildings lie well within the bounds published in the BNES for this building category. The yearly average specific energy consumption is somewhat higher for the nursing and retirement homes analysed in this thesis. However, the sample is very limited, with only three buildings included in the analysis.

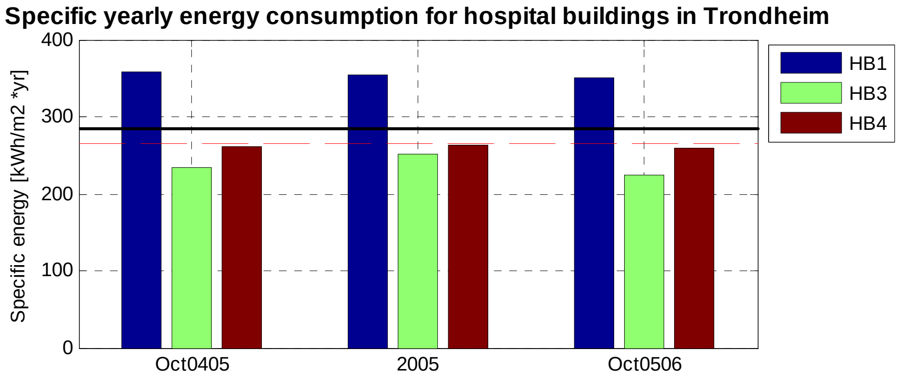

Figure 7.15 Specific yearly energy consumption for hospital buildings plotted for the periods from October 1, 2004 until October 1, 2005, January 1, 2005 until January 1, 2006 and October 1, 2005 until October 1, 2006.

The specific district heat and electricity consumption for hospital buildings are plotted in Figure 7.16. The average temperature-corrected district heat consumption for the period was 152 $\mathrm{kWh/m^2 \cdot yr}$, with a variation from 104 to 212 $\mathrm{kWh/m^2 \cdot yr}$. The average electricity consumption for the same period was 132 $\mathrm{kWh/m^2 \cdot yr}$, with a variation from 120 to 147 $\mathrm{kWh/m^2 \cdot yr}$. The black lines in Figure 7.16 illustrate the average specific district heat and electricity consumption respectively.

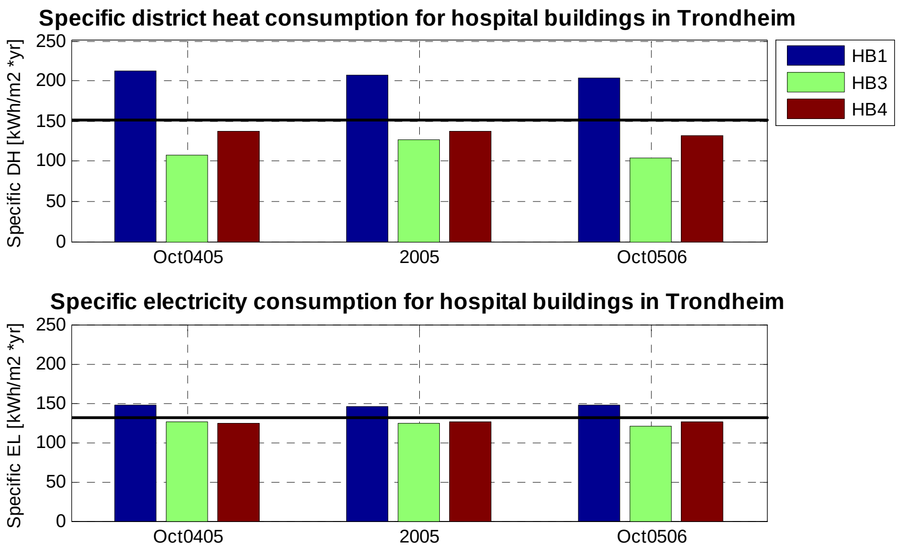

Figure 7.16 Specific yearly district heat and electricity consumption for hospital buildings plotted for the periods from October 1, 2004 until October 1, 2005, January 1, 2005 until January 1, 2006 and October 1, 2005 until October 1, 2006.

Hotels and restaurants

The total specific energy consumption for the selected hotels and restaurants are plotted in Figure 7.17. The average specific energy consumption for the period was 233 $\mathrm{kWh/m^2 \cdot yr}$, as shown by the black solid line in Figure 7.17, with a variation from 170 to 284 $\mathrm{kWh/m^2 \cdot yr}$. The Building Network has collected total specific energy consumption for 83 hotel buildings, which show an average yearly temperature-corrected energy consumption of 259 $\mathrm{kWh/m^2 \cdot yr}$ (see the dotted line in Figure 7.17). Here, the average specific energy consumption varied from approximately 100 to 450 $\mathrm{kWh/m^2 \cdot yr}$ (BNES, 2005). The numbers for hotels and restaurants selected for this thesis lie within the bounds published in the Building Network's Energy Statistics, but the average value is a bit lower for the buildings analysed.

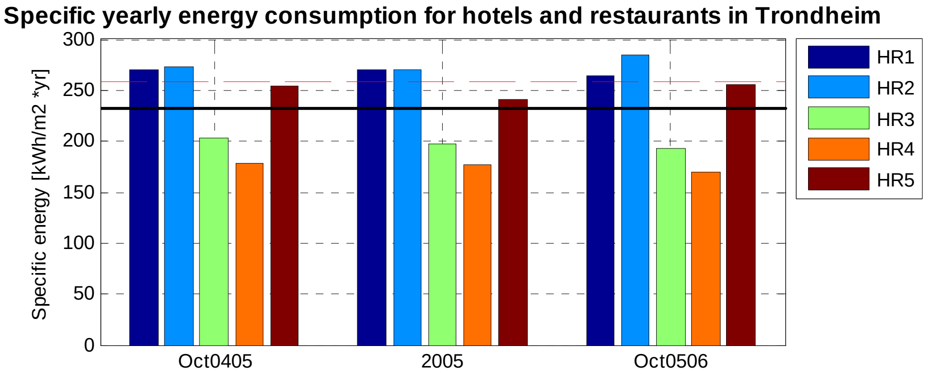

Figure 7.17 Specific yearly energy consumption for hotels and restaurants plotted for the periods from October 1, 2004 until October 1, 2005, January 1, 2005 until January 1, 2006 and October 1, 2005 until October 1, 2006.

The specific district heat and electricity consumption for hotels and restaurants are plotted in Figure 7.18. The average temperature corrected district heat consumption for the period was 113 $\mathrm{kWh/m^2 \cdot yr}$, with a variation from 95 to 142 $\mathrm{kWh/m^2 \cdot yr}$. The average electricity consumption for the same period was 120 $\mathrm{kWh/m^2 \cdot yr}$, with a variation from 76 to 152 $\mathrm{kWh/m^2 \cdot yr}$. The black lines in Figure 7.18 illustrate the average specific district heat and electricity consumption respectively.

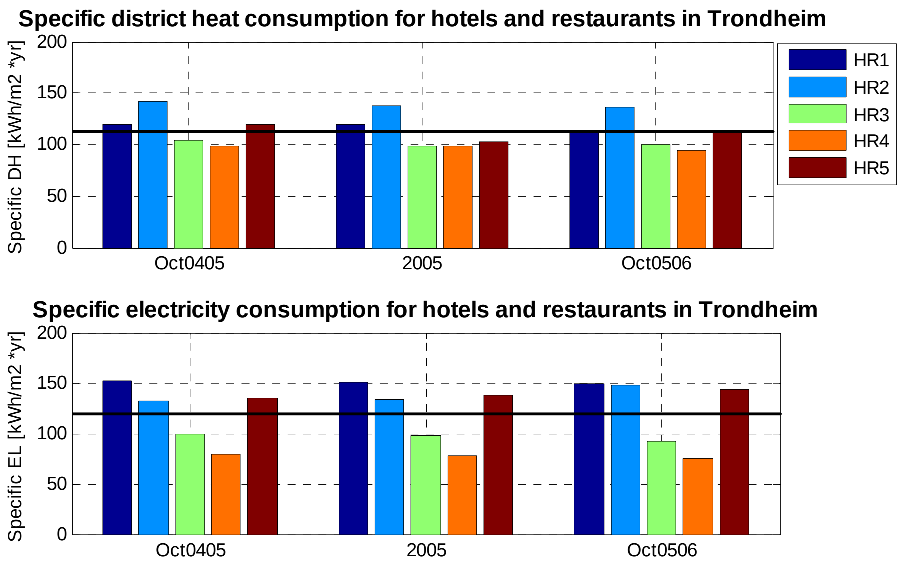

Figure 7.18 Specific yearly district heat and electricity consumption for hotels and restaurants plotted for the periods from October 1, 2004 until October 1, 2005, January 1, 2005 until January 1, 2006 and October 1, 2005 until October 1, 2006.

7.3 Load profiles for different building categories

This chapter presents the daily generalised load profiles for each building category/archetype along with yearly load profiles and load duration profiles for both heat and electricity purposes.

7.3.1 Daily load profiles for heat and electricity

The generalised heat load profiles for design conditions are presented graphically for every building category analysed. The generalised heat load profile for the temperature-independent season, i.e. hot tap water, is tabulated in Appendix B. The generalised electricity load profiles for the different seasons for every building category are also presented graphically. The generalised standard deviations for all building categories are presented for all load profiles. Load profiles for all the buildings analysed in this thesis are given in Appendix A. The actual variables are tabulated in Appendix B for all building categories.

Single family houses and apartment blocks

The single family houses, detached houses and apartment blocks have been analysed in clusters of approximately ten buildings each. Quality assurance of the district heat consumption data showed that 53 out of 167 buildings had continuous measurements for the period of nine months. Five clusters, all including ten randomly chosen buildings, have been analysed for heat load demand. The remaining three buildings have been excluded from the heat load profile analysis.

Figure 7.19 shows the generalised design heat load profile for single family houses and apartment blocks for both weekdays and weekends. The peak heat load demand occurs at 7 a.m. on weekdays and at 10 a.m. on weekends. The heat load demand drops more during the day for weekdays than weekends due to work routines. The peak heat load demand in the mornings is very dependent on the hot tap water consumption due to the lack of accumulator tanks in this building category.

The standard deviations for this building category are high compared to some of the other building categories analysed. Single family houses and apartment blocks lack the homogeneous routines that characterise other building categories such as office buildings and hospital buildings. As a consequence, the load demand is unevenly distributed, resulting in relatively high standard deviations.

It is important to keep in mind that buildings in this building category often have installed a secondary heat source such as an open fireplace or wood-burning stove which may reduce the peak heat load. This phenomenon could not be investigated using the collected measurements, because of the short measurement period and the relatively high outdoor temperatures; the most extreme mean daily temperature was -5.6°C.

The measurement resolution for hourly district heat consumption of 1 kWh/h may have influenced the heat load profile for this building category to some extent. A better measurement resolution might produce more accurate heat load profiles for single family houses and apartment blocks, but this phenomenon will have to be investigated when such measurements are available.

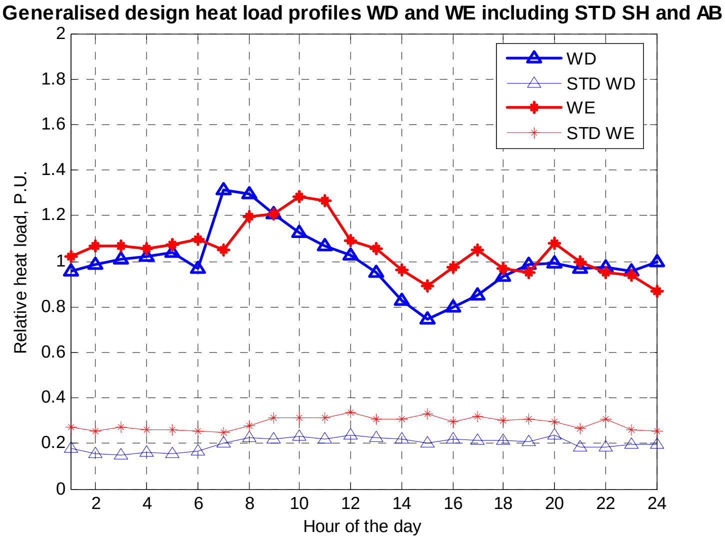

Figure 7.19   Generalised design heat load profiles for single family houses and apartment blocks on weekdays and weekends.

Only 38 out of 167 buildings with hourly electricity measurements passed the quality assurance test. This resulted in four clusters; three clusters contained ten buildings, while the last cluster included only eight buildings.

Figure 7.20 and Figure 7.21 show the generalised seasonal electricity load profiles, including standard deviations for weekdays and weekends respectively. The peak electricity load occurs at 9 p.m. on weekdays and at 8 p.m. on weekends. The difference between day hours and evening hours is more evident for weekdays than weekends due to working hours.

The seasonal profiles are very similar during night hours for both day types. However, the differences in daytime electricity load demand for the various seasons are quite evident.

The standard deviations for the electricity load are also high due to the same criteria described for the standard deviations for the heat load profiles.

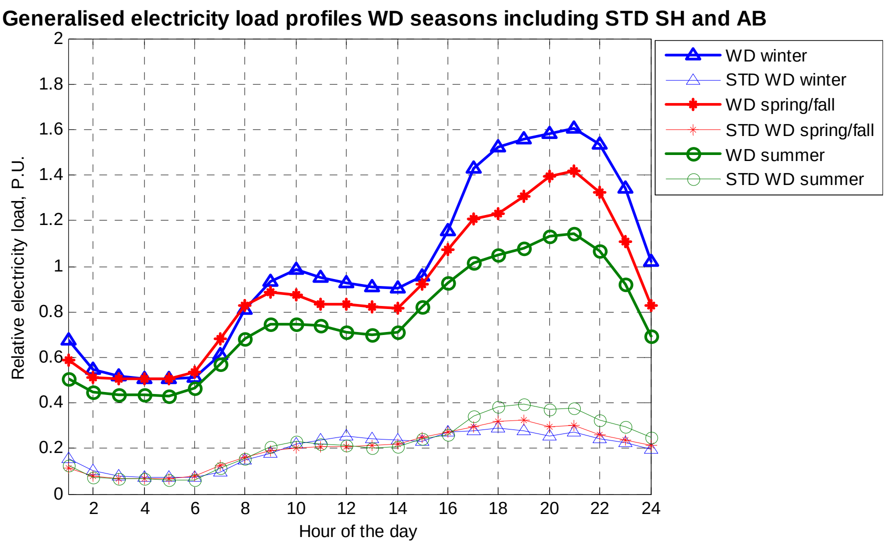

Figure 7.20 Generalised electricity load profiles, weekdays, for all seasons, including standard deviation for single family houses and apartment blocks.

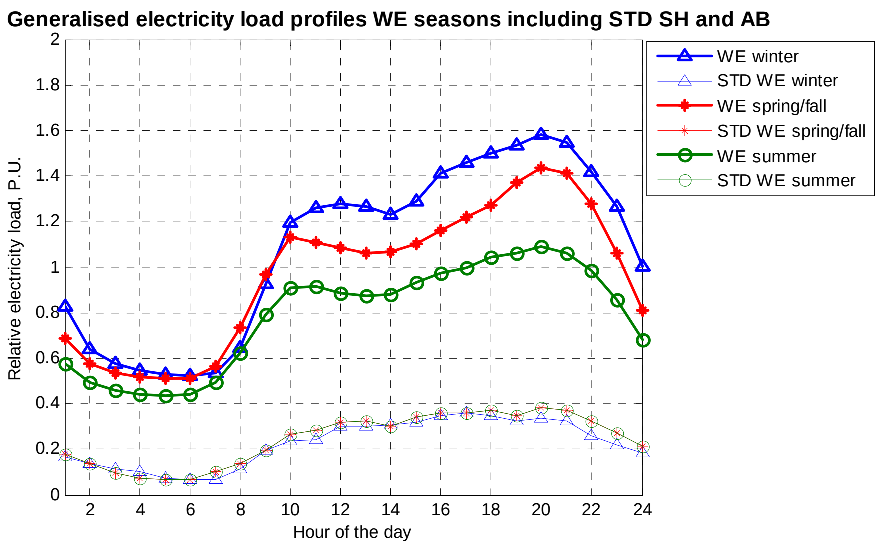

Figure 7.21 Generalised electricity load profiles, weekends, for all seasons, including standard deviation for single family houses and apartment blocks.

Office buildings

The main characteristics of the heat load profiles for office buildings are due to the operation of the ventilation system. For most office buildings analysed, the ventilation systems ran during daytime and working hours and were shut down during non-working hours and weekends/holidays. Most ventilation systems are operated using some manner of time control. However, some of the office buildings also had occupancy control; in other words, the systems operated depending on the presence of people. The limited number of office buildings investigated with hourly measurements of district heat and electricity consumption made it difficult to differentiate between these two regulation regimes.

Due to the small number of office buildings with continuously run ventilation systems, only one, the main archetype for heat load demand in office buildings, is based on time control of the ventilation system as the sole criteria. This means that the ventilation system operated during working hours plus/minus a few hours and was shut down or strongly reduced during non-working hours. Figure 7.22 shows the generalised design heat load profile for office buildings of both day types including standard deviations. OB1 has not been included in this analysis due to the continuous operation of the ventilation system during both day types.

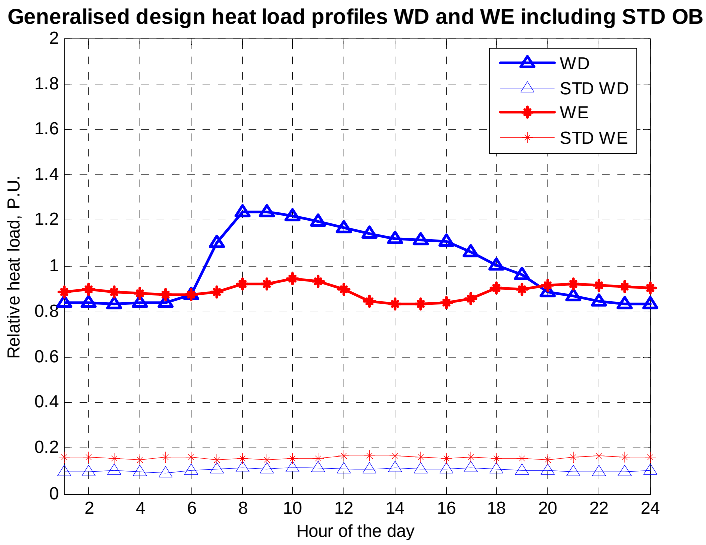

Figure 7.22 Generalised design heat load profiles for office buildings, weekdays and weekends, based on time control of the ventilation systems. The ventilation systems mainly run during working hours.

The electricity load profile has proven to be quite similar for all office buildings analysed, based on the criterion of working hours. The archetype is based on the division of day types alone, and OB1 was excluded for analysis of electricity load profiles during weekends due to the operation of the fans in the ventilation system during this day type.

Figure 7.23 and Figure 7.24 show the generalised electricity load profiles for office buildings for all seasons for weekdays and weekends respectively. The standard deviations are included for all seasons as well. The winter and spring/fall electricity load profiles for weekdays are quite similar, but the summer profile shows a lower high load demand. The seasonal electricity load profiles for weekends only show small variations suggesting that most of the electricity consumption during this day type is of a standby variety.

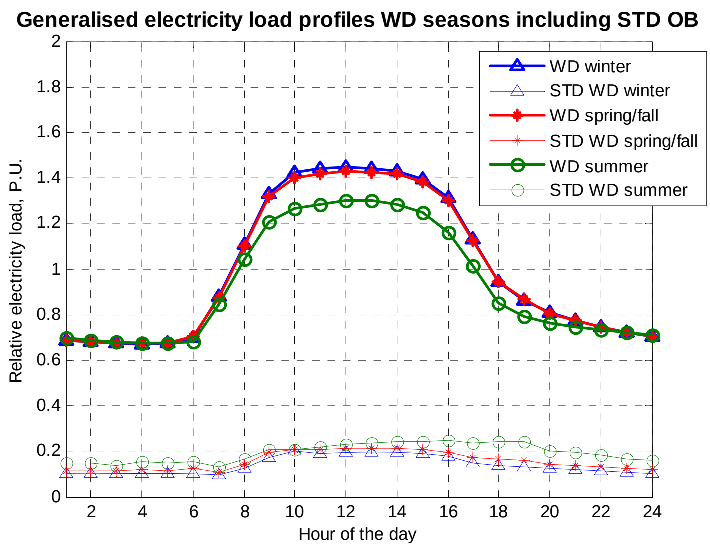

Figure 7.23 Generalised electricity load profiles for office buildings, weekdays, for all seasons, including standard deviation.

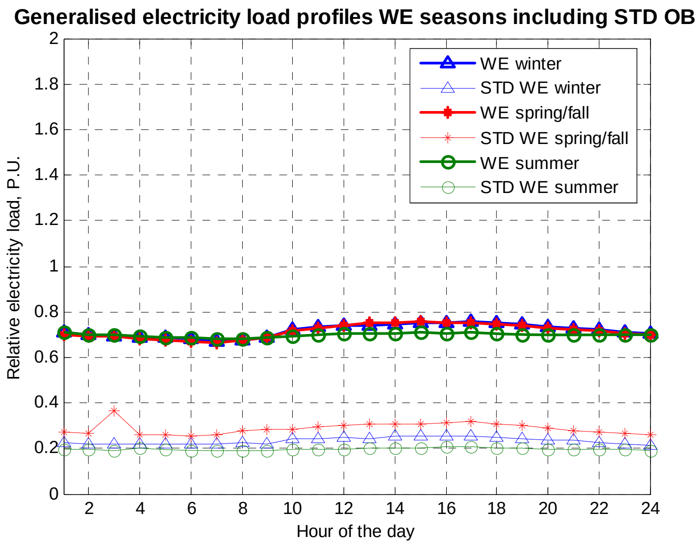

Figure 7.24 Generalised electricity load profile for office buildings, weekends, for all seasons, including standard deviation.

Educational buildings

A partitioning of the educational buildings according to school type; primary school and/or high school, did not result in any significant differences in heat and electricity load profiles.

All educational buildings analysed for this thesis had ventilation systems with time control, so that the systems ran during school hours and only during weekdays. The 15 educational buildings analysed showed a distinct division in heat load profiles between buildings built before and after 1997. Based on this criteria, the heat load profiles for educational buildings have been divided into two archetypes. Figure 7.25 shows generalised design heat load profiles for archetype 1, ventilation system with time control, for buildings built before 1997.

Figure 7.26 shows generalised design heat load profiles for archetype 2; time control of the ventilation system for buildings built in 1997 and after. EB9 was included in this group after the analysis, even though this building was constructed in 1980. The building underwent an extensive upgrade in 2000 which included installation of a new central control and monitoring system for heat and ventilation supply.

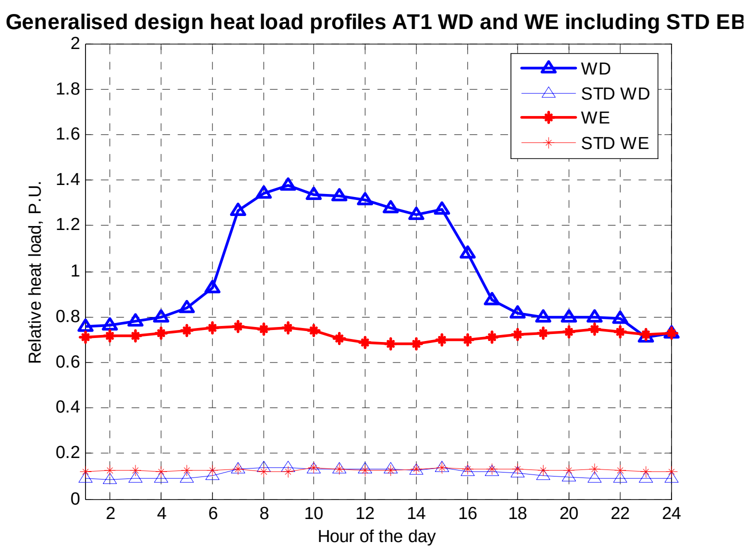

Figure 7.25 Generalised design heat load profiles for educational buildings, weekdays and weekends, for archetype 1, ventilation systems with time control for buildings built before 1997.

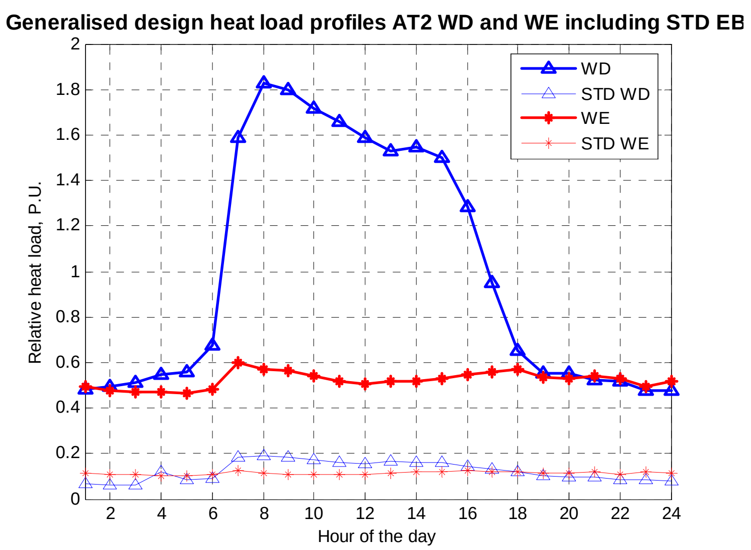

Figure 7.26 Generalised design heat load profiles for educational buildings, weekdays and weekends, for archetype 2, ventilation systems with time control for buildings built in 1997 and after.

The difference in heat load profiles for buildings built before and after 1997 can mainly be explained by two factors in the Technical Regulations under the Planning and Building Act (TEK, 1997):

1. More stringent requirements for the coefficient of thermal transmittance for the building envelope, which reduces the amount of space heating in new and renovated buildings.
2. More stringent requirements for the ventilation rate in new and renovated buildings, which increases the ventilation heat demand.

Efficient heat recovery units could reduce the latter effect, but all buildings analysed, both old and new, had installed heat recovery units. It has not been possible to categorise the buildings according to heat recovery efficiency due to inadequate background information.

New building code regulations have also been introduced in 1949, 1969, 1985 and 1987 (http://www.be.no), but it was not possible to differentiate between the buildings constructed during the latter periods. Most old buildings analysed have also undertaken small or major renovations, which made it difficult to classify them according to construction year.

Most schools offered after-school activities such as sports, band practice and/or up-grading courses. As a consequence, the generalised electricity load profiles during winter and spring/fall indicate an activity level during the afternoon. This phenomenon could have resulted in two different archetypes for the electricity load profiles if accurate information regarding after-school activities had been collected. However, the afternoon activity level may differ from one day to the next during the weekdays, which would have resulted in a more detailed partition of weekdays. As a result, only one generalised electricity load profile for each season and day type has been calculated for educational buildings.

The generalised electricity load profiles for all seasons for weekdays are shown in Figure 7.27. The peak electricity load demand occurs at 11 a.m. The summer load profile is much lower than in the winter and the spring/fall because of the decrease in activity levels in educational buildings during June, July and August.

The generalised standard deviations for electricity purposes are relatively high. This resulted from high relative standard deviations for each school due to various activity levels throughout the year.

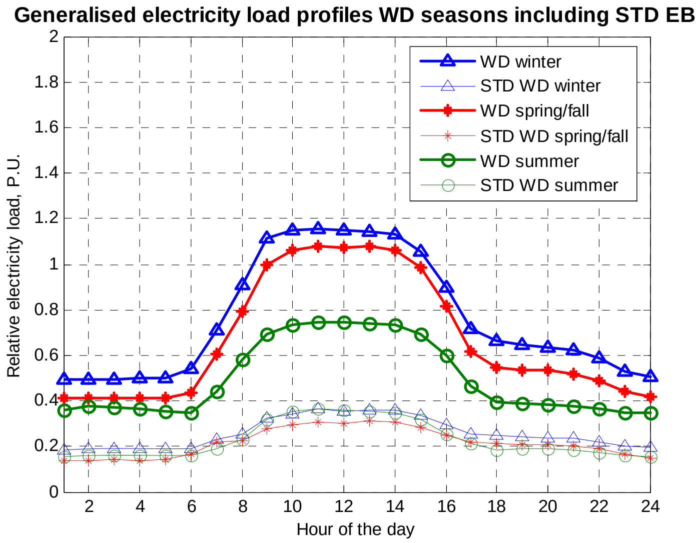

Figure 7.27 Generalised electricity load profiles for educational buildings for all seasons, weekdays, including standard deviations.

The generalised electricity load profiles for all seasons, weekends, for educational buildings are shown in Figure 7.28. The activity level during this day type is very low, which suggests the use of only standby electricity consumption. The peak electricity load demand occurs at 5 p.m., indicating some afternoon activity during the weekends.

The seasonal electricity load profiles for educational buildings varied in size during the night hours for weekdays and throughout the day and night for weekends. The variation between the winter and spring/fall electricity load profiles, which was higher for educational buildings than for other building categories, may be caused by the use of a small amount of electricity for heat purposes. This was also shown by the t-test and the questionnaires. Several building owners and operation managers reported some use of portable electric heaters.

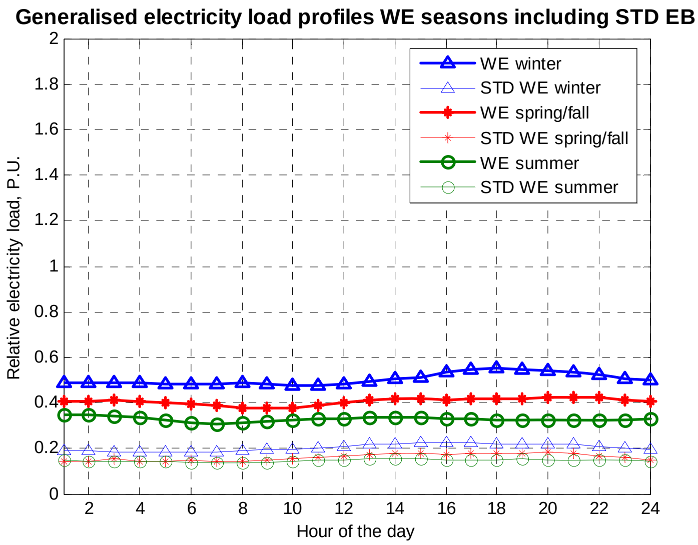

Figure 7.28   Generalised electricity load profiles for educational buildings for all seasons, weekends, including standard deviations.

Hospital buildings

The hospital buildings category is comprised of only retirement and nursing homes. These buildings mainly had ventilation systems with time control, which meant they were running during the daytime for both weekdays and weekends. The utilisation time for the ventilation system in this building category is much higher than in office buildings and educational buildings, for example from 7 a.m. to 10 p.m. for weekdays and weekends.

The peak at 10 a.m for weekdays in Figure 7.29 may be caused by extensive hot tap water use as well as supply air heating. The peak heat load for weekends occurs at 9 a.m.

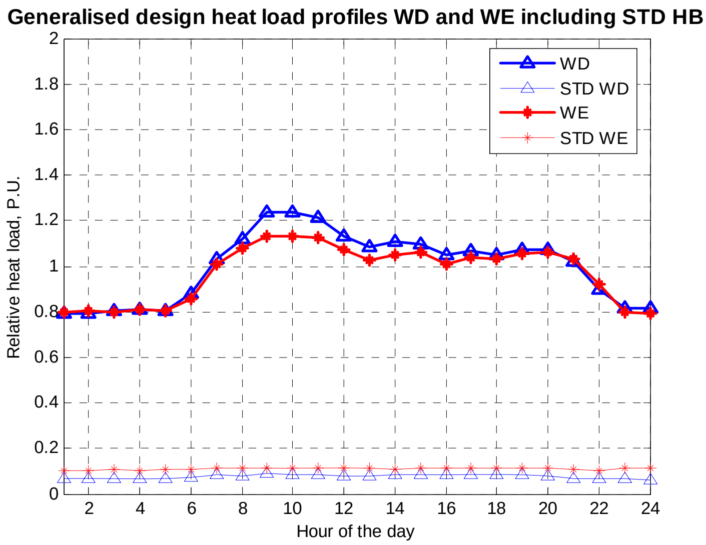

Figure 7.29 Generalised design heat load profiles for hospital buildings, weekdays and weekends, including standard deviations.

The generalised seasonal electricity load profiles for hospital buildings are shown in Figure 7.30 and Figure 7.31 for weekdays and weekends respectively. The shapes for both day types are quite equal, with peak electricity load demand at 1 p.m., but the level during the weekdays is higher than during weekends for ordinary working hours. The level during the afternoon for both weekdays and weekends is almost the same.

The generalised seasonal load profiles for both weekdays and weekends are similar in shape, with a variation between summer and winter of approximately 0.2 P.U. for high load hours and approximately 0.1 P.U. for low load hours for both day types.

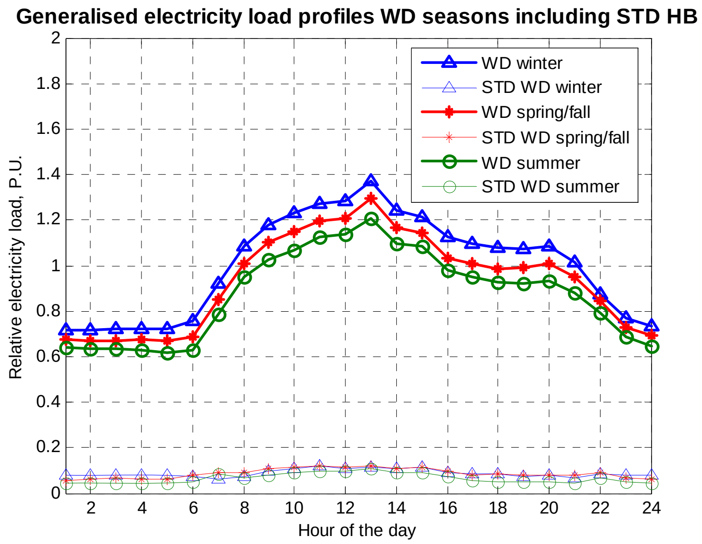

Figure 7.30 Generalised electricity load profiles for hospital buildings for all seasons, weekdays, including standard deviations.

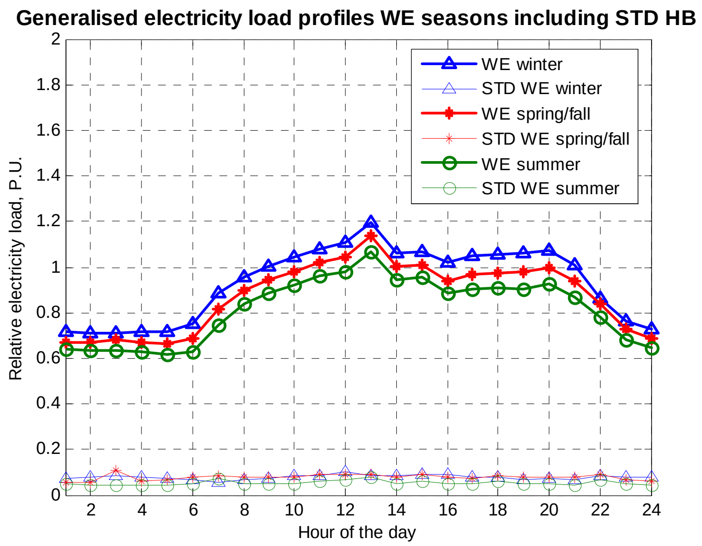

Figure 7.31 Generalised electricity load profiles for hospital buildings for all seasons, weekends, including standard deviations.

Hotels and restaurants

Figure 7.32 shows the generalised design heat load profiles for the hotels with restaurants analysed for both weekdays and weekends, including standard deviations. HR2 has been omitted from the heat load analysis due to night set-back of the space heating system. Appendix A contains the relative heat load profile for HR2.

Most hotels with restaurants ran their ventilation systems continuously. The peak load during the day for both day types is caused by the demand for morning hot tap water, which occurs around 8 a.m. on weekdays and 10 a.m. on weekends.

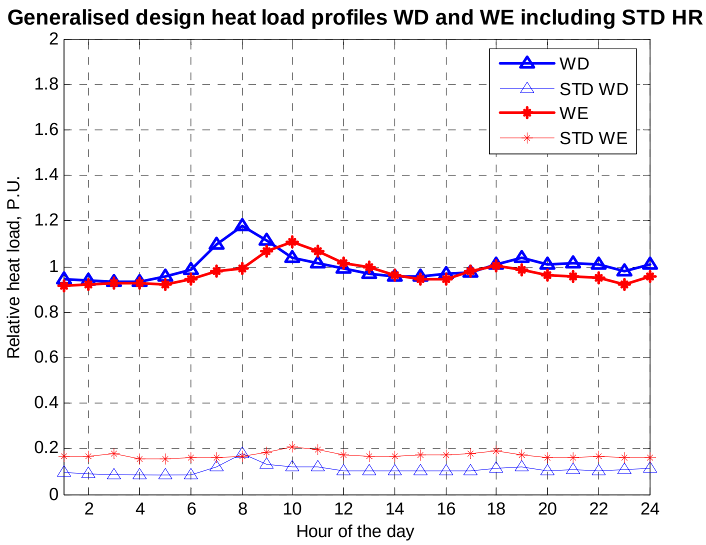

Figure 7.32 Generalised design heat load profiles for hotel and restaurant buildings, weekdays and weekends, including standard deviations.

The generalised seasonal electricity load profiles for hotels with restaurants for weekdays and weekends are shown in Figure 7.33 and Figure 7.34 respectively. The winter and spring/fall electricity load profiles are quite equal in size and shape for both day types, while the summer load profiles are slightly lower. Much like the heat load demand, the peak electricity load demand occurs at different hours for the various day types; in this case at 9 a.m. on weekdays and at 10 a.m. on weekends.

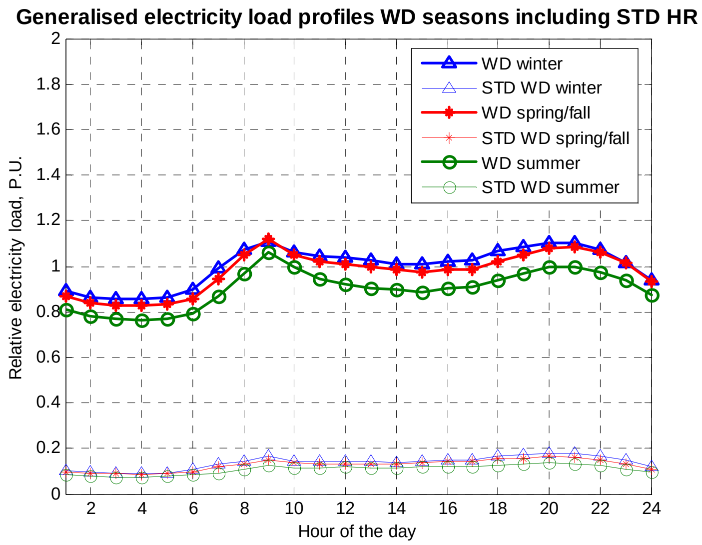

Figure 7.33   Generalised electricity load profiles for hotel and restaurant buildings for all seasons, weekdays, including standard deviations.

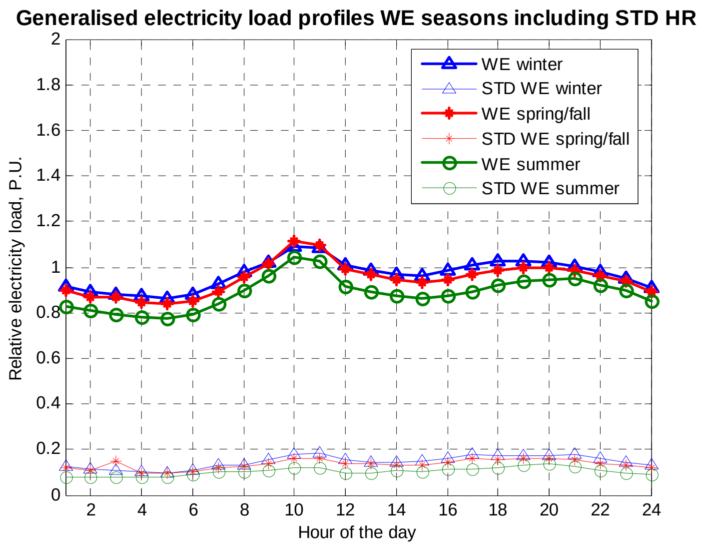

Figure 7.34   Generalised electricity load profiles for hotel and restaurant buildings for all seasons, weekdays, including standard deviations.

7.3.2 Yearly and duration load profiles based on DRY

The yearly heat load profiles for the different building categories are based on a reference year, as explained in Chapter 5.3.3. The design reference year (DRY) was chosen and the daily mean temperatures have been calculated based on the 8760 values obtained for hourly outdoor temperature. The change-point temperatures estimated for each building category/archetype have been used for weekdays and weekends respectively. The same change-point temperature was used for all hours during the various day types, and the expected heat load value could never be lower than the expected hot tap water demand during the temperature-independent season.

The yearly load profiles for electricity are based on the different seasons, i.e. following the calendar months successively starting from January to December.

The reference year has been assumed to start on a Monday and all holidays have been incorporated accordingly for both heat and electricity load demand.

In order to level the yearly and duration load profiles, the expected annual specific energy consumption, HCI and ELCI, estimated for each building category for heat and electricity purposes were used, as outlined in Table 7.5. The average yearly mean load was calculating according to Equation 7.4:

$$\overline{\Phi}_{yearly} = \frac{ECI \cdot 1000\ \text{[W/kW]}}{8760\ \text{[h/yr]}}\ [\text{kWh/(h} \cdot \text{m}^2)] \qquad (7.4)$$

where:

ECI HCI or ELCI depending on purpose, in $[\text{kWh/m}^2 \cdot \text{yr}]$.

The DRY is based on Oslo climate. The difference in normal degree days for Oslo and Trondheim is only 1.6% (BNES, 2005), and the HCI for Trondheim climate has been applied for all building categories.

The yearly load profiles are presented chronologically as well as in descending order, as load duration profiles. The areas beneath these profiles are equal to the annual specific energy consumption within each building category. Two randomly chosen building categories/archetypes are selected to illustrate the yearly load profiles for heat and electricity demand.

The yearly specific heat load profiles are presented for archetype 1 and 2 for educational buildings in Figure 7.35. The regular workdays during the Christmas break and the winter holidays have not been defined as weekend day types in these profiles. Individual adjustments have to be made in the definition of day types when applying the model for the purpose of energy planning in general, and load estimation in particular.

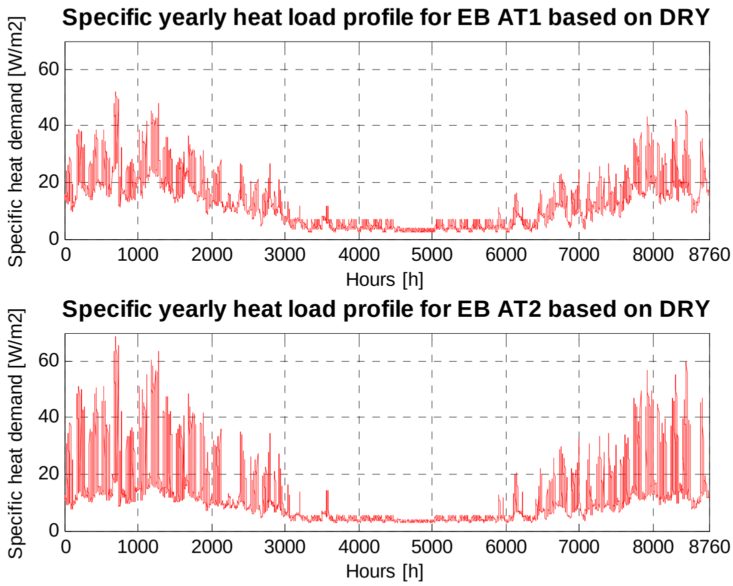

Figure 7.35 Specific yearly heat load profiles for educational buildings for archetype 1 and 2 based on the design reference year (DRY).

The specific heat load duration profiles for all building categories/ archetypes analysed in this thesis are presented in Figure 7.36.

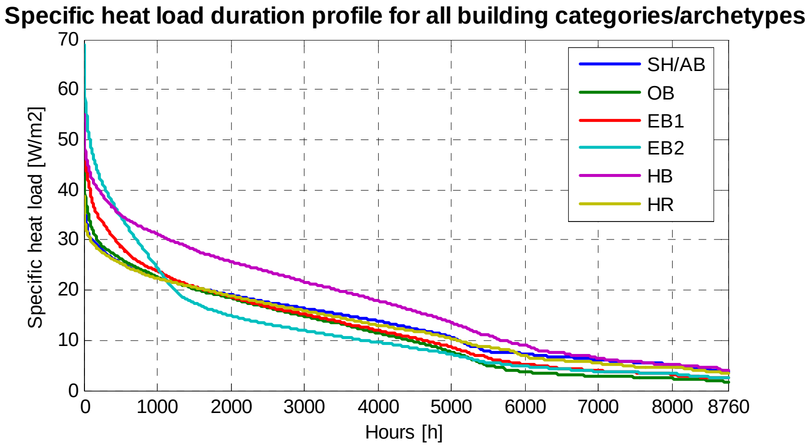

Figure 7.36 Specific heat load duration profiles for different building categories and archetypes calculated using DRY.

The yearly specific electricity load profiles are presented for educational buildings and hospital buildings in Figure 7.37. The seasonal electricity profiles are static, meaning that they are only dependent on time of year and day type. The summer holidays, Christmas days and Easter are incorporated in the model as weekends. The graphical electricity load profiles are scaled to be equal to the heat load profiles to allow comparisons.

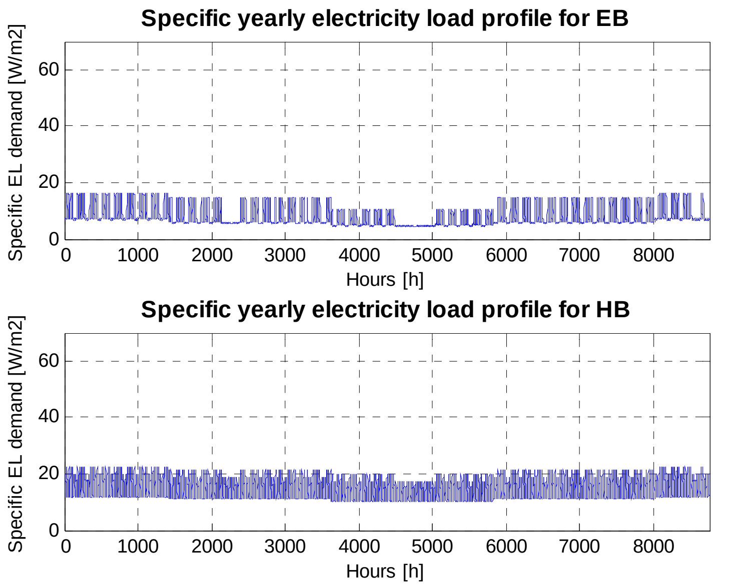

Figure 7.37   Specific yearly electricity load profiles for educational buildings and hospital buildings based on a reference year.

The specific electricity load duration profiles for all building categories analysed in this thesis are presented in Figure 7.38.

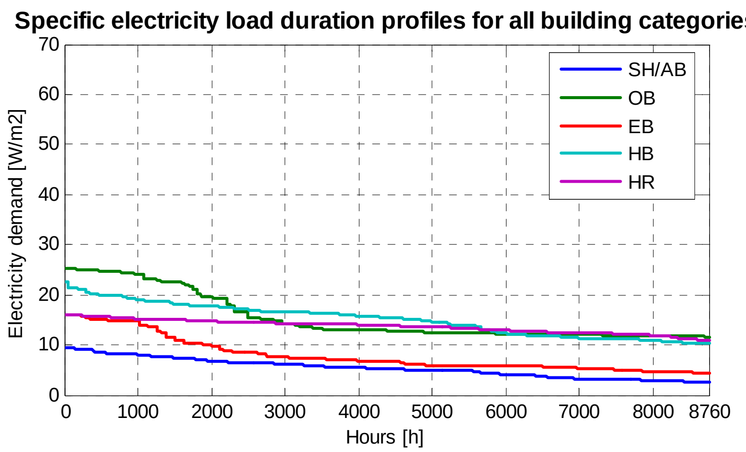

Figure 7.38   Specific electricity load duration profiles for different building categories calculated using seasonal electricity load profiles.

7.4 Verification of the heat and electricity load model

The verification of the heat and electricity load model is based on trade-offs outlined by the systems engineering process. Different methods developed for load modelling have been investigated and the most feasible solutions were chosen for heat and electricity load modelling in mixed energy distribution systems.

First of all, the calculated and real load duration profiles are presented graphically for randomly chosen buildings within each building category to allow comparisons. Secondly, the different methods developed throughout the thesis work are presented in this chapter along with a comparison of the various methods for heat and electricity purposes respectively.

7.4.1 Calculated and real load duration profiles

This chapter presents the calculated load duration profiles for randomly chosen buildings within the different building categories as compared to the real load duration curves for selected buildings for 2005. Single family houses and apartment blocks are not included in this analysis due to the lack of one complete year of measurements.

In order to compare the calculated and the real load duration profiles, the load level had to be normalised. The calculated yearly average load is set equal to 1 kWh/h using a scaling factor. The real average load is also set equal to 1 kWh/h using a different scaling factor:

$$\bar{\Phi} \cdot \mathrm{Factor} = 1 \text{ [kWh/h]} \tag{7.5}$$

$$\mathrm{Factor1} = \frac{1}{\bar{\Phi}_{\mathrm{Calculated}}} \tag{7.6}$$

$$\mathrm{Factor2} = \frac{1}{\bar{\Phi}_{\mathrm{Real}}} \tag{7.7}$$

where $\bar{\Phi}$ is the average yearly load level for both district heat and electricity.

The selected buildings have been chosen using a random function in Excel which calculated a random integer for the total number of buildings within each building category.

Figure 7.39 through Figure 7.42 show the goodness of fit for the heat load duration profiles for OB4, EB2, HB2 and HR4 respectively.

The normalised heat load duration profiles for the office building, the hospital building and the hotel and restaurant show a good fit, while the goodness of fit for the educational building is not as strong.

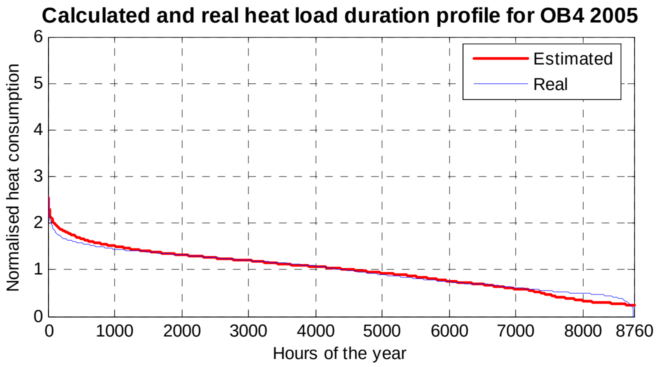

Figure 7.39 Calculated and real heat load duration profiles for OB4 for 2005.

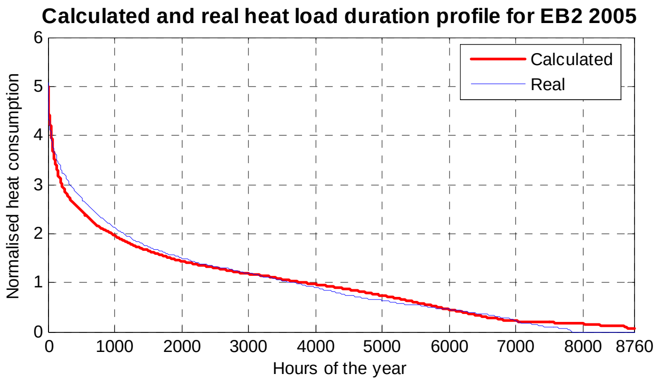

Figure 7.40 Calculated and real heat load duration profiles for EB2 for 2005.

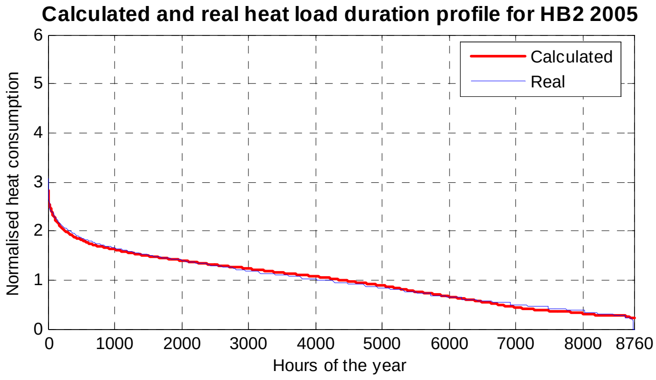

Figure 7.41 Calculated and real heat load duration profiles for HB2 for 2005.

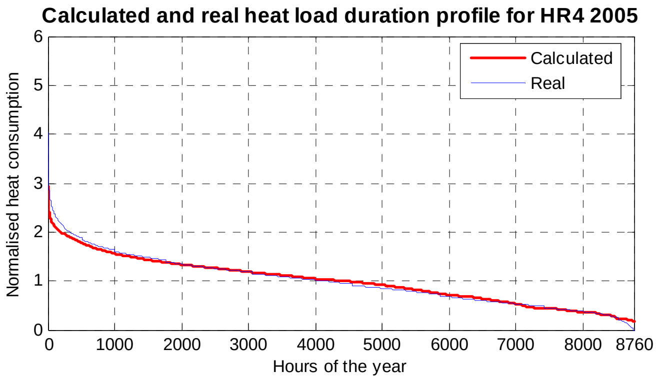

Figure 7.42 Calculated and real heat load duration profiles for HR4 for 2005.

Figure 7.43 through Figure 7.46 show the goodness of fit for the seasonal electricity load duration profiles for OB2, EB15, HB1 and HR4 respectively.

The normalised electricity load duration profiles for the office building and the hospital building show a good fit, while the goodness of fit for the educational building and the hotel and restaurant are not as strong.

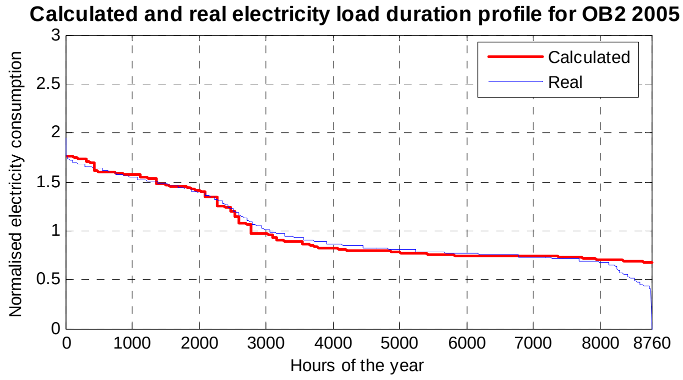

Figure 7.43 Calculated and real electricity load duration profiles for OB2 for 2005.

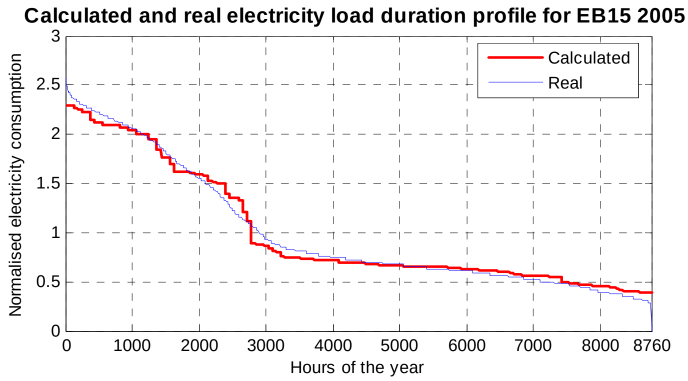

Figure 7.44 Calculated and real electricity load duration profiles for EB15 for 2005.

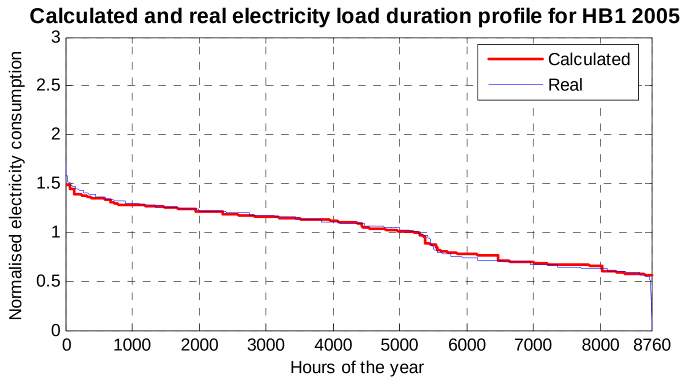

Figure 7.45 Calculated and real electricity load duration profiles for HB1 for 2005.

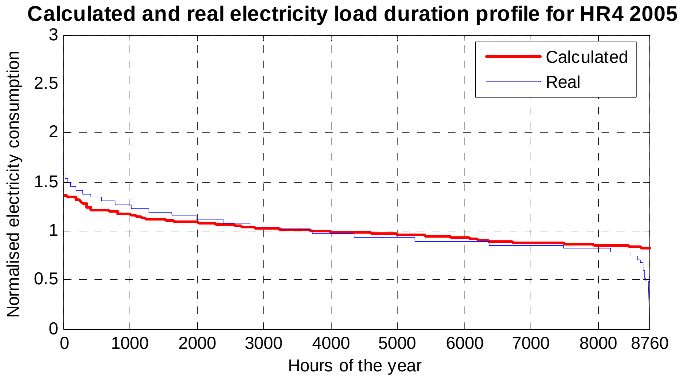

Figure 7.46 Calculated and real electricity load duration profiles for HR4 for 2005.

7.4.2 Different methods for heat load modelling

Four different methods were eventually developed and tested for heat load modelling: change-point method with constant beta value, change-point method with least RMSE (Root Mean Square Error), yearly regression, and seasonal regression. The different methods are presented and compared in the following paragraphs.

Change-point method with constant beta value

The change-point method with constant beta value is the selected method for heat load modelling. This method has been described in Chapter 6.3: Heat load model based on regression analysis.

Change-point method with least RMSE

The change-point method with least RMSE (Root Mean Square Error) is based on the same approach as the change-point method with constant beta value. The RMSE for a given hour is found by (Kissock et al., 1998):

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}{n-2}} \tag{7.8}$$

where:

Y_i The hourly measured heat consumption at a given temperature.

$\bar{Y}$ The expected heat value for a given temperature.

The RMSE is calculated for every step $\Delta\theta$ from high to low outdoor temperatures and the change-point is determined based on the least RMSE value. This method has been applied in the EModel (1994) and by Kissock et al. (1998) on daily, weekly and monthly regression analyses.

The heat load profile during the temperature-independent season is estimated using a normal distribution for every hour and day type.

Yearly regression

The yearly regression analysis is based on all hourly district heat measurements within a given hour and day type in order to calculate alpha and beta values.

Seasonal regression

The seasonal regression analysis is based on hourly district heat measurements within a season for a given hour and day type. The seasons have been divided into winter, spring, summer and fall. Alpha and beta values are calculated for every season. This model has been applied in USELOAD (Feilberg, 2002) for estimation of hourly electricity consumption in all electric buildings.

Comparison of the different methods for heat load modelling

The different methods are compared in relation to their advantages and disadvantages as well as the goodness of fit the different methods show in relation to real measurements.

Table 7.6 Comparison of the different methods developed for heat load modelling with advantages and disadvantages.

Method	Advantage	Disadvantage
Change-point constant beta value	• Realistic change-point temperature for temperature-dependent season • Robust • Small variations for the temperature-dependent season throughout the day	• May give too high load for design temperature
Change-point least RMSE	• Robust	• Very high change-point temperature for temperature-dependent season • Large variations for temperature-dependent season throughout the day
Yearly regression	• Easy to use • No concern about change-point temperature	• Lacks the nuances of the physical heat load demand, especially during summer • May give negative load values for high outdoor temperature • May give too low load for design temperature
Seasonal regression	• Easy to use • No concern about change-point temperature	• Negative values for heat load when the temperature within the season varies a lot from the estimated

The goodness of fit for the different heat load models have been calculated in relation to measured heat load duration curves for the different building categories for 2005. The Root Mean Square Error (RMSE) for the 8760 values is applied in order to estimate the difference between the real load values and the calculated load values. The normalised heat load duration profiles have been used for every building. Table 7.7 shows the average RMSE for all methods and building categories. The mathematical ranking of the methods for the various building categories is shown in parenthesis. The ranking was not consistent for the various building categories and no precise conclusion could be drawn on this basis alone.

Table 7.7 Average RMSE for the various heat load models for the building categories with one year of continuous hourly measurements, including a ranking of the different models within each building category.

	Building categories			
Model	**OB (rank)**	**EB (rank)**	**HB (rank)**	**HR (rank)**
CPM	0.0808 (2)	0.1044 (2)	0.0417 (2)	0.0955 (2)
RMSE	0.0769 (1)	0.1107 (3)	0.0562 (3)	0.0987 (3)
Year	0.1157 (4)	0.1396 (4)	0.0393 (1)	0.1145 (4)
Season	0.0834 (3)	0.0821 (1)	0.0743 (2)	0.0936 (1)

Based on the advantages and disadvantages listed in Table 7.6 and the mathematical ranking of the different methods, the change-point method with constant beta was chosen. This alternative was chosen because of the method's robustness, realistic portrayals and only small variations in the change-point temperature throughout the day, as well as the high mathematical ranking for all building categories.

The change-point method with constant beta can be used for one building as well as for the generalisation of heat load profiles for a building category.

The RMSE for calculated and real heat load duration profiles for all large buildings analysed are shown in Figure 7.47 through Figure 7.50.

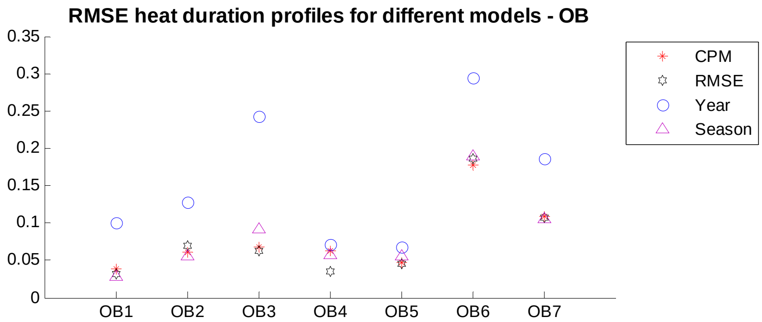

Figure 7.47 RMSE for calculated and real normalised heat load duration profiles for all office buildings analysed.

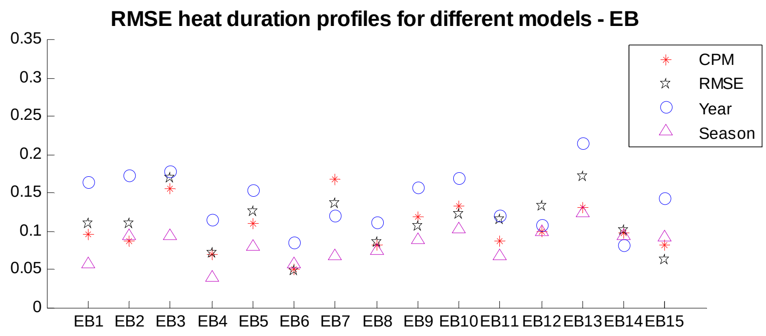

Figure 7.48 RMSE for calculated and real normalised heat load duration profiles for all educational buildings analysed

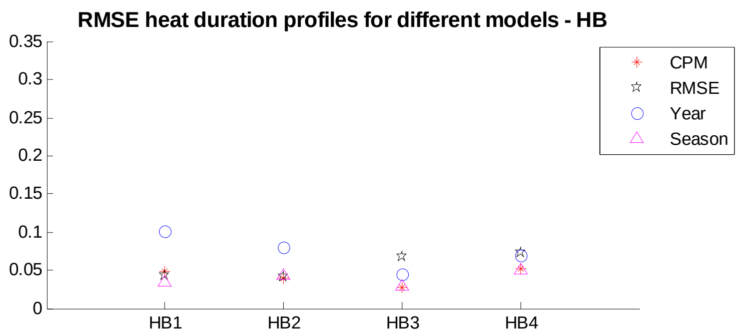

Figure 7.49 RMSE for calculated and real normalised heat load duration profiles for all hospital buildings analysed

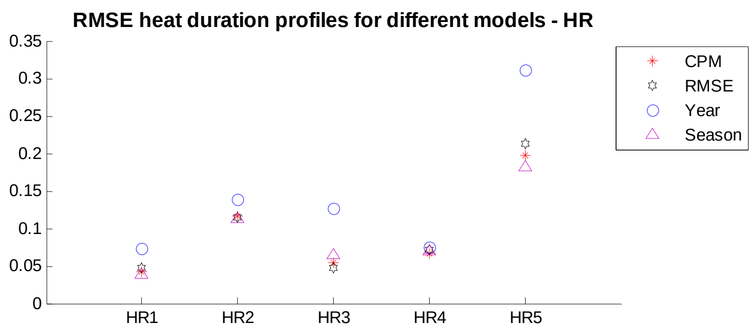

Figure 7.50 RMSE for calculated and real normalised heat load duration profiles for all hotels and restaurants analysed

7.4.3 Different methods for electricity load modelling

Six different methods were developed and tested for electricity load modelling: yearly distribution, seasonal distribution, monthly distribution, temperature interval distribution, yearly regression and seasonal regression.

Yearly distributions

The hourly electricity consumption is divided into weekdays and weekends/holidays, and the expected values and standard deviations are calculated based on normal and lognormal distributions.

Seasonal distributions

The hourly electricity consumption is divided into different day types as well as winter, spring/fall and summer seasons. The expected values and standard deviations are calculated based on mainly normal distribution. This method has been described in Chapter 6.4: Electricity load model based on probability distributions.

Monthly distributions

The monthly distribution method is based on hourly electricity consumption for each day type within every month of the year, from January to December. The expected values and standard deviations are calculated for each month based on normal distribution.

Temperature interval distribution

The temperature interval distribution method has been applied by Norén (1999) as well as in the early development of the heat and electricity load model (Pedersen and Ulseth, 2004). The expected values and standard deviations are calculated based on the normal distribution within temperature intervals of 5°C.

Yearly regression

Based on the t-test, some buildings showed a correlation with outdoor temperature, but the influence of hours of daylight and sun could not be disregarded. However, linear regression analysis has been applied to the hourly electricity measurements in relation to daily mean temperature. The alpha and beta values are calculated for every hour and day type for the selected buildings.

Seasonal regression

The seasonal regression method used for electricity consumption calculations is equal to the seasonal regression method used for the district heat consumption. The alpha and beta values within each season are calculated based on the method of least squares.

Comparison of the different methods for electricity load modelling

The different methods for electricity load modelling are also compared in relation to their advantages and disadvantages as well as the goodness of fit the different methods show in relation to real electricity measurements.

Table 7.8 Comparison of the different methods developed for electricity load modelling with advantages and disadvantages.

Method	Advantage	Disadvantage
Yearly distribution	• Easy to use	• Lacking the nuances of the electricity load throughout the year • Static model
Seasonal distribution	• Easy to use • Include seasonal variations	• Static model
Monthly distribution	• Easy to use • Include monthly variations	• Static model
Temperature interval distribution	• Easy to use • Include variations depending on outdoor temperature	• Regression analyses give better fit
Yearly regression	• Dynamic model	• The slope may be descending or ascending depending on electricity for heating or cooling purposes
Seasonal regression	• Dynamic model	• The slope may be descending or ascending depending on electricity for heating or cooling purposes

The goodness of fit for the different electricity load models has also been calculated in relation to measured electricity load duration curves for the different building categories for 2005. Table 7.9 shows the average RMSE for all methods and building categories. The mathematical ranking of the methods for the various building categories are shown in parenthesis.

Table 7.9 Average RMSE for the various electricity load models for building categories with one year of continuous hourly measurements, including a ranking of the different models within each building category.

	Building categories			
Model	**OB (rank)**	**EB (rank)**	**HB (rank)**	**HR (rank)**
Year dist.	0.0669 (5)	0.1830 (6)	0.0480 (5)	0.0810 (5)
Season dist.	0.0513 (3)	0.1153 (3)	0.0340 (4)	0.0651 (4)
Month dist.	0.0428 (1)	0.1138 (1)	0.0319 (2)	0.0606 (1)
TempInt dist.	0.0710 (6)	0.1757 (5)	0.0493 (6)	0.0819 (6)
Year reg.	0.0557 (4)	0.1239 (4)	0.0334 (3)	0.0620 (2)
Season reg.	0,0482 (2)	0.1144 (2)	0.0316 (1)	0.0620 (2)

The methods based on regression analysis show a good fit, but they have both been rejected. The slopes of the regression analyses were both descending and ascending, suggesting that the electricity load data analysed supplied a small amount of heating and cooling respectively. Based on this criteria and the objective of developing a model that estimates the electricity demand for electricity purposes only, the distribution methods have been preferred.

Based on the advantages and disadvantages listed in Table 7.8 and the mathematical ranking of the different distribution methods, the seasonal distribution method was chosen. The monthly distribution method gave a better fit for the individual buildings, but the generalisation of the electricity load profiles based on this method did not differentiate between the months due to larger variations among the buildings analysed. As a result, a division of seasons for electricity load estimation was found to be good enough for the purpose of energy planning for a specified planning area.

It was also interesting to note that the monthly and seasonal distribution methods showed better fits than the temperature interval distribution method for all large buildings analysed. This may imply a seasonal electricity load variation rather than a temperature-dependent electricity load variation in general.

If electricity load data is to be analysed for one individual building for retrofit options, or in other words, if an analysis of the electricity load profile before and after retrofit measures is desired, it is possible to calculate the method which gives the best fit. Both regression methods as well as monthly and seasonal distribution methods should be considered in this case.

The RMSE for calculated and real electricity load duration profiles for all large buildings analysed are shown in Figure 7.51 to Figure 7.54.

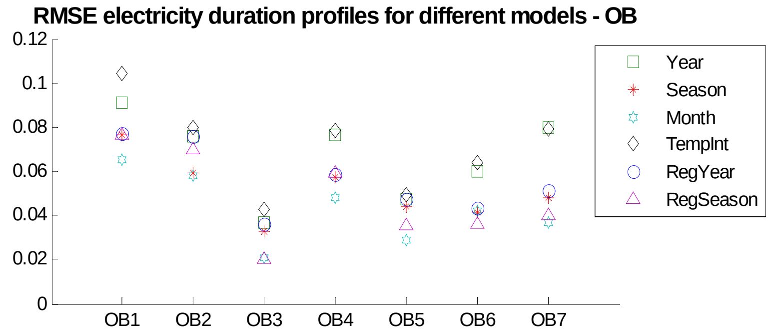

Figure 7.51 RMSE for calculated and real normalised electricity load duration profiles for all office buildings analysed.

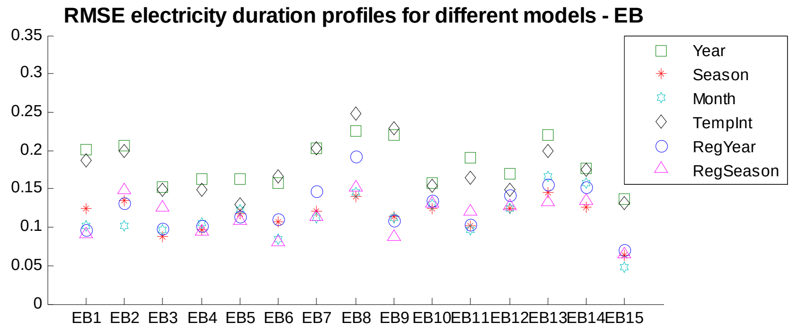

Figure 7.52 RMSE for calculated and real normalised electricity load duration profiles for all educational buildings analysed.

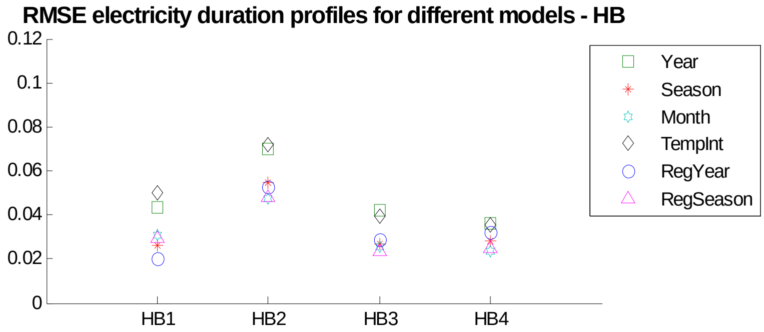

Figure 7.53 RMSE for calculated and real normalised electricity load duration profiles for all hospital buildings analysed.

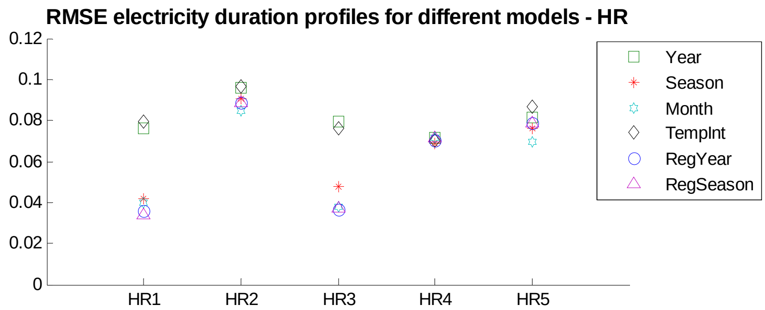

Figure 7.54 RMSE for calculated and real normalised electricity load duration profiles for all hotels and restaurants analysed.

8 Applying the method

8.1 Introduction

The purpose of this chapter is to show how the generalised load profiles can be applied to a specified planning area in order to estimate the maximum load, yearly load profile, load duration profile and annual energy demand divided into heat and electricity purposes. A theoretical case study has been applied due to the lack of hourly heat and electricity measurements at an aggregated level.

8.2 Description of planning area

In order to estimate the maximum load and annual energy demand for a planning area, the system boundaries have to be set. A number of facts have to be collected in relation to the required input variables; these are:

1. Numbers of buildings within each building category/ archetype.
2. Available area for each building.
3. Construction year for each building.
4. Major rehabilitation, if any, for each building.
5. Type of heating: hydronic heating system or electricity distribution system only.
6. Future development, if any, within the system boundaries.

The first two issues must always be addressed when planning for mixed energy distribution systems. Issues 3 to 5 must be addressed when buildings already exist within the system boundaries. The planning horizon for energy distribution infrastructure is 30 to 50 years, and as a consequence, it is very important to allow for future development within the system boundaries. Therefore, development prognosis and scenario analyses should be applied.

The case study for this thesis is based on a fictitious development area located in Trondheim climate. This means that all the buildings defined within the system boundaries will be built within the planning horizon. The various construction stages must be identified. Only the resulting heat and electricity profiles for the fictitious development area have been estimated in this case study, but the different construction stages could easily be implemented in the model for estimating heat and electricity load profiles for each stage. Changes in the HCIs and ELCIs need to be incorporated into the model applying different scenarios concerning the future development in the building sector. This case study only show the steady state scenario.

Table 8.1 shows the 311 buildings selected for the case study, including the average available area for the development project.

Table 8.1 Number of buildings located within the fictitious development area including average available area for every building category.

Building category	**Number**	**Average available area [m^2]**
Single family houses	100	140
Apartment blocks	200	80
Office buildings	5	5000
Schools	3	4000
Hospitals (nursing homes)	2	5000
Hotels and restaurants	1	6000

The heat demand is analysed in relation to all energy carriers by incorporating the maximum load losses and annual energy losses for electricity, district heating and natural gas distribution systems respectively. The electricity demand is only analysed in relation to electricity as the energy carrier. The system boundaries for the electricity supply are set at the regional grid, which means that losses from the central grid were omitted.

Table 8.2 shows the selected maximum load and annual energy losses based on the criteria listed above, as well as the discussion concerning distribution losses in the various energy systems in Chapter 6.5.5. The system boundaries are set outside the energy production unit(s), which means that the losses in relation to energy production and/or transformation have been omitted.

The electricity density for the specified planning area is assumed to be medium, and the electricity grid is assumed to be composed of cables buried in ditches. The district heating system is assumed to have a twin pipe distribution system, which minimizes the annual heat losses. The heat density for the selected area is also assumed to be medium. The natural gas system is assumed to supply condensing gas boilers within each building, but a few gas stoves and surface mounted gas heaters are also factored in for the single family houses and apartment blocks.

Table 8.2 Overview of the load losses at maximum load and annual energy losses for the various energy carriers

Energy carrier	**Electricity (EL)**	**District heating (DH)**	**Natural gas (GAS)**
Load loss at maximum load [%]	8	2	9
Annual energy loss [%]	5	12	3

8.3 Solution procedure

The solution procedure for aggregating load profiles for a specified planning area has been presented in Figure 2.11 in Chapter 2.4.4, as well as in Chapter 6.2.2.

When the specified planning area is identified with all the required input parameters for the various buildings, the generalised load profiles for heat and electricity purposes are applied. The specific load indicators along with the maximum load hour for all building categories are used to restore the design load profile for each building in the area. The ratio between the specific load indicator and the relative maximum load for each building is calculated and multiplied by the building's available area according to Equation 8.1. Every hour of the weekday's design load profile is then multiplied by this factor, because the design heat load will always occur during this day type for the buildings analysed in this thesis. The relative standard deviations for each building are also multiplied by the same factor.

$$\Phi_{factor} = \frac{\Phi_{specific}}{\Phi_{relative(maximum)}} \cdot A_{building} \tag{8.1}$$

The yearly load profiles divided into heat and electricity are calculated based on the generalised load profiles. The HCIs and ELCIs are applied to restore the yearly load profiles for each building within the selected development area using Equation 7.4 as well as the available area.

The design load profiles and yearly load profiles estimated for each building are aggregated according to Equation 6.23. The aggregated standard deviation for design load profiles is found by using Equation 6.24. The maximum load was estimating using the 95% t-quantile with n-1 = 310 degrees of freedom, based on the number of buildings within the selected planning area. For the fictitious case study, the t_{α}-value is equal to 1.65.

The expected yearly load profiles for heat and electricity are estimated based on the DRY for Oslo climate and a reference year respectively. The HCI and ELCI estimated from the buildings located in Trondheim are applied due to the small difference between the degree days for Trondheim- and Oslo-climate. The load duration profiles are also calculated for both heat and electricity purposes.

Finally, the distribution losses for maximum load and annual energy consumption are included in the analysis for each energy carrier.

8.4 Results

The results are presented as design load profiles divided into heat purposes for every energy carrier and electricity purposes for electricity only. The maximum loads for each scenario are estimated based on the t-quantile analysis. The coincidence factor is given by the design load profiles' shapes, that is, the maximum load for the area is divided by the sum of the maximum load for each building's generalised load profile.

The yearly load profiles and the load duration profiles for every energy carrier are presented, as well as the expected annual energy demand divided into the different energy carriers.

Design load profiles for heat and electricity demand

The load losses have not been differentiated based on the load level throughout the day. The maximum load losses are added to the specific load indicators with the percentages tabulated in Table 8.2.

The design heat load profiles for the development area are shown in Figure 8.1 for all energy carriers. The maximum heat load will occur at 8 a.m. during weekdays with a heat coincidence factor of 0.975. This is the heat coincidence factor for the generalised load profiles and not the real heat coincidence factor for the development area.

The heat load profiles supplied by either electricity or natural gas coincide because the maximum load losses only vary by one per cent.

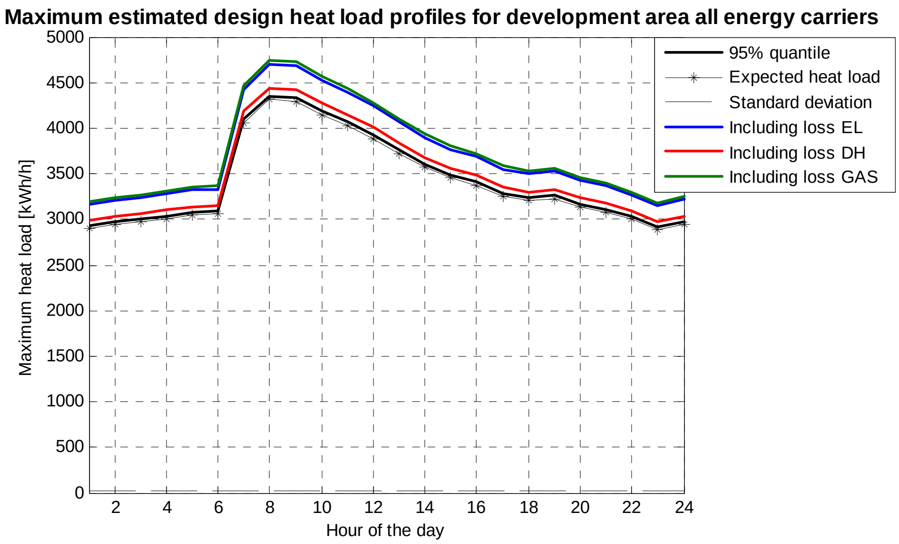

Figure 8.1 Maximum estimated design heat load profiles for all energy carriers for the fictitious development area analysed.

The maximum estimated heat load for the electricity, district heating and natural gas distribution systems are presented in Table 8.3.

Table 8.3 Maximum estimated heat load for the various energy carriers supplying the fictitious development area.

Energy carrier	**EL**	**DH**	**GAS**
Maximum heat load	4.70 MWh/h	4.44 MWh/h	4.75 MWh/h

The design electricity load profile for electricity for the development area is shown in Figure 8.2. The maximum electricity load will occur at 13 p.m. for weekdays with an electricity coincidence factor of 0.899. The maximum electricity load is estimated to 1.54 MWh/h, which constitutes for approximately 25% of the total load demand for the development area.

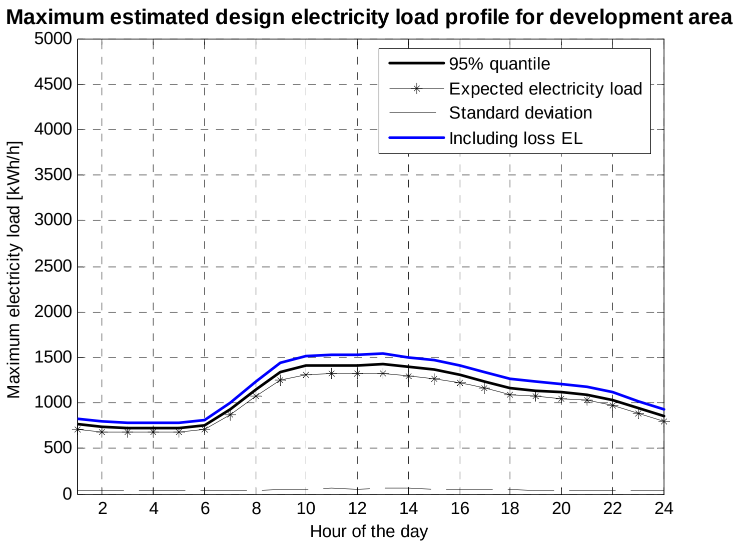

Figure 8.2 Maximum estimated design electricity load profile for the fictitious development area analysed.

The standard deviation is higher for electricity load estimations due to the nature of the electricity load model. The residuals are more scattered when continuous probability distribution analysis rather than regression analysis has been applied. The division of day types is also more challenging for the electricity load model because the climatic influence is diminished by using seasonal load profiles. However, the aggregated standard deviations for both heat and electricity design load profiles decrease relatively as the number of buildings analysed increases.

Yearly load profiles and duration profiles

The annual heat and electricity losses are added to the HCIs and ELCIs indicators respectively with the percentages tabulated in Table 8.2. The yearly load profiles are shown in Figure 8.3 and Figure 8.4 for heat and electricity demand supplied by district heat and electricity respectively. The load duration profiles are included in both figures.

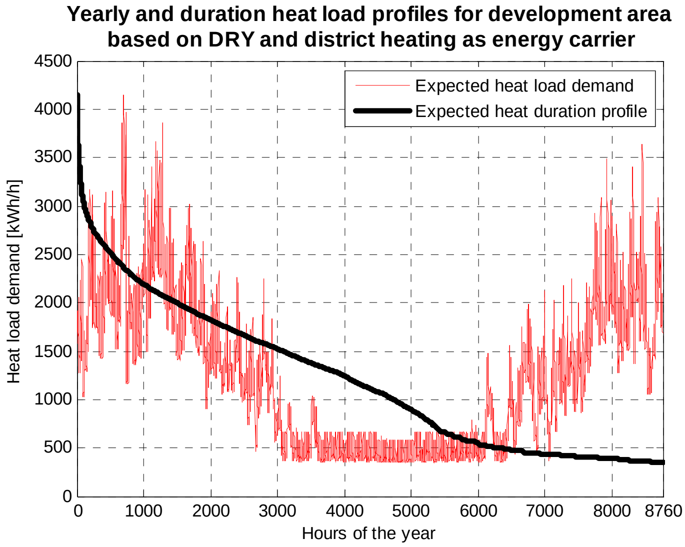

Figure 8.3 Yearly and duration heat load profiles for the selected development area. The profiles are based on the DRY for Oslo climate and district heating as the energy carrier.

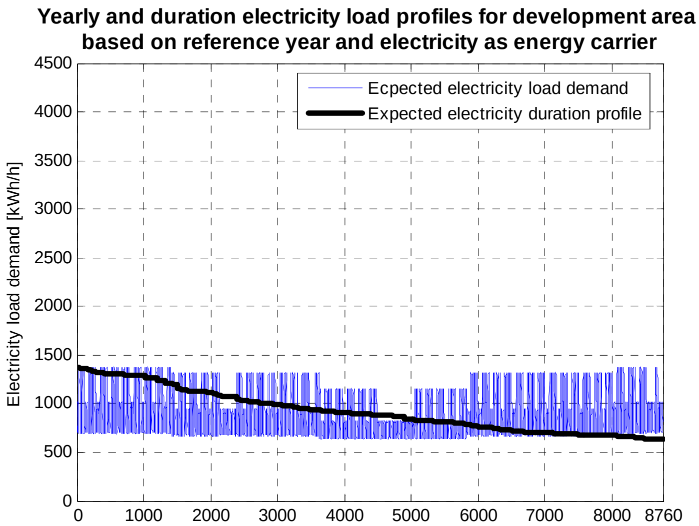

Figure 8.4 Yearly and duration electricity load profiles for the selected development area. The profiles are based on a reference year, with electricity as the energy carrier.

The yearly expected energy demand for the selected development area for various energy carriers is presented in Table 8.4 along with the utilisation times. The annual energy losses are included as fixed values, which caused the normalised utilisation times to be equal.

The minimum daily mean temperature for the DRY for Oslo climate is -15°C. The design temperature for Trondheim is -19°C, and as a consequence, the utilisation times presented in Table 8.4 are different.

Table 8.4 Yearly energy demand and utilisation times from the analysis of the fictitious development area.

Purpose	**Heat**			**Electricity**
Energy carrier	**EL**	**DH**	**GAS**	**EL**
Yearly energy demand [MWh/yr]	9935	10597	9746	8099
Normalised utilisation time[1] [h/yr]	2552	2552	2552	5917
Utilisation time maximum load[2] [h/yr]	2114	2387	2052	5259

1. Annual expected energy demand divided on maximum load for DRY and reference year.
2. Annual expected energy demand divided on maximum design load.

The load losses throughout the year are based on different criteria for various energy carriers. The electricity load losses are higher at high load hours than low load hours, causing the load losses to be higher in the winter season than in the summer season. This phenomenon is the opposite for district heating, resulting in small load losses during the winter and much higher load losses during the summer when the heat demand is very low. The difference in load losses will influence the load duration profiles based on the kind of energy carrier that is eventually chosen for the development area.

This phenomenon is illustrated in Figure 8.5 based on the heat demand being supplied by electricity or district heating. The electricity duration load profile is included in the figure as well as the total duration load profile for the development area based on electricity supply alone.

Heat losses from district heating systems are assumed to be linear with a maximum load loss of 2% and an annual heat loss of about 11%. This resulted in a load loss during minimum output rate during the summer of approximately 30%.

The electricity losses for the heat supply are calculated based on Equation 6.31. The k-value has been assumed to be constant for the development area's grid throughout the year (Feilberg, 2002). The annual electricity loss for heat purposes is set to 5% and the k-value was then estimated to 3.34E-5 [1/kW]. This resulted in a maximum load loss of approximately 11% and a minimum load loss of about 1%.

The annual electricity loss for total electricity supply to the planning area is estimated to 4.3%, with a similar maximum load loss of approximately 11%. The maximum estimated load for the development area including distribution losses for electricity supply alone based on the DRY was 5.5 MWh/h. The total estimated design load for the planning area based on electricity was 6.2 MWh/h, which is about 11% higher. The same numbers for mixed energy distribution systems based on district heating or natural gas were 5.9 MWh/h and 6.3 MWh/h respectively.

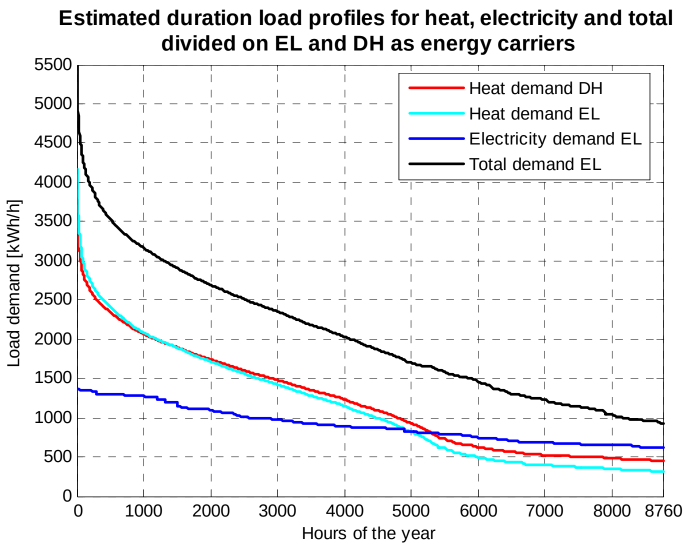

Figure 8.5 Estimated duration load profiles for heat, electricity and total load demands divided into district heating and electricity as energy carriers.

The difference in the high heat load demand based on district heating or electricity for the development area is emphasised in Figure 8.6. The maximum estimated heat load demands for DRY Oslo were 3.79 MWh/h for district heating supply and 4.16 MWh/h for electricity supply.

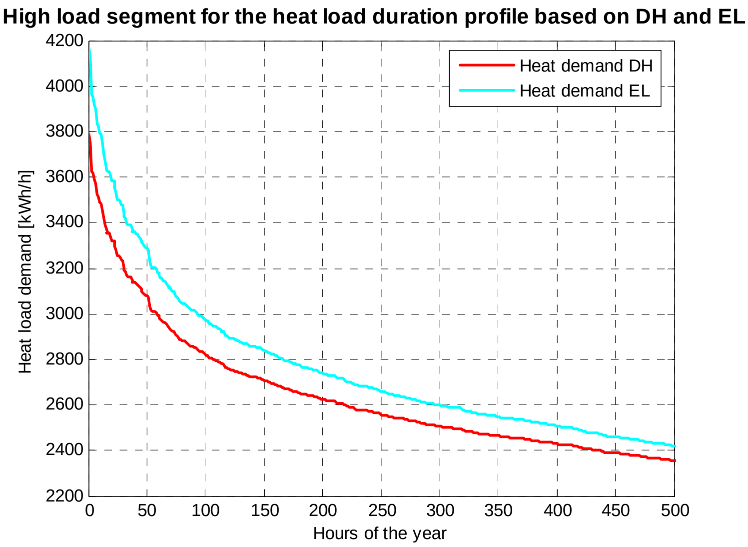

Figure 8.6 High load segment for the heat load duration profile based on district heating or electricity as the energy carrier.

9 Conclusions and recommendations for further work

9.1 Concluding summary

The SEDS project had as one of its main objectives energy planning for mixed energy distribution systems. This involved load modelling of buildings divided into different purposes, such as heat (space heating, ventilation heating and hot tap water) and electricity (lighting, pumps and fans, electrical appliances, and others). The main findings of this thesis have been a method for the load modelling of heat and electricity demand in buildings, as well as the load aggregation for a specified planning area. The focus was on conductor- and pipe-based infrastructure, and on electricity, district heating and natural gas as energy carriers. Energy planners need to use this type of load modelling of buildings in order to plan for an optimal energy system in terms of economics, technology and environmental impact.

Three principal methodologies for load and energy estimations in buildings were identified, but the method developed for load modelling of buildings in mixed energy distribution systems was based on statistical analyses alone. This required the collection of a great deal of data. Hourly district heat and electricity data from simultaneously measured buildings were collected from TEV Fjernvarme and BKK Varme, which are the district heating companies in Trondheim and Bergen respectively. The building category division used in this thesis was taken from the Energy Performance of Buildings Directive (EPBD, 2002). The main focus was on single family houses and apartment blocks, as well as office buildings, educational buildings, hospital buildings, and hotels and restaurants as building categories.

The heat load model was based on piece-wise linear regression analyses for every hour of the day for two different day types, weekdays and weekends/holidays. The hourly district heat consumption was divided into temperature-dependent and temperature-independent consumption. The change-point temperature was calculated based on a temperature band with constant beta-values. Linear regression analyses were performed on the temperature-dependent consumption only, whereas the normal distribution was applied to the temperature-independent consumption, which mainly represented hot tap water. The expected values and standard deviations were calculated for every hour of the day and day type for both temperature-dependent and temperature-independent consumption.

The electricity load model was based on continuous probability distributions, such as the normal distribution, the lognormal distribution, and the Student's t distribution. The last distribution showed the best fit for most hours and day types, with the only exception being high load hours for some educational buildings where the lognormal distribution showed the best fit. The Student's t distribution was substituted by the normal distribution when the sample size exceeded 30, which was always the case when the individual buildings' electricity load measurements were analysed. The expected values and standard deviations were calculated for every hour of the day and day type, as well as for every season; winter, spring/fall and summer.

Relative load profiles for all buildings analysed were calculated by dividing the individual load profiles by a baseload. This allowed for comparisons of the heat and electricity load profiles in the same building category. Generalised relative load profiles divided into heat and electricity purposes were developed for single family houses and apartment blocks based on cluster analyses. Generalised relative heat and electricity load profiles were also developed for office buildings, educational buildings, retirement homes and hotels with restaurants. The division of load profiles into different archetypes was augmented by developing two different heat load profiles for educational buildings constructed before and after 1997.

Specific heat and electricity load and energy consumption indicators, in $[W/m^2]$ and $[kWh/m^2 \cdot yr]$ respectively, were calculated for the various building categories that were analysed. The specific load indicators were needed to restore the design load profiles from relative to real values in order to estimate the maximum heat and electricity demand for a specified planning area. The uncertainty was included in a 95% t-quantile analysis. The specific heat consumption indicators (HCI), as well as outdoor temperatures from the constructed Design Reference Year, were used to estimate real yearly heat load profiles, and consequently, heat load duration profiles for each building category. Yearly electricity load profiles were calculated based on seasonal electricity load profiles, as well as specific electricity consumption indicators (ELCI).

The method developed for load aggregation was based on the sum of the real expected values for each building included in the specified planning area, as well as the standard deviations. The maximum load losses and yearly energy losses for the various energy carriers have to be included when planning for design load, yearly and load duration profiles, as well as yearly energy demand for a specified planning area, all divided into heat and electricity purposes. A theoretical case study was undertaken to illustrate how to apply the generalised relative load profiles along with the specific load and energy indicators for the purpose of planning for mixed energy distribution systems.

Load profiles divided into heat and electricity have only been developed for selected building categories and archetypes. However, the method developed for load modelling of buildings is applicable for all building categories, if load data divided into different purposes are available. For the purpose of generalising load profiles, an emphasis must be placed on the building's age, control regime and/or whether the structure has undergone major rehabilitation. The operation of the ventilation systems, for example, has been shown to have a great impact on the heat load profiles.

The specific contributions from this work have been summarized in Chapter 1: Introduction.

9.2 Recommendations for further work

Throughout the work for this project, several ideas have been rejected as being outside of the scope of this thesis, or too time consuming for the purpose of the work. Other ideas were rejected due to the lack of available data. Some of the most important ideas that were not investigated in detail have been identified as recommendations for further work in the field of energy planning in general, and load modelling of buildings in particular.

Collection and analyses of load data

- More data divided into heat and electricity purposes could be collected for the purpose of performing a quantitative analysis. At least 20 to 30 buildings with hourly measurements divided into heat and electricity for each building category should be analysed.
- Aggregated load for limited areas that have data available for district heat and electricity consumption could be collected for the purpose of verification and calibration of the aggregation procedure.
- The increased demand for cooling, especially in service buildings such as office buildings and retail stores, could be investigated. Cooling load profiles for various building categories should then be developed.
- Collection of data from buildings at various locations could be undertaken in order to compare climatic variations and possible correction to the normal climate, i.e. Oslo.
- The influence of other climatic parameters could be investigated, such as hours of sunlight and windspeed, using multiple regression analyses for heat and electricity load modelling.

Future energy consumption development and trends

- An analysis of energy consumption development scenarios could be performed. This is strongly related to changes in the building code regulations and technological development, as well as external factors, such as trends that influence the energy consumption in various building categories.

Develop a software tool

- The presentation requirement from the requirement traceability information model in Chapter 2 was not emphasised in this thesis. The presentation of the data required a product that in itself required a certain resolution and a certain format. A user friendly software tool could be developed to meet these requirements, which would also allow the load models to easily be used for energy planning.

Hybrid models

- Energy simulation programs, in addition to statistical analyses, could be applied to adjust the generalised relative heat and electricity load profiles to an individual building's design and control regime to provide more in-depth analyses.
- Statistical analyses could be integrated with artificial neural networks. Recent literature has shown that integration of statistical analyses and neural networks can improve the models that predict a building's energy use (Karatasou et al., 2006).

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APPENDIX A - LOAD PROFILES FOR ALL BUILDINGS

Load profiles for both heat and electricity purposes for all buildings analysed in this thesis are presented in Appendix A. Only the winter season is presented for the electricity load profiles.

Single family houses and apartment blocks

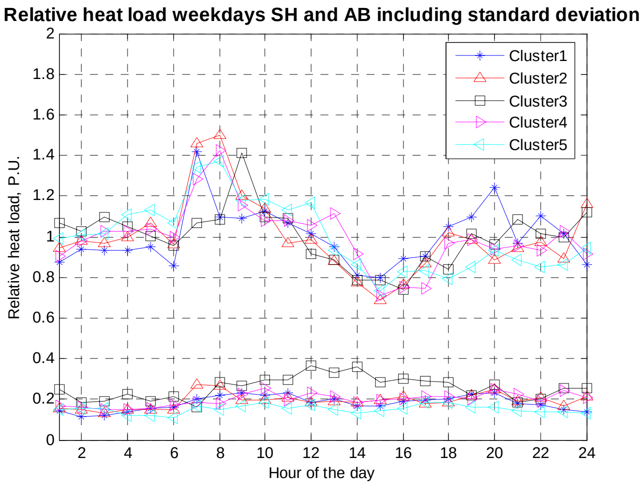

Figure 0.1 Design heat load profiles weekdays for all SH and AB clusters analysed.

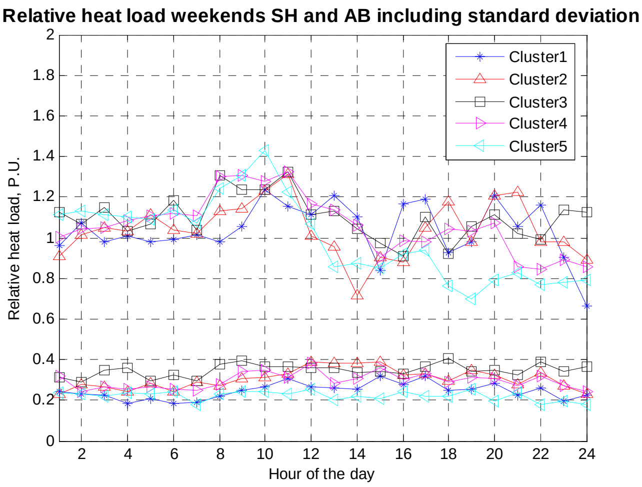

Figure 0.2 Design heat load profiles weekends for all SH and AB clusters analysed.

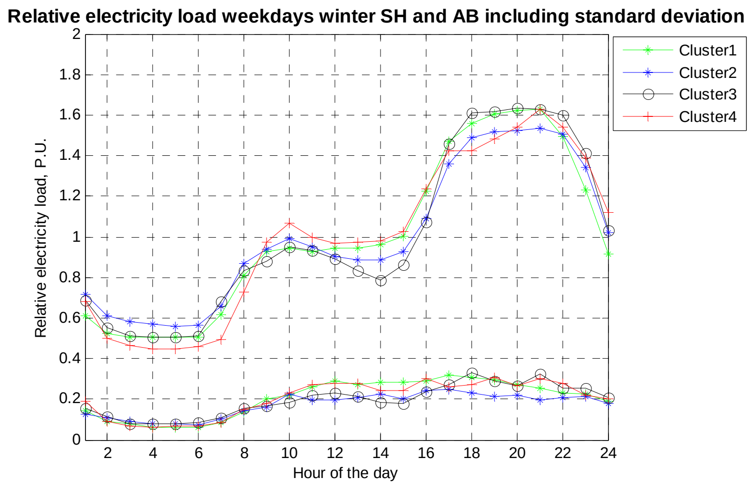

Figure 0.3 Winter season electricity load profiles weekdays for all SH and AB clusters analysed.

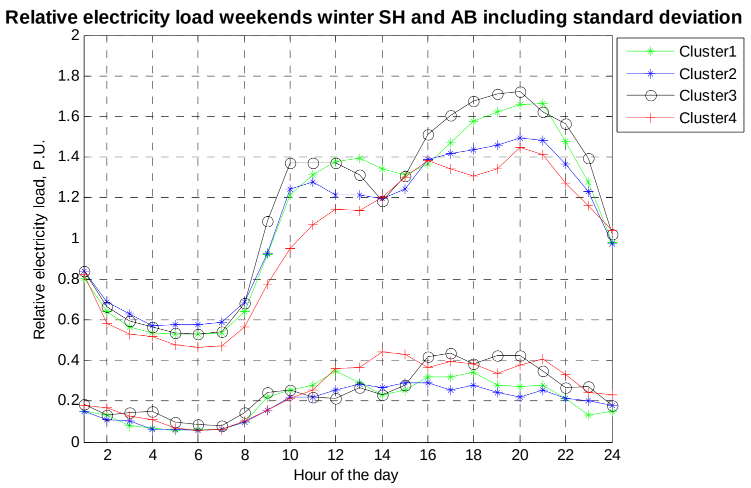

Figure 0.4 Winter season electricity load profiles weekends for all SH and AB clusters analysed

Office buildings

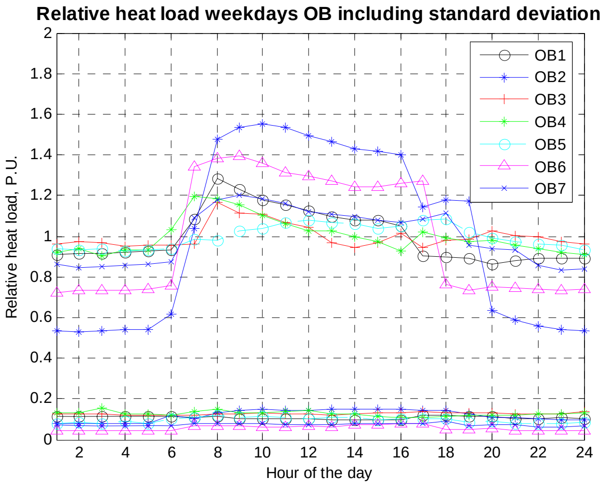

Figure 0.5 Design heat load profiles weekdays for all OB analysed.

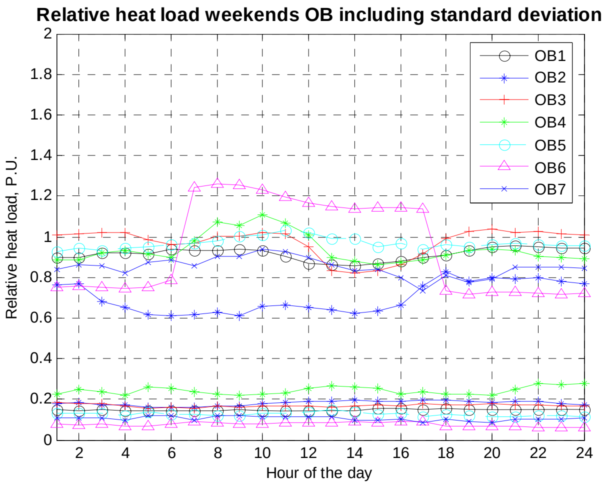

Figure 0.6 Design heat load profiles weekends for all OB analysed.

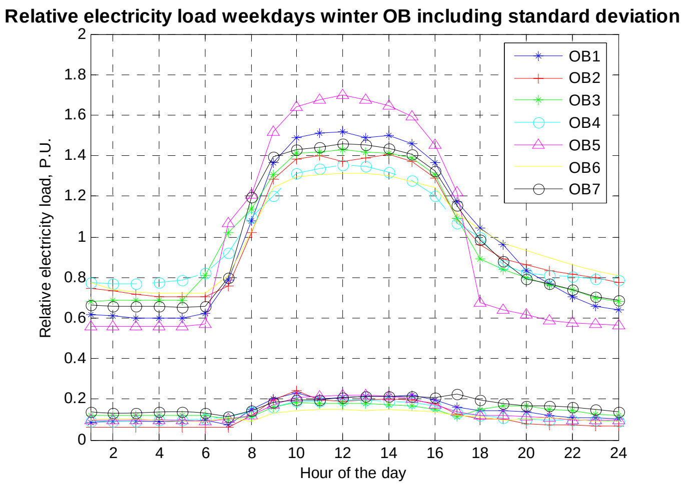

Figure 0.7 Winter season electricity load profiles weekdays for all OB analysed.

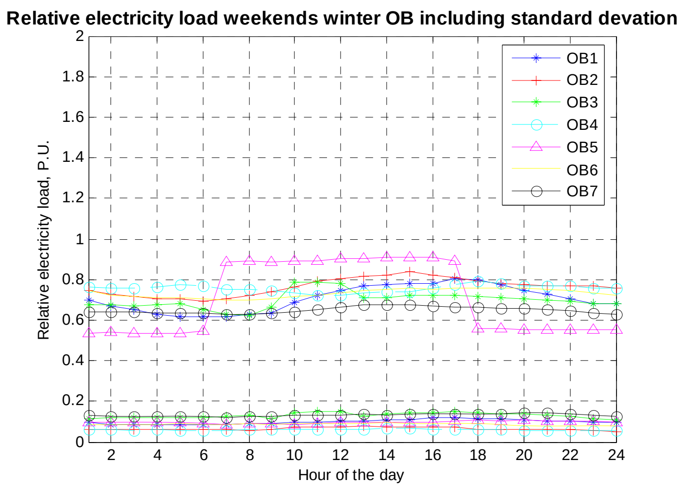

Figure 0.8 Winter season electricity load profiles weekdays for all OB analysed.

Educational buildings

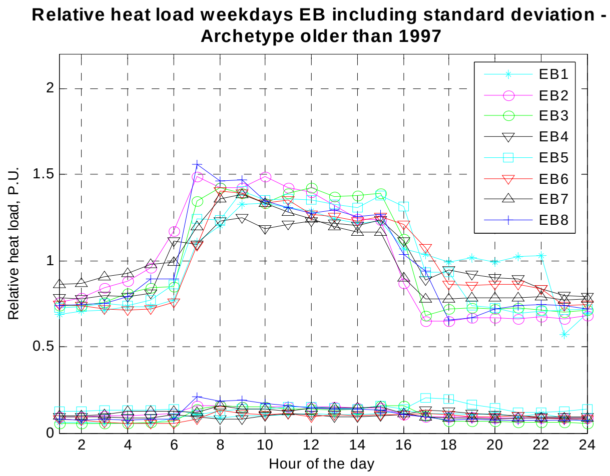

Figure 0.9 Design heat load profile weekdays for all OB analysed within archetype 1.

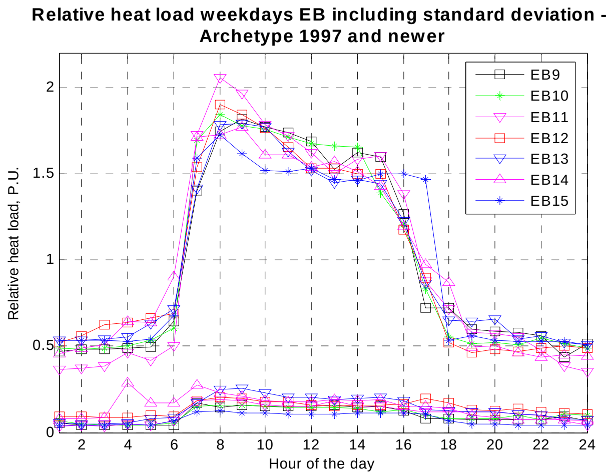

Figure 0.10 Design heat load profile weekdays for all OB analysed within archetype 2.

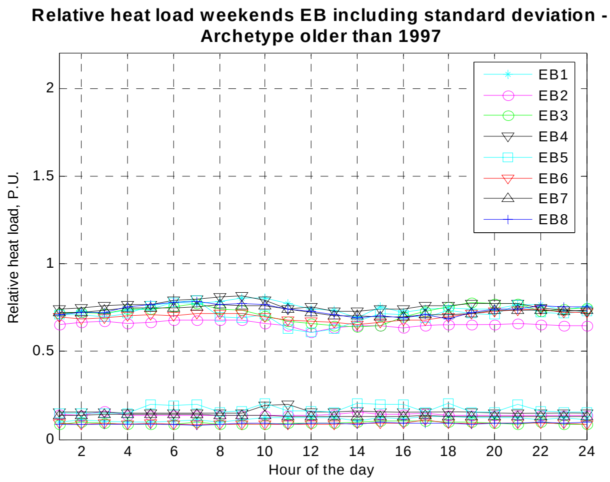

Figure 0.11 Design heat load profile weekends for all OB analysed within archetype 1.

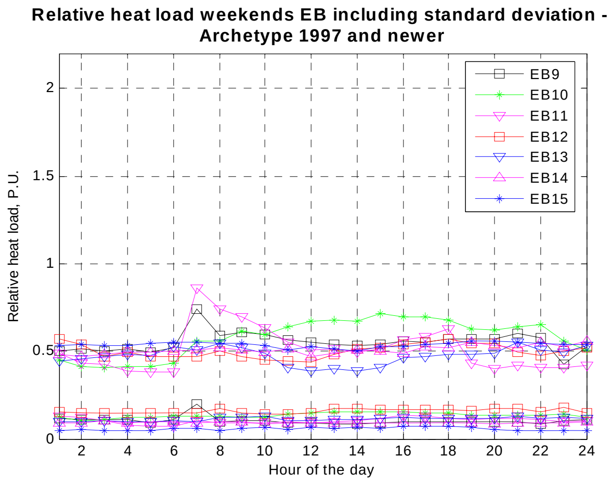

Figure 0.12 Design heat load profile weekends for all OB analysed within archetype 2.

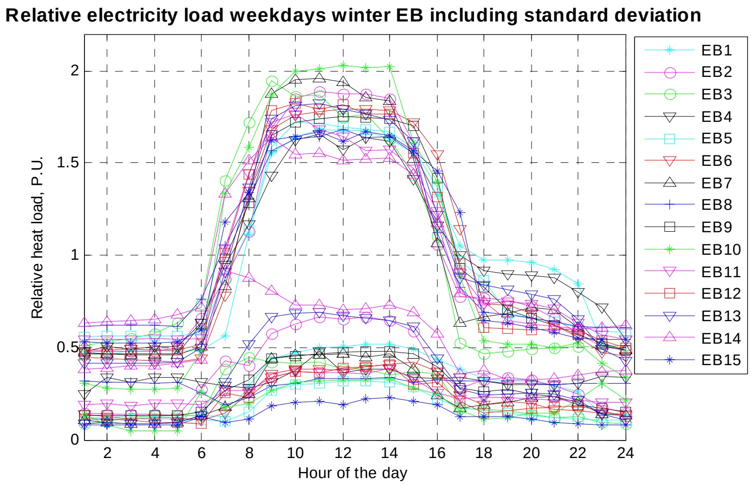

Figure 0.13 Winter season electricity load profiles weekdays for all EB analysed.

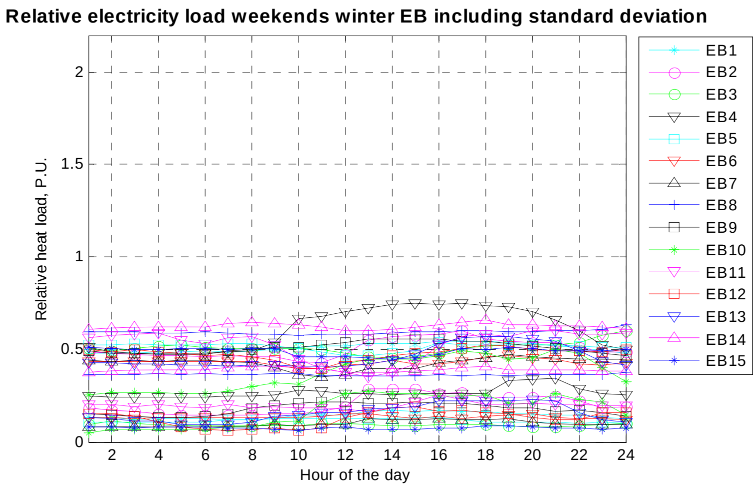

Figure 0.14 Winter season electricity load profiles weekends for all OB analysed.

Hospitals

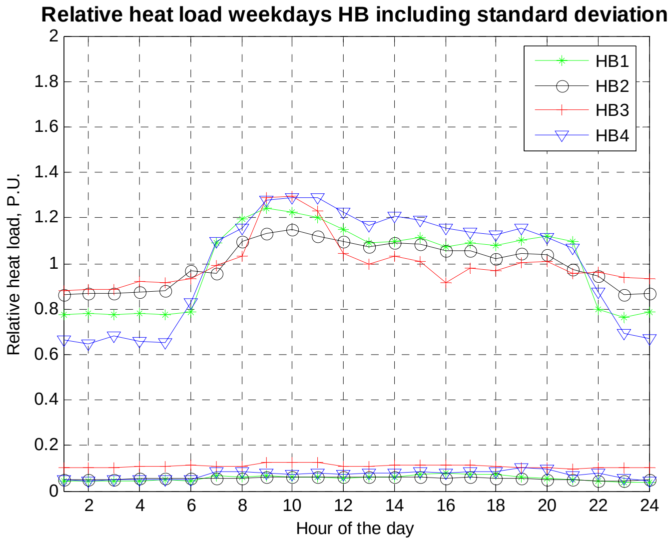

Figure 0.15 Design heat load profiles weekdays for all HB analysed.

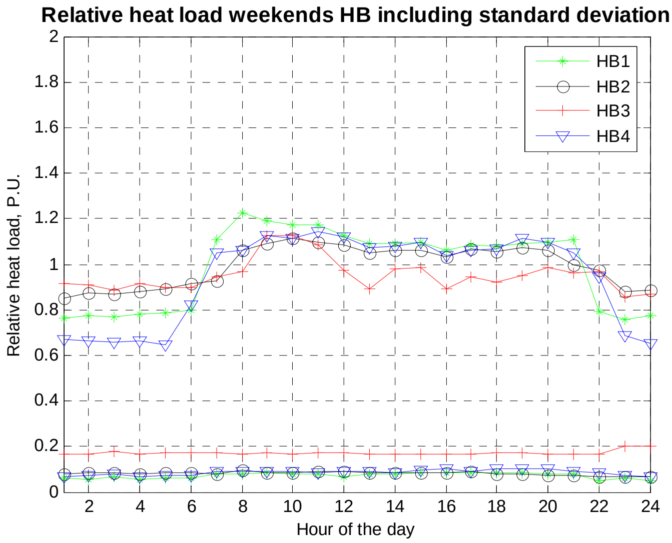

Figure 0.16 Design heat load profiles weekends for all HB analysed.

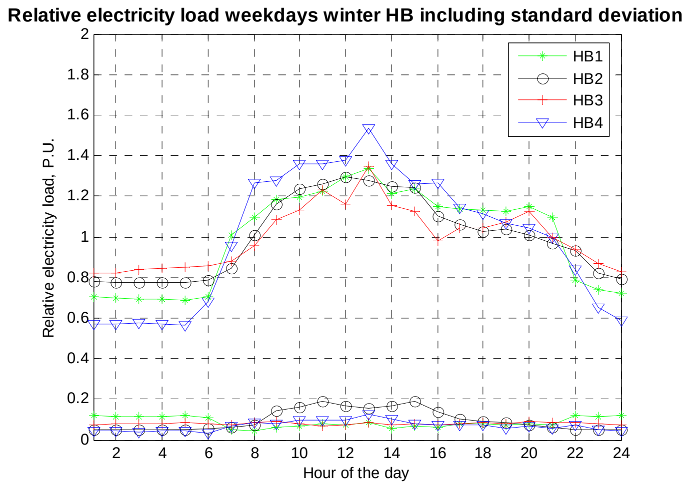

Figure 0.17 Winter season electricity load profiles weekdays for all HB analysed.

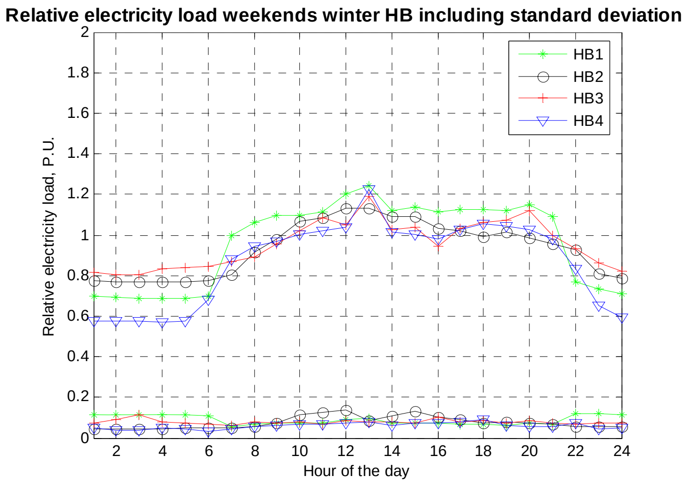

Figure 0.18 Winter season electricity load profiles weekends for all HB analysed.

Hotels and restaurants

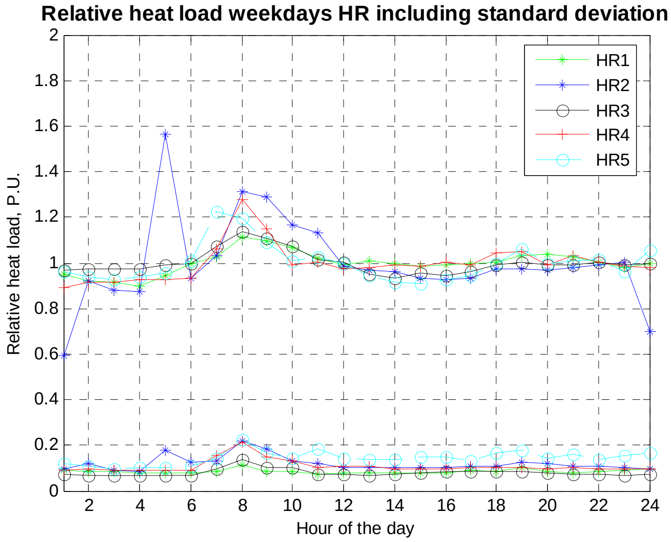

Figure 0.19 Design heat load profiles weekdays for all HR analysed.

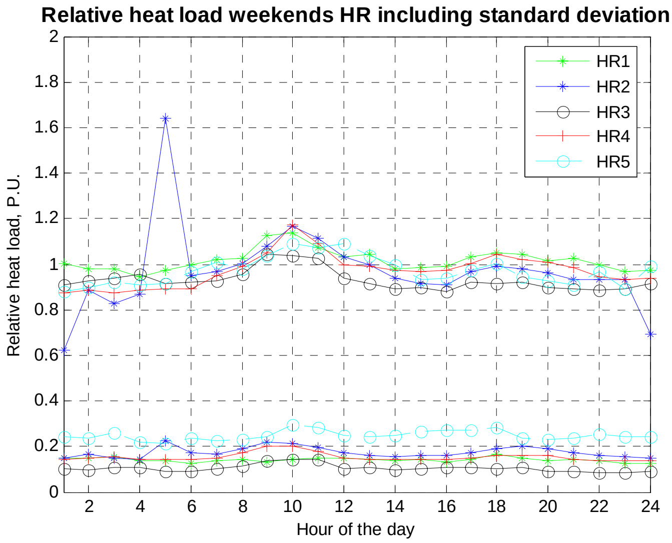

Figure 0.20 Design heat load profiles weekends for all HR analysed.

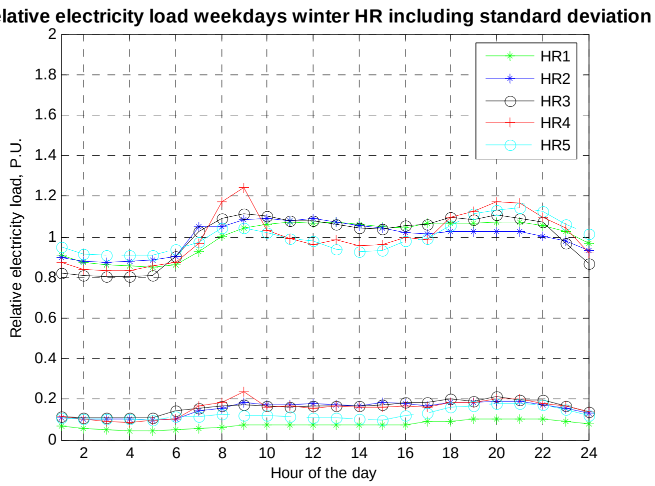

Figure 0.21 Winter season electricity load profiles weekdays for all HR analysed.

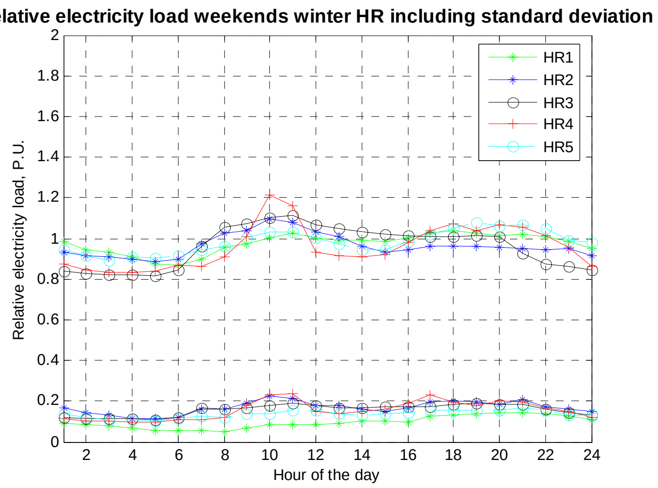

Figure 0.22 Winter season electricity load profiles weekends for all HR analysed.

APPENDIX B - PARAMETERS FOR DIFFERENT BUILDING CATEGORIES

All variables calculated for heat and electricity load profiles including standard deviations and change-point temperatures (CPT) for all building categories analysed in this thesis are presented in Appendix B.

	Single family house and apartment block heat load model									
	Weekdays (CPT = 9,7 degree Celsius)					Weekends (CPT = 10,6 degree Celsius)				
Hour	Alpha	Beta	STD	HTW	HTW STD	Alpha	Beta	STD	HTW	HTW STD
1	0,610	-0,035	0,176	0,215	0,143	0,638	-0,038	0,271	0,163	0,092
2	0,620	-0,037	0,154	0,151	0,097	0,643	-0,042	0,255	0,157	0,084
3	0,632	-0,038	0,151	0,154	0,098	0,650	-0,042	0,270	0,167	0,112
4	0,637	-0,039	0,161	0,169	0,114	0,647	-0,041	0,262	0,161	0,099
5	0,649	-0,039	0,154	0,173	0,096	0,661	-0,041	0,259	0,178	0,103
6	0,678	-0,029	0,164	0,280	0,127	0,672	-0,042	0,254	0,140	0,087
7	0,891	-0,042	0,201	0,280	0,144	0,685	-0,037	0,246	0,182	0,091
8	0,899	-0,040	0,226	0,292	0,175	0,769	-0,042	0,280	0,274	0,145
9	0,822	-0,039	0,219	0,262	0,141	0,829	-0,038	0,312	0,335	0,189
10	0,759	-0,037	0,233	0,281	0,172	0,861	-0,042	0,310	0,328	0,172
11	0,728	-0,034	0,222	0,240	0,153	0,862	-0,040	0,313	0,274	0,186
12	0,704	-0,032	0,238	0,214	0,144	0,768	-0,032	0,335	0,289	0,175
13	0,660	-0,029	0,226	0,209	0,131	0,737	-0,032	0,304	0,247	0,172
14	0,598	-0,023	0,221	0,207	0,144	0,694	-0,027	0,306	0,239	0,142
15	0,568	-0,018	0,203	0,241	0,140	0,668	-0,023	0,330	0,248	0,185
16	0,594	-0,020	0,218	0,264	0,138	0,672	-0,030	0,296	0,217	0,107
17	0,636	-0,021	0,216	0,251	0,145	0,707	-0,034	0,318	0,228	0,134
18	0,672	-0,026	0,215	0,226	0,131	0,686	-0,028	0,299	0,226	0,129
19	0,673	-0,031	0,208	0,254	0,142	0,665	-0,028	0,305	0,273	0,156
20	0,681	-0,031	0,235	0,290	0,165	0,718	-0,036	0,296	0,197	0,101
21	0,644	-0,032	0,185	0,216	0,115	0,652	-0,035	0,269	0,210	0,129
22	0,641	-0,033	0,182	0,212	0,112	0,630	-0,032	0,306	0,231	0,133
23	0,625	-0,033	0,195	0,249	0,150	0,613	-0,032	0,261	0,191	0,102
24	0,635	-0,036	0,196	0,204	0,124	0,591	-0,028	0,257	0,167	0,103

	Single family house and apartment block electricity load model											
	Weekdays						Weekends					
Hour	Winter	Spring/ fall	Summer	Winter STD	Spring/ fall STD	Summer STD	Winter	Spring/ fall	Summer	Winter STD	Spring/ fall STD	Summer STD
1	0,674	0,586	0,507	0,156	0,113	0,123	0,826	0,689	0,574	0,166	0,178	0,178
2	0,548	0,513	0,447	0,101	0,076	0,073	0,643	0,577	0,497	0,135	0,138	0,138
3	0,516	0,505	0,438	0,080	0,069	0,069	0,578	0,534	0,460	0,116	0,097	0,097
4	0,509	0,505	0,435	0,070	0,066	0,065	0,547	0,515	0,442	0,103	0,074	0,074
5	0,505	0,505	0,431	0,072	0,066	0,064	0,530	0,512	0,437	0,073	0,068	0,068
6	0,510	0,537	0,463	0,074	0,079	0,064	0,525	0,510	0,443	0,065	0,066	0,066
7	0,613	0,681	0,570	0,094	0,125	0,114	0,533	0,563	0,497	0,066	0,103	0,103
8	0,810	0,827	0,682	0,147	0,163	0,158	0,644	0,732	0,623	0,112	0,140	0,140
9	0,930	0,888	0,743	0,177	0,189	0,208	0,927	0,967	0,790	0,195	0,195	0,195
10	0,988	0,872	0,748	0,217	0,203	0,230	1,195	1,131	0,909	0,235	0,269	0,269
11	0,952	0,836	0,737	0,237	0,207	0,219	1,258	1,108	0,913	0,245	0,284	0,284
12	0,928	0,832	0,710	0,252	0,208	0,216	1,276	1,084	0,887	0,301	0,316	0,316
13	0,909	0,820	0,702	0,244	0,215	0,204	1,265	1,059	0,871	0,302	0,322	0,322
14	0,904	0,815	0,709	0,237	0,217	0,208	1,231	1,069	0,880	0,306	0,303	0,303
15	0,956	0,921	0,820	0,230	0,248	0,245	1,292	1,103	0,931	0,322	0,341	0,341
16	1,155	1,075	0,926	0,270	0,275	0,258	1,412	1,162	0,971	0,350	0,362	0,362
17	1,427	1,206	1,014	0,278	0,296	0,345	1,460	1,217	0,995	0,359	0,363	0,363
18	1,521	1,233	1,052	0,287	0,318	0,381	1,500	1,273	1,047	0,349	0,370	0,370
19	1,556	1,308	1,080	0,280	0,324	0,392	1,533	1,368	1,063	0,327	0,350	0,350
20	1,582	1,396	1,130	0,257	0,293	0,372	1,581	1,435	1,089	0,334	0,382	0,382
21	1,607	1,417	1,142	0,273	0,299	0,376	1,545	1,410	1,060	0,327	0,374	0,374
22	1,536	1,323	1,066	0,244	0,260	0,323	1,419	1,275	0,983	0,260	0,325	0,325
23	1,344	1,109	0,923	0,228	0,238	0,294	1,265	1,059	0,855	0,218	0,269	0,269
24	1,021	0,825	0,696	0,194	0,212	0,250	1,004	0,813	0,683	0,187	0,213	0,213

	Office building heat load model									
	Weekdays (CPT = 11,0 degree Celsius)					Weekends (CPT = 11,6 degree Celsius)				
Hour	Alpha	Beta	STD	HTW	HTW STD	Alpha	Beta	STD	HTW	HTW STD
1	0,385	-0,024	0,098	0,070	0,057	0,407	-0,025	0,159	0,073	0,057
2	0,389	-0,024	0,097	0,073	0,059	0,412	-0,025	0,162	0,077	0,062
3	0,393	-0,023	0,101	0,082	0,064	0,410	-0,025	0,158	0,073	0,058
4	0,396	-0,023	0,096	0,083	0,061	0,409	-0,025	0,150	0,067	0,051
5	0,398	-0,023	0,093	0,080	0,059	0,408	-0,025	0,159	0,086	0,065
6	0,418	-0,024	0,102	0,093	0,066	0,409	-0,025	0,159	0,085	0,063
7	0,513	-0,031	0,106	0,098	0,075	0,409	-0,025	0,151	0,068	0,056
8	0,586	-0,034	0,115	0,121	0,092	0,417	-0,026	0,153	0,074	0,060
9	0,570	-0,035	0,111	0,112	0,081	0,408	-0,027	0,151	0,065	0,051
10	0,549	-0,035	0,113	0,098	0,074	0,414	-0,028	0,154	0,067	0,056
11	0,527	-0,035	0,111	0,092	0,074	0,403	-0,028	0,157	0,066	0,056
12	0,508	-0,035	0,111	0,083	0,063	0,385	-0,027	0,164	0,070	0,059
13	0,491	-0,034	0,108	0,076	0,061	0,367	-0,025	0,168	0,070	0,057
14	0,480	-0,034	0,111	0,076	0,060	0,362	-0,025	0,165	0,065	0,056
15	0,470	-0,034	0,109	0,069	0,052	0,358	-0,025	0,164	0,060	0,050
16	0,463	-0,034	0,110	0,063	0,046	0,356	-0,026	0,158	0,050	0,039
17	0,430	-0,033	0,111	0,056	0,044	0,366	-0,026	0,159	0,049	0,040
18	0,413	-0,031	0,111	0,059	0,049	0,375	-0,028	0,157	0,048	0,039
19	0,403	-0,029	0,104	0,055	0,045	0,383	-0,027	0,154	0,045	0,040
20	0,375	-0,027	0,102	0,060	0,049	0,392	-0,027	0,152	0,044	0,037
21	0,374	-0,026	0,097	0,054	0,044	0,398	-0,027	0,160	0,050	0,044
22	0,375	-0,025	0,096	0,057	0,046	0,404	-0,027	0,166	0,058	0,055
23	0,376	-0,024	0,096	0,060	0,046	0,407	-0,026	0,163	0,059	0,055
24	0,379	-0,024	0,100	0,067	0,052	0,410	-0,026	0,163	0,063	0,057

	Office building electricity load model											
	Weekdays						Weekends					
Hour	Winter	Spring/ fall	Summer	Winter STD	Spring/ fall STD	Summer STD	Winter	Spring/ fall	Summer	Winter STD	Spring/ fall STD	Summer STD
1	0,689	0,688	0,697	0,101	0,115	0,152	0,711	0,701	0,709	0,225	0,270	0,194
2	0,680	0,678	0,686	0,102	0,116	0,147	0,699	0,690	0,701	0,220	0,267	0,195
3	0,674	0,675	0,680	0,102	0,115	0,140	0,692	0,694	0,697	0,220	0,367	0,193
4	0,672	0,673	0,675	0,102	0,117	0,153	0,686	0,679	0,691	0,219	0,259	0,199
5	0,673	0,674	0,673	0,101	0,117	0,148	0,686	0,676	0,689	0,218	0,257	0,196
6	0,701	0,702	0,680	0,101	0,123	0,157	0,678	0,671	0,686	0,216	0,254	0,190
7	0,880	0,876	0,844	0,099	0,107	0,129	0,671	0,664	0,679	0,219	0,262	0,189
8	1,109	1,103	1,041	0,127	0,145	0,165	0,676	0,677	0,681	0,224	0,275	0,190
9	1,330	1,321	1,209	0,174	0,196	0,206	0,688	0,686	0,684	0,222	0,285	0,190
10	1,422	1,403	1,265	0,201	0,206	0,209	0,720	0,716	0,692	0,245	0,284	0,193
11	1,442	1,421	1,286	0,191	0,208	0,219	0,733	0,729	0,700	0,245	0,294	0,193
12	1,448	1,428	1,301	0,193	0,215	0,229	0,742	0,741	0,703	0,249	0,302	0,197
13	1,441	1,426	1,299	0,196	0,212	0,236	0,741	0,749	0,706	0,245	0,307	0,200
14	1,432	1,420	1,283	0,196	0,213	0,244	0,747	0,753	0,707	0,252	0,309	0,203
15	1,396	1,385	1,250	0,190	0,208	0,245	0,751	0,756	0,708	0,254	0,310	0,203
16	1,312	1,299	1,159	0,176	0,196	0,247	0,752	0,754	0,706	0,256	0,313	0,207
17	1,131	1,126	1,016	0,150	0,175	0,238	0,755	0,754	0,711	0,256	0,320	0,207
18	0,943	0,947	0,853	0,139	0,169	0,242	0,754	0,745	0,707	0,249	0,308	0,202
19	0,864	0,871	0,792	0,134	0,162	0,244	0,744	0,738	0,701	0,240	0,299	0,201
20	0,809	0,806	0,761	0,127	0,145	0,204	0,735	0,729	0,699	0,240	0,291	0,198
21	0,775	0,774	0,746	0,120	0,139	0,193	0,728	0,721	0,698	0,234	0,278	0,198
22	0,748	0,746	0,732	0,115	0,133	0,184	0,721	0,714	0,698	0,227	0,273	0,198
23	0,722	0,719	0,721	0,107	0,123	0,168	0,710	0,706	0,698	0,218	0,267	0,196
24	0,706	0,704	0,712	0,103	0,121	0,160	0,704	0,700	0,697	0,213	0,262	0,191

	Educational building heat load model Archetype 1									
	Weekdays (CPT = 11,4 degree Celsius)					Weekends (CPT = 13,7 degree Celsius)				
Hour	Alpha	Beta	STD	HTW	HTW STD	Alpha	Beta	STD	HTW	HTW STD
1	0,357	-0,021	0,089	0,091	0,053	0,349	-0,019	0,121	0,065	0,031
2	0,361	-0,021	0,088	0,101	0,053	0,351	-0,019	0,123	0,082	0,031
3	0,368	-0,022	0,089	0,099	0,054	0,354	-0,019	0,127	0,077	0,039
4	0,379	-0,022	0,090	0,098	0,054	0,357	-0,020	0,121	0,074	0,032
5	0,397	-0,023	0,092	0,097	0,053	0,359	-0,020	0,128	0,081	0,039
6	0,445	-0,025	0,100	0,102	0,058	0,364	-0,020	0,127	0,079	0,039
7	0,609	-0,034	0,132	0,129	0,076	0,366	-0,021	0,130	0,086	0,044
8	0,658	-0,036	0,138	0,161	0,093	0,363	-0,020	0,121	0,070	0,029
9	0,656	-0,038	0,137	0,144	0,081	0,358	-0,021	0,123	0,070	0,029
10	0,633	-0,037	0,134	0,137	0,077	0,348	-0,021	0,139	0,077	0,040
11	0,619	-0,037	0,133	0,123	0,069	0,335	-0,020	0,131	0,069	0,032
12	0,605	-0,037	0,133	0,120	0,065	0,326	-0,019	0,124	0,062	0,027
13	0,581	-0,037	0,129	0,114	0,065	0,322	-0,019	0,125	0,059	0,023
14	0,567	-0,036	0,129	0,110	0,060	0,319	-0,019	0,133	0,064	0,030
15	0,573	-0,037	0,136	0,113	0,062	0,321	-0,020	0,135	0,063	0,031
16	0,490	-0,031	0,123	0,099	0,055	0,322	-0,020	0,133	0,061	0,028
17	0,403	-0,025	0,122	0,085	0,055	0,328	-0,020	0,130	0,062	0,030
18	0,374	-0,023	0,115	0,083	0,048	0,333	-0,020	0,134	0,062	0,031
19	0,366	-0,023	0,104	0,078	0,043	0,339	-0,020	0,125	0,059	0,026
20	0,367	-0,023	0,099	0,085	0,051	0,343	-0,020	0,124	0,058	0,026
21	0,369	-0,023	0,092	0,082	0,049	0,349	-0,021	0,131	0,065	0,037
22	0,369	-0,022	0,093	0,090	0,054	0,351	-0,020	0,123	0,066	0,039
23	0,336	-0,020	0,089	0,090	0,053	0,350	-0,020	0,122	0,062	0,029
24	0,345	-0,020	0,088	0,087	0,049	0,354	-0,020	0,122	0,063	0,028

	Educational building heat load model Archetype 2									
	Weekdays (CPT = 12,0 degree Celsius)					Weekends (CPT = 13,1 degree Celsius)				
Hour	Alpha	Beta	STD	HTW	HTW STD	Alpha	Beta	STD	HTW	HTW STD
1	0,249	-0,012	0,065	0,090	0,044	0,261	-0,012	0,114	0,094	0,040
2	0,254	-0,013	0,060	0,090	0,041	0,251	-0,012	0,108	0,095	0,037
3	0,263	-0,013	0,059	0,090	0,044	0,247	-0,012	0,108	0,092	0,044
4	0,296	-0,013	0,122	0,111	0,075	0,245	-0,012	0,105	0,091	0,037
5	0,287	-0,014	0,086	0,102	0,055	0,246	-0,012	0,102	0,092	0,039
6	0,337	-0,018	0,093	0,102	0,056	0,248	-0,012	0,106	0,089	0,038
7	0,734	-0,045	0,186	0,124	0,087	0,300	-0,016	0,125	0,089	0,043
8	0,867	-0,051	0,192	0,131	0,073	0,279	-0,015	0,114	0,081	0,036
9	0,849	-0,050	0,186	0,131	0,079	0,277	-0,015	0,110	0,077	0,031
10	0,798	-0,048	0,171	0,112	0,066	0,266	-0,015	0,109	0,072	0,032
11	0,764	-0,047	0,163	0,110	0,063	0,260	-0,014	0,107	0,062	0,029
12	0,723	-0,046	0,158	0,108	0,062	0,255	-0,013	0,110	0,070	0,028
13	0,689	-0,044	0,165	0,113	0,068	0,257	-0,014	0,117	0,067	0,035
14	0,689	-0,045	0,159	0,104	0,059	0,258	-0,014	0,117	0,063	0,025
15	0,669	-0,044	0,160	0,098	0,057	0,262	-0,014	0,119	0,062	0,026
16	0,574	-0,037	0,146	0,084	0,041	0,267	-0,015	0,124	0,062	0,028
17	0,425	-0,028	0,132	0,084	0,043	0,272	-0,015	0,122	0,062	0,028
18	0,317	-0,018	0,118	0,080	0,040	0,277	-0,015	0,120	0,063	0,030
19	0,272	-0,015	0,101	0,077	0,037	0,266	-0,014	0,114	0,064	0,032
20	0,272	-0,015	0,098	0,075	0,037	0,266	-0,014	0,115	0,068	0,033
21	0,264	-0,014	0,096	0,080	0,038	0,272	-0,014	0,119	0,070	0,034
22	0,263	-0,013	0,087	0,078	0,036	0,272	-0,014	0,111	0,066	0,032
23	0,246	-0,012	0,087	0,083	0,046	0,255	-0,013	0,118	0,076	0,040
24	0,246	-0,012	0,077	0,089	0,052	0,263	-0,013	0,112	0,079	0,037

	Educational building electricity load model											
	Weekdays						Weekends					
Hour	Winter	Spring/ fall	Summer	Winter STD	Spring/ fall STD	Summer STD	Winter	Spring/ fall	Summer	Winter STD	Spring/ fall STD	Summer STD
1	0,492	0,411	0,359	0,183	0,137	0,153	0,488	0,409	0,345	0,190	0,142	0,147
2	0,494	0,410	0,379	0,191	0,135	0,160	0,486	0,407	0,347	0,189	0,146	0,144
3	0,497	0,415	0,374	0,187	0,143	0,159	0,487	0,413	0,342	0,187	0,155	0,141
4	0,498	0,413	0,366	0,190	0,139	0,159	0,486	0,405	0,335	0,187	0,142	0,141
5	0,500	0,412	0,353	0,187	0,143	0,160	0,483	0,401	0,322	0,183	0,145	0,142
6	0,539	0,438	0,349	0,190	0,166	0,162	0,480	0,395	0,312	0,183	0,146	0,139
7	0,712	0,603	0,442	0,228	0,220	0,192	0,485	0,386	0,307	0,187	0,146	0,137
8	0,908	0,791	0,580	0,256	0,225	0,231	0,487	0,378	0,311	0,190	0,145	0,137
9	1,111	0,999	0,693	0,323	0,275	0,320	0,485	0,376	0,317	0,194	0,148	0,139
10	1,148	1,064	0,732	0,342	0,297	0,355	0,476	0,380	0,325	0,198	0,153	0,145
11	1,158	1,079	0,745	0,363	0,305	0,365	0,474	0,390	0,330	0,202	0,160	0,148
12	1,148	1,071	0,743	0,353	0,302	0,358	0,483	0,400	0,333	0,208	0,166	0,150
13	1,146	1,078	0,741	0,358	0,310	0,356	0,493	0,412	0,336	0,218	0,175	0,153
14	1,134	1,064	0,732	0,358	0,306	0,350	0,504	0,417	0,337	0,220	0,179	0,154
15	1,056	0,984	0,690	0,338	0,286	0,320	0,511	0,416	0,334	0,223	0,180	0,153
16	0,895	0,816	0,602	0,296	0,249	0,254	0,534	0,415	0,331	0,226	0,173	0,151
17	0,716	0,619	0,466	0,257	0,222	0,212	0,548	0,417	0,328	0,224	0,176	0,147
18	0,663	0,547	0,396	0,249	0,211	0,186	0,550	0,416	0,327	0,220	0,177	0,147
19	0,644	0,535	0,387	0,243	0,209	0,189	0,545	0,421	0,327	0,220	0,179	0,153
20	0,637	0,533	0,385	0,239	0,209	0,188	0,540	0,425	0,326	0,219	0,183	0,152
21	0,621	0,519	0,377	0,235	0,200	0,182	0,535	0,426	0,324	0,222	0,178	0,150
22	0,585	0,488	0,365	0,220	0,187	0,173	0,521	0,423	0,327	0,208	0,170	0,151
23	0,529	0,439	0,348	0,204	0,166	0,162	0,504	0,413	0,325	0,200	0,161	0,149
24	0,503	0,420	0,350	0,195	0,149	0,153	0,499	0,408	0,333	0,195	0,151	0,144

	Hospital building heat load model									
	Weekdays (CPT = 11,8 degree Celsius)					Weekends (CPT = 13,2 degree Celsius)				
Hour	Alpha	Beta	STD	HTW	HTW STD	Alpha	Beta	STD	HTW	HTW STD
1	0,409	-0,020	0,066	0,114	0,062	0,412	-0,020	0,103	0,092	0,047
2	0,414	-0,020	0,066	0,122	0,064	0,416	-0,021	0,105	0,107	0,045
3	0,421	-0,020	0,066	0,121	0,061	0,419	-0,020	0,111	0,097	0,046
4	0,423	-0,020	0,069	0,138	0,069	0,421	-0,021	0,103	0,106	0,042
5	0,422	-0,020	0,069	0,140	0,070	0,422	-0,020	0,107	0,111	0,047
6	0,455	-0,022	0,071	0,140	0,069	0,445	-0,022	0,107	0,118	0,047
7	0,535	-0,026	0,082	0,157	0,066	0,522	-0,026	0,112	0,125	0,046
8	0,587	-0,028	0,080	0,185	0,076	0,564	-0,027	0,114	0,139	0,052
9	0,660	-0,030	0,088	0,228	0,064	0,586	-0,029	0,113	0,171	0,051
10	0,639	-0,032	0,086	0,202	0,062	0,573	-0,029	0,111	0,143	0,047
11	0,629	-0,031	0,084	0,191	0,052	0,567	-0,029	0,113	0,160	0,048
12	0,568	-0,030	0,078	0,159	0,046	0,536	-0,028	0,113	0,154	0,051
13	0,526	-0,029	0,080	0,127	0,041	0,496	-0,028	0,111	0,107	0,036
14	0,549	-0,029	0,083	0,150	0,045	0,515	-0,028	0,111	0,117	0,039
15	0,543	-0,029	0,085	0,155	0,043	0,515	-0,029	0,113	0,129	0,037
16	0,491	-0,029	0,086	0,106	0,045	0,470	-0,028	0,116	0,090	0,042
17	0,506	-0,029	0,085	0,117	0,047	0,495	-0,029	0,114	0,103	0,035
18	0,489	-0,029	0,084	0,100	0,049	0,481	-0,029	0,115	0,084	0,037
19	0,513	-0,030	0,083	0,108	0,046	0,505	-0,029	0,116	0,095	0,036
20	0,526	-0,029	0,081	0,124	0,048	0,526	-0,028	0,113	0,112	0,038
21	0,505	-0,027	0,069	0,096	0,038	0,508	-0,027	0,109	0,092	0,041
22	0,460	-0,023	0,070	0,116	0,053	0,463	-0,024	0,103	0,083	0,038
23	0,405	-0,022	0,065	0,098	0,047	0,407	-0,020	0,116	0,103	0,065
24	0,410	-0,021	0,063	0,091	0,038	0,411	-0,020	0,114	0,099	0,052

	Hospital building electricity load model											
	Weekdays						Weekends					
Hour	Winter	Spring/ fall	Summer	Winter STD	Spring/ fall STD	Summer STD	Winter	Spring/ fall	Summer	Winter STD	Spring/ fall STD	Summer STD
1	0,719	0,675	0,639	0,076	0,058	0,043	0,717	0,672	0,641	0,076	0,055	0,047
2	0,717	0,670	0,634	0,078	0,059	0,042	0,711	0,667	0,634	0,078	0,057	0,044
3	0,720	0,671	0,635	0,078	0,065	0,044	0,709	0,679	0,633	0,085	0,109	0,044
4	0,721	0,673	0,631	0,079	0,063	0,046	0,715	0,669	0,628	0,077	0,062	0,042
5	0,720	0,669	0,619	0,080	0,063	0,044	0,717	0,666	0,618	0,074	0,064	0,042
6	0,756	0,690	0,629	0,076	0,078	0,050	0,751	0,687	0,630	0,070	0,078	0,050
7	0,922	0,850	0,785	0,063	0,092	0,084	0,888	0,817	0,747	0,055	0,083	0,076
8	1,082	1,009	0,948	0,073	0,091	0,066	0,954	0,898	0,838	0,064	0,076	0,049
9	1,177	1,100	1,025	0,099	0,109	0,080	1,001	0,942	0,884	0,071	0,079	0,049
10	1,231	1,149	1,069	0,107	0,112	0,088	1,046	0,979	0,922	0,085	0,080	0,050
11	1,270	1,197	1,124	0,118	0,117	0,094	1,076	1,018	0,961	0,087	0,088	0,059
12	1,282	1,209	1,137	0,109	0,114	0,095	1,106	1,044	0,981	0,100	0,090	0,069
13	1,373	1,293	1,210	0,116	0,122	0,109	1,198	1,135	1,066	0,085	0,092	0,076
14	1,244	1,167	1,095	0,110	0,108	0,091	1,063	1,004	0,943	0,082	0,081	0,052
15	1,216	1,141	1,083	0,116	0,112	0,091	1,068	1,008	0,959	0,093	0,090	0,063
16	1,124	1,034	0,978	0,091	0,094	0,070	1,018	0,940	0,885	0,089	0,079	0,050
17	1,097	1,012	0,950	0,085	0,081	0,058	1,052	0,965	0,906	0,079	0,076	0,048
18	1,078	0,988	0,925	0,082	0,082	0,051	1,058	0,972	0,908	0,080	0,085	0,059
19	1,076	0,993	0,919	0,073	0,077	0,049	1,061	0,978	0,904	0,068	0,077	0,049
20	1,083	1,006	0,934	0,079	0,079	0,049	1,071	0,999	0,924	0,073	0,077	0,049
21	1,013	0,950	0,880	0,070	0,080	0,045	1,006	0,940	0,870	0,066	0,079	0,045
22	0,875	0,844	0,793	0,085	0,093	0,069	0,865	0,838	0,783	0,084	0,093	0,069
23	0,771	0,728	0,684	0,079	0,066	0,048	0,763	0,728	0,680	0,078	0,068	0,047
24	0,734	0,690	0,649	0,077	0,059	0,045	0,729	0,688	0,645	0,078	0,059	0,044

	Hotel and restaurant building heat load model									
	Weekdays (CPT = 10,5 degree Celsius)					Weekends (CPT = 12,6 degree Celsius)				
Hour	Alpha	Beta	STD	HTW	HTW STD	Alpha	Beta	STD	HTW	HTW STD
1	0,439	-0,026	0,094	0,128	0,074	0,455	-0,024	0,167	0,149	0,069
2	0,433	-0,026	0,090	0,112	0,071	0,443	-0,025	0,165	0,126	0,067
3	0,431	-0,026	0,087	0,107	0,070	0,442	-0,026	0,180	0,127	0,095
4	0,433	-0,026	0,086	0,098	0,067	0,441	-0,025	0,157	0,114	0,071
5	0,443	-0,027	0,085	0,102	0,066	0,440	-0,025	0,153	0,103	0,070
6	0,463	-0,027	0,087	0,122	0,073	0,448	-0,026	0,159	0,108	0,068
7	0,601	-0,026	0,122	0,228	0,104	0,502	-0,025	0,160	0,147	0,075
8	0,704	-0,025	0,179	0,362	0,148	0,553	-0,023	0,169	0,235	0,085
9	0,621	-0,026	0,132	0,329	0,115	0,649	-0,022	0,185	0,341	0,106
10	0,534	-0,026	0,118	0,247	0,108	0,659	-0,024	0,205	0,338	0,107
11	0,495	-0,027	0,117	0,177	0,086	0,567	-0,026	0,197	0,246	0,090
12	0,482	-0,027	0,104	0,162	0,075	0,522	-0,026	0,170	0,191	0,080
13	0,467	-0,027	0,102	0,147	0,077	0,486	-0,027	0,166	0,160	0,071
14	0,456	-0,026	0,100	0,131	0,069	0,465	-0,026	0,166	0,138	0,073
15	0,449	-0,027	0,104	0,126	0,062	0,451	-0,026	0,175	0,126	0,063
16	0,449	-0,027	0,105	0,128	0,067	0,452	-0,026	0,175	0,118	0,068
17	0,454	-0,027	0,104	0,131	0,067	0,470	-0,027	0,179	0,128	0,071
18	0,479	-0,028	0,114	0,152	0,073	0,489	-0,027	0,190	0,145	0,079
19	0,506	-0,028	0,121	0,179	0,082	0,498	-0,026	0,171	0,161	0,070
20	0,492	-0,027	0,105	0,173	0,079	0,485	-0,025	0,162	0,143	0,070
21	0,491	-0,028	0,109	0,165	0,076	0,475	-0,025	0,162	0,139	0,063
22	0,497	-0,027	0,100	0,171	0,077	0,473	-0,025	0,167	0,144	0,074
23	0,471	-0,027	0,107	0,164	0,076	0,453	-0,025	0,159	0,137	0,064
24	0,474	-0,028	0,112	0,168	0,074	0,456	-0,026	0,160	0,131	0,063

	Hotel and restaurant building electricity load model											
	Weekdays						Weekends					
Hour	Winter	Spring/ fall	Summer	Winter STD	Spring/ fall STD	Summer STD	Winter	Spring/ fall	Summer	Winter STD	Spring/ fall STD	Summer STD
1	0,891	0,868	0,809	0,103	0,097	0,083	0,915	0,896	0,829	0,129	0,119	0,079
2	0,864	0,841	0,782	0,097	0,091	0,077	0,889	0,871	0,808	0,115	0,106	0,080
3	0,857	0,830	0,770	0,093	0,089	0,076	0,878	0,869	0,791	0,108	0,149	0,079
4	0,856	0,825	0,763	0,091	0,088	0,075	0,873	0,845	0,781	0,103	0,098	0,076
5	0,863	0,834	0,768	0,092	0,089	0,077	0,864	0,840	0,776	0,098	0,097	0,078
6	0,898	0,858	0,792	0,107	0,099	0,082	0,879	0,851	0,791	0,106	0,102	0,090
7	0,989	0,946	0,866	0,132	0,119	0,093	0,927	0,895	0,837	0,130	0,121	0,103
8	1,071	1,053	0,969	0,146	0,132	0,107	0,981	0,956	0,895	0,130	0,125	0,105
9	1,106	1,118	1,059	0,167	0,148	0,126	1,019	1,013	0,962	0,155	0,139	0,107
10	1,062	1,048	0,998	0,144	0,135	0,116	1,090	1,113	1,047	0,181	0,163	0,120
11	1,044	1,019	0,944	0,141	0,131	0,115	1,082	1,097	1,027	0,182	0,161	0,122
12	1,035	1,010	0,920	0,141	0,132	0,118	1,008	0,993	0,916	0,153	0,136	0,098
13	1,026	0,997	0,904	0,144	0,133	0,115	0,988	0,970	0,893	0,146	0,136	0,096
14	1,008	0,984	0,896	0,139	0,129	0,113	0,967	0,945	0,872	0,144	0,131	0,106
15	1,006	0,976	0,888	0,144	0,135	0,119	0,961	0,934	0,861	0,147	0,132	0,101
16	1,020	0,985	0,903	0,151	0,141	0,122	0,985	0,945	0,872	0,158	0,144	0,113
17	1,025	0,987	0,910	0,151	0,142	0,118	1,011	0,968	0,893	0,178	0,161	0,117
18	1,067	1,023	0,938	0,169	0,156	0,127	1,027	0,983	0,923	0,175	0,158	0,122
19	1,084	1,050	0,970	0,170	0,158	0,132	1,024	0,995	0,937	0,173	0,162	0,132
20	1,103	1,079	0,996	0,181	0,165	0,136	1,022	0,999	0,947	0,175	0,163	0,139
21	1,100	1,084	0,999	0,177	0,162	0,134	1,004	0,988	0,949	0,180	0,158	0,127
22	1,072	1,061	0,975	0,165	0,149	0,124	0,977	0,962	0,923	0,159	0,138	0,109
23	1,015	1,016	0,941	0,149	0,132	0,110	0,950	0,940	0,900	0,144	0,130	0,099
24	0,939	0,934	0,872	0,122	0,111	0,097	0,911	0,893	0,849	0,129	0,118	0,090

APPENDIX C - ARTICLES

The candidate has written five journal/conference articles throughout the thesis work, two in Norwegian and three in English. The last two articles written in English are presented entirely in Appendix C:

1. "*Method for load modelling of heat and electricity demand*", 10th International Symposium on District Heating and Cooling, Hanover, Germany, September 3 - 5, 2006
2. *"Use of different methodologies for thermal load and energy estimations in buildings including meteorological and sociological input parameters"*, Renewable and Sustainable Energy Review, Volume 11, Issue 5, June, 2007, pp. 998 - 1007

The first article was written for a conference in Hanover in September 2006 with supervisor Rolf Ulseth as co-author. The method for load modelling of buildings has been developed further since the article was actually written in April and May 2006, and therefore, some changes may occur compared to the method presented in this thesis.

The second article was written as a review article and accepted by the journal Renewable and Sustainable Energy Review in August 2005. The article has been presented on-line, as well as in the written edition in June 2007.

The last three articles have been omitted due to the Norwegian language and very early presentation of the method developed in the first English written article.

Method for Load Modelling of Heat and Electricity Demand

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Abstract
Energy planning is important for development areas in need of new energy distribution systems. In order to plan for the most economical, technical and environmental optimal energy supply systems, it is especially important to estimate the expected maximum load and the load profile for the area in question. This paper describes a method for estimation of load profiles for heat and electricity for a given building category. The division of building categories is primarily based on the EU-Energy Performance of Buildings Directive (EPBD, 2002). Design load profiles divided on heat and electrical end-uses are especially useful for optimising CHP plants.

The method is based on simultaneous metered delivered energy of district heat and electricity on hourly basis as well as background information of the metered buildings. Load profiles for specific building categories are developed based on statistical analyses of the metered data. The estimation of heat load profiles is based on regression analyses, while the estimation of electricity load profiles is based on statistical distributions. Both methods are presented in this paper. The load demand for cooling is not discussed.

Keywords: *district heat metering, electricity metering, building categories, load aggregation, load profiles*

1 Introduction

The objective of this paper is to present a method developed for load modelling in mixed energy distribution systems, i.e. estimation of load demand divided on different end-uses. This task is especially important when planning for combined heat and power systems.

There are mainly three different methodologies which are utilized in estimation of load and energy demand for a given building or an area (Pedersen, 2005);

- Statistical analyses
- Energy simulation programs
- Intelligent computer systems

Load profiles for specific building categories are developed based on statistical analyses of the metered data. The method developed for estimation of heat load profiles is based on regression analysis, while the estimation of electricity load profiles is based on statistical distributions.

2 Method developed for load modelling

The method presented is based on the method for estimation of load profiles during design conditions developed by Pedersen and Ulseth (2004). The estimation of heat demand has been further developed, and the method developed for estimation of electricity demand has been revised in this paper.

The method is based on simultaneous district heat and electricity meterings on hourly basis as well as background information of the metered buildings. Figure 1 shows a flow chart of the method for estimation of heat and electricity load profiles, which will be presented in section 2.1 and 2.2 respectively.

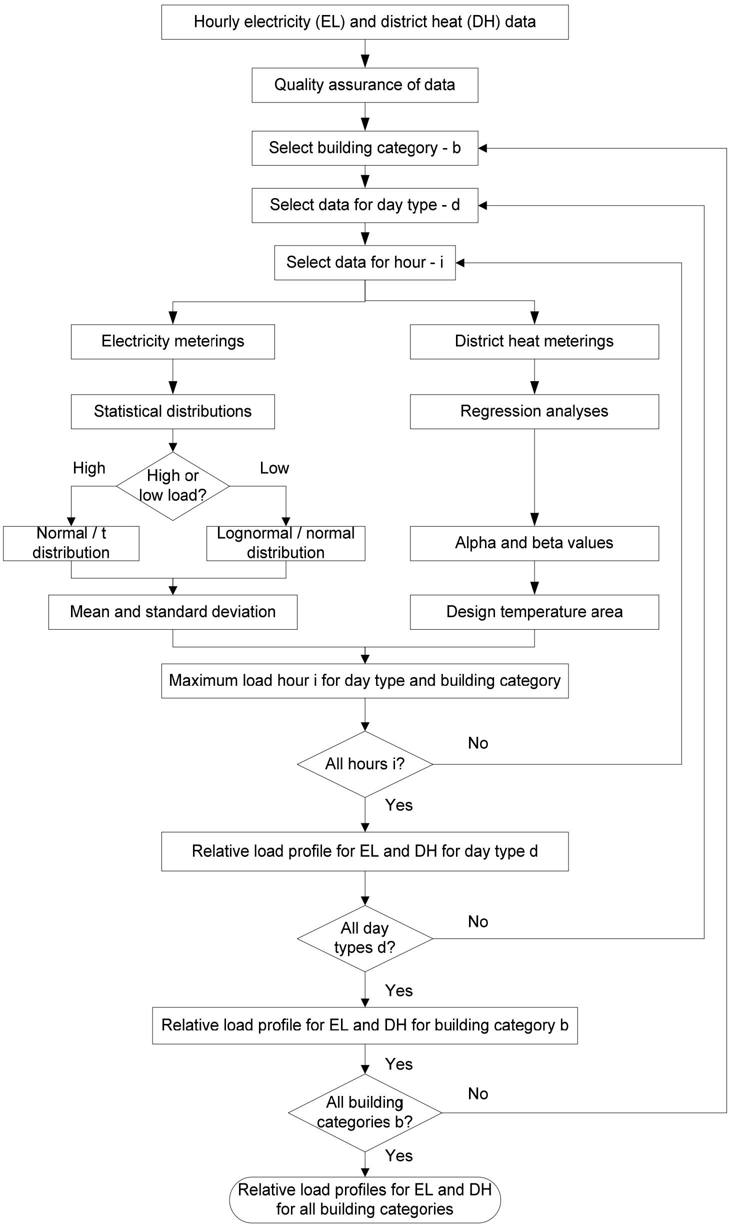


Figure 1 Flow chat of load modelling for mixed energy distribution systems.

The building categories are divided into nine different categories according to the EU-Energy Performance of Buildings Directive (EPBD, 2002). The day types are divided in two; weekdays (Mondays through Fridays) and weekends (Saturdays and Sundays). The hours are divided into 24, estimating the load for each hour of the day for both heat and electricity demand.

2.1 Heat load model

Heat demand includes demand for space heating, ventilation heating and hot tap water. An adjusted energy-signature model (Aronsson, 1996) has been applied on the building level in order to estimate the heat load profile for a given building category.

The steady state hourly heat demand from Pedersen and Ulseth (2004) for every hour, *j*, states;

$$\phi_{n,j} = \alpha_j + \beta_j \cdot \theta_{mdt} + e_j \qquad \textit{Equation 1}$$

where:

- $\phi_{n,j}$ Heat demand (space heating, ventilation heating and hot tap water) [W]
- α_j Specific regression coefficient [W]
- β_j Specific regression coefficient [W/K]
- θ_{mdt} Mean daily temperature [°C]
- e_j Residual (the error in the fit)

It is important to divide the consumption between temperature dependent and temperature independent consumption in order to perform regression analyses on the district heat meterings.

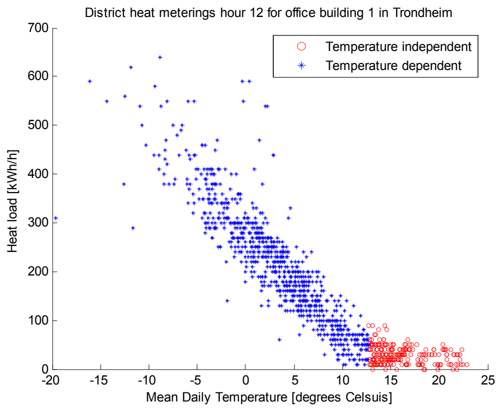


Figure 2 Scatter plot of hourly district heating consumption.

The regression analysis for every hour of the day is performed on the temperature dependent consumption only. The length of the heating season is dependent on the climate as well as the type of building, isolation thickness, control system, consumers, and more. Figure 2 shows an example of a scatter plot of hourly district heat meterings for an office building in Trondheim during a four year period. The temperature dependent consumption (blue asterisks), and the temperature independent consumption (red circles) are shown.

A mathematical approach has been developed to find the partition between the temperature dependent and the non-dependent season. The *β* value in equation 1 gives the slope of the regression equation and indicates how much the heat load decreases with increasing mean daily temperature. The *α* and *β* values are calculated using the method of least squares.

The temperature dependent season is found by calculating *β* values for the temperature dependent season decreasing from 20°C to -10°C with an interval of 0.1°C. The idea is to find the temperature span where the *β* value is approximately constant, i.e. varying within a few percent. The variation is defined to be the beta band. The temperature span where the beta band occurs, defined as the temperature band, should be at least a couple of degrees wide. The temperature dependent season is defined to start at a mean daily temperature within the temperature band.

Figure 3 shows β values for the same office building as in Figure 2 - hour 12, i.e. from 11 a.m. to 12 a.m. With a beta band of 1 %, meaning that the β values are allowed to vary ± 1 %, the largest corresponding temperature span occurs from 12.7°C to 9°C.

When the temperature band is found, the α values within the temperature band are controlled and should be relatively constant within the band. The α values specify where the regression line crosses 0°C. High α values in Figure 4 indicate that the slope line has been "lifted" due to exclusion of data points in the cases where the temperature dependent season starts at low mean daily temperatures.

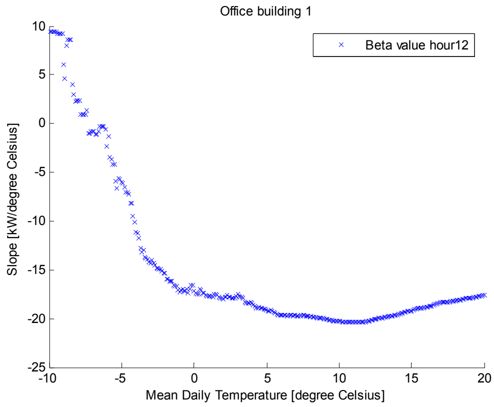


Figure 3 β values for office building 1

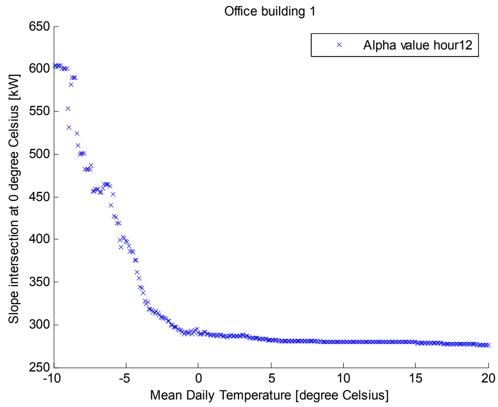


Figure 4 α values for office building 1

Every building category will be assigned their unique α_j values and β_j values for hours j = 1, 2, …, 24. As a consequence, each building category will be assigned two vectors, **A** and **B**, of length 24 for each day type;

A = $[\alpha_1\ \alpha_2\ \alpha_3 \ldots \alpha_{23}\ \alpha_{24}]$
B = $[\beta_1\ \beta_2\ \beta_3 \ldots \beta_{23}\ \beta_{24}]$

A and **B** inserted into equation 1 for each day type gives;

$$\mathbf{\Phi}_n = \mathbf{A} + \mathbf{B} \cdot \theta_{mdt} \qquad \textit{Equation 2}$$

It is desirable to make the load profiles compatible for a possible grouping, i.e. by building category. For this reason, it is important that the load profiles are presented on the same basis (Jardini et. Al., 2000). A base load, Φ_B, is chosen according to equation 3;

$$\phi_B = \frac{1}{24}\sum_{j=1}^{24}\phi_{M,j} = \frac{DailyConsumption(kWh)}{24} \qquad \textit{Equation 3}$$

where:

$\phi_{M,j}$ Maximum heat load for hour j in the diurnal

The maximum heat load is found by inserting the design temperature for the given location into equation 2 for every hour (Pedersen and Ulseth, 2004). The relative heat load profile is found by dividing the maximum load for a given hour, j, by the base load, see equation 4;

$$\phi_{R,j} = \frac{\phi_{M,j}}{\phi_B} \qquad \textit{Equation 4}$$

2.2 Electricity load model

Electricity load includes demand for lighting, pumps, fans, electrical appliances and others.

The electricity consumption is found to be less dependent on climatic conditions than the district heat consumption. In order to analyse the electricity consumption, the metered data have been analysed in relation to continuous probability distributions. The most common assumption for electricity load in all electric buildings is the normal distribution. In the Finnish load model Seppälä (1996) has shown that the normal distribution applies for electricity load during high load periods (day hours), while lognormal distribution applies during low load periods (night hours).

Figure 5 and Figure 6 show normal and lognormal probability density functions modelled for low and high electric load hours for office buildings. The number of bins used in the histograms is specified by the Freedman-Diaconis rule. The difference between normal and lognormal density functions for the low electric load case (from 12 p.m. to 1 a.m.) shows that there is no significant difference between the two distributions based on electricity consumption.

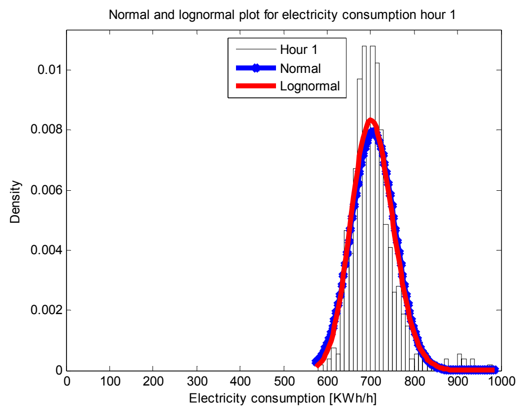


Figure 5 Normal and lognormal plot low load

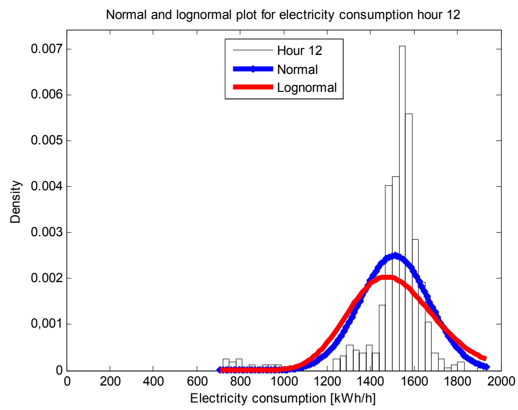


Figure 6 Normal and lognormal plot high load

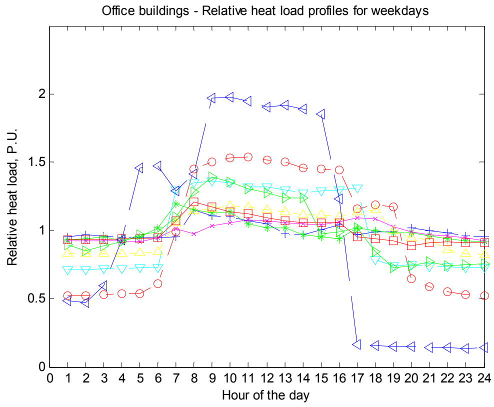
As a result, the electricity load is modelled using a normal distribution for all hours in this paper. The graphical method of a normal test plot has been applied in order to investigate the electricity load's goodness of fit in relation to normal distribution, but the plots themselves will not be presented here. The electricity load profiles will be presented on a relative basis based on equation 3 and 4.

3 Relative load profiles

The method developed for load modelling in mixed energy distribution systems is presented for the office building category. Hourly simultaneous electricity and district heat meterings have been collected for nine office buildings in Trondheim for a period of almost four years. The office buildings range from 3440 m^2 and up to 15 400 m^2 with different control regimes and user preferences. The relative heat and electricity load profiles are presented in the following sections.

3.1 Heat load results

Figure 7 and Figure 8 show the relative heat load profiles for nine different office buildings during weekdays and weekends respectively. The beta band is set to ± 1.5 %.



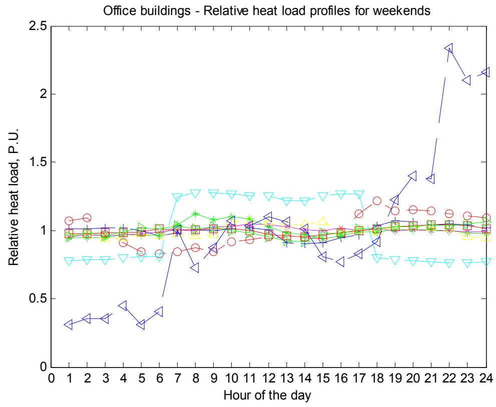
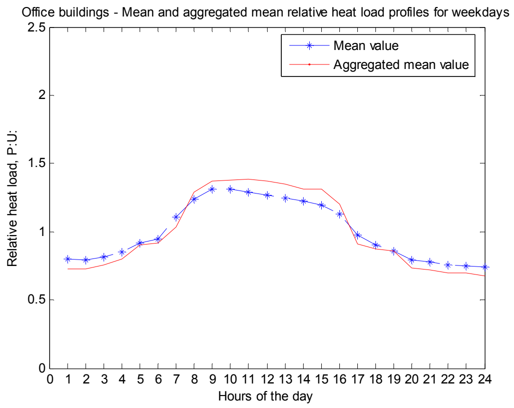


Figure 7 Relative heat load profiles for nine office buildings weekdays

Figure 8 Relative heat load profiles for nine office buildings weekends

Based on the load profiles for the different office buildings and background information, it seems to be two general heat load profiles for weekdays and one for weekends. This is most likely due to the different control regimes for the ventilation systems during weekdays, i.e. running only during working hours or running 24 hours a day. The two different heat load profiles for office buildings are defined as archetypes. The variations between the buildings may be due to the accuracy of the control system, thermal inertia of the buildings, what building code applied during the building's construction period, consumers' behaviour, and more.

The mean value for the relative heat load profiles for the nine office buildings along with the aggregated mean value are shown in Figure 9 and Figure 10 for weekdays and weekends respectively. The aggregated load is found by adding up the district heat meterings for all the office buildings and performing regression analysis on the total consumption.



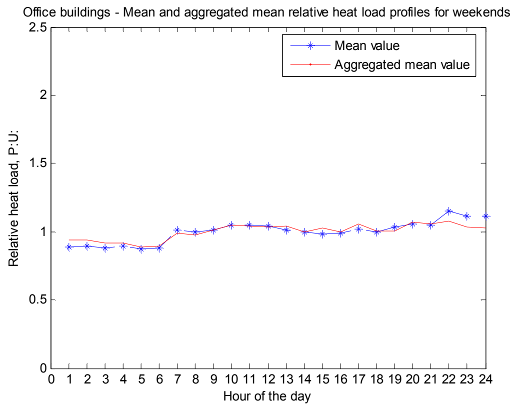


Figure 9 Mean and aggregated mean relative heat load profiles for office buildings weekdays

Figure 10 Mean and aggregated mean relative heat load profiles for office buildings weekends

The heat load during weekdays for office buildings varies mainly due to the running of the ventilation systems. Heat load during weekends are more or less constant throughout the day according to Figure 10. This is due to the low activity level in office buildings during weekends and the shut-down of the ventilation systems.

The difference between the mean heat load and the aggregated mean heat load for both weekdays and weekends is small. The mean load is based on the relative load profiles and does not differentiate between the size of the office buildings. The aggregated mean load, on the other hand, is based on real heat meterings and consequently, gives a more accurate profile.

The number of hourly metered office buildings is quite small in order to estimate a precise mean heat load profile for the office building category. As a consequence, an increase in hourly metered buildings may eventually lead to more accurate profiles.

The real load profile in [kWh/h] for a given building floor area is found by multiplying the relative load profiles for the different building categories by indicators like the specific load [kW/m^2]. This applies for both heat and electricity load profiles. The composition of buildings as well as background information like building category, area, control regime, and more have to be known.

3.2 Electricity load results

Figure 11 and Figure 12 show the relative electricity load profiles for nine different office buildings during weekdays and weekends respectively assuming normal distribution. According to the analyses, the electricity load for the nine office buildings during weekdays do not vary much in shape, even though the ventilation systems run differently in the buildings. Consequently, the electricity load in office buildings varies throughout the working day mainly due to the use of electrical appliances and lighting. The load profiles are generally steeper in the morning than in the afternoon indicating that people work late hours. The low activity level in office buildings during weekends is also reflected in the electricity load profiles in Figure 12.

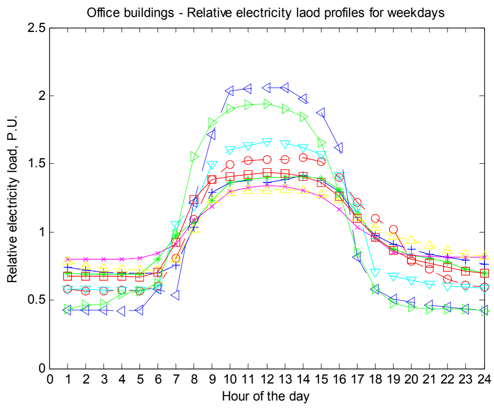


Figure 11 Relative electricity load profiles for nine office buildings weekdays

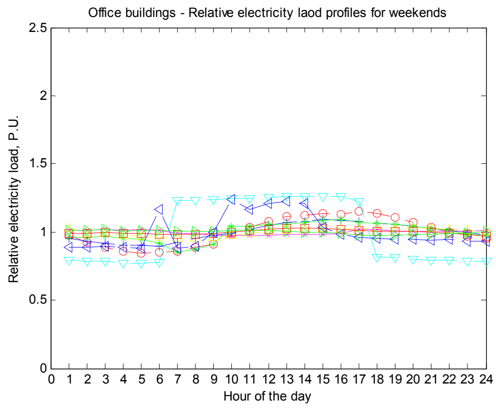


Figure 12 Relative electricity load profiles for nine office buildings weekends

Figure 13 and Figure 14 show the relative mean and the aggregated relative mean electricity load profile for weekdays and weekends respectively including aggregated standard deviation. It is a 68 % probability that the load differs less than one standard deviation from the mean and 95 % probability that the load differs less than two standard deviations from the mean (Løvås, 2004).

As for heat load, the difference between the mean electricity load and the aggregated mean electricity load for both weekdays and weekends is small.

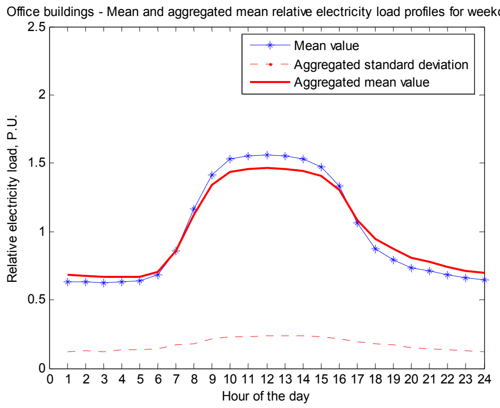


Figure 13 Mean and aggregated mean relative electricity load profiles for office buildings weekdays

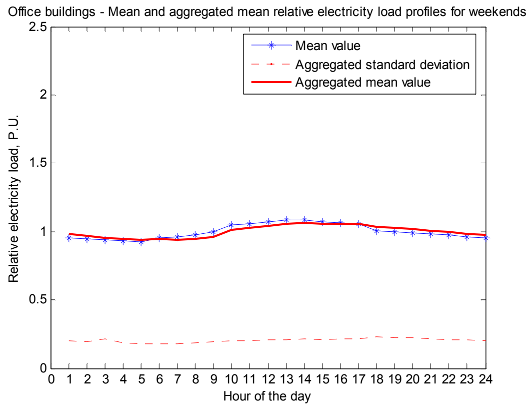


Figure 14 Mean and aggregated mean relative electricity load profiles for office buildings weekends

4 Conclusion

The method developed for heat load demand is based on regression analyses and the energy-signature model. The correlation between mean daily temperature and district heat meterings are examined and relative heat load profiles are developed on the basis of base loads.

The electricity load includes lighting, pumps, fans, electrical appliances and others, and the electricity consumption is examined using statistical distributions. The utilization of normal test plots have revealed that the electricity demand may be modelled by normal distributions during low load periods, i.e. weekdays except working hours and weekends. The goodness of fit for high load hours during weekdays is low for some hours, indicating that it might not be possible to model the electricity load using the same distributions as Seppälä (1996) used for the electricity load in all electric buildings. According to the distribution fitting tool in Matlab, the t location-scale (t-student distribution) seems more suitable for high load hours. The t distribution only depends on the single parameter v (nu) which indicates the degree of freedom. If the sample includes more than 30 observations, the t distribution converges to the standard normal distribution as the number of observations goes to infinity (Løvås, 2004). This has not been further examined in the paper, but it will be investigated more.

The method developed for modelling of heat and electricity load profiles have been exemplified through the office building category. The method is also applicable for single-family houses, apartment blocks, educational buildings, etc. (EPBD, 2002). The relative load profiles for the different building categories may eventually be adjusted to a specific building and aggregated to a given area using indicators which specify the building's core activity and the respective load demand. Load profiles divided on heat and electricity demand are generally important in the task of energy planning and especially important for optimising CHP plants.

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Use of different methodologies for thermal load and energy estimations in buildings including meteorological and sociological input parameters

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Abstract

This review paper provides first an overview of the background for meteorological and sociological influences on thermal load and energy estimations. The different yearly representations of weather parameters (test reference year (TRY), design reference year (DRY), typical meteorological year (TMY) and weather year for energy calculations (WYEC)) are discussed, and compared to simplified representations of weather characteristics. Sociological influences on energy demand are discussed in relation to attitude and culture.

Many methods exist for estimating thermal load and energy consumption in buildings, and they are primarily based on three different methodologies; regression analyses, energy simulation programs and intelligent computer systems. Regression analyses are mainly based on large amounts of metered load data, long-term weather characteristics and some information about the buildings. Energy simulation programs require detailed information about the buildings and sociological parameters, as well as thorough representation of weather data. Intelligent computer systems require metered load data, weather parameters and building information. The advantages and disadvantages of the alternative methodologies are discussed, as well as when and where to use them. Finally, the more specific usages of the methodologies are exemplified through three specific methods: conditional demand analysis (CDA), engineering method (EM) and neural networks (NN).

Keywords: Energy planning; Methodologies; Load estimations; Regression analyses; Energy simulation; Intelligent computer systems

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Contents

1. Introduction

Energy planning is a complex task that includes many uncertainties such as available energy resources and energy carriers, distribution systems, peak load values, load profiles and total energy demand. Load and energy demand may be estimated using many different methods. The problem is, which method should the energy planner choose for his or her estimates of the maximum load, load profile and total energy demand for the area in question? Energy planners need this information to be able to project an economically, technologically and environmentally optimal energy system in terms of design and operation [1].

The maximum load value indicates the load level that the energy production unit has to fulfill, and the load level also helps to establish what kind of existing technology can meet that requirement. The running costs and the environmental impact of the energy system are dependent on the operation of the system. The load profile for the specific area will give an indication of the system's behavior throughout the year and will also show the optimal operation of the energy system. It is important to estimate the total energy demand in terms of the possible exploitation of available energy resources in the surrounding area.

The following textbox specifies the difference between the methodology concept and the method concept used in this review article:

> *Methodology*—the fundamental background for the different methods.
> *Methods*—the different estimation techniques developed for load and energy estimations.

This review paper first provides an overview of the background for the meteorological and sociological influences on thermal load and energy estimations. The most common methodologies that have been developed for such estimations are then described, with a discussion on the advantages and disadvantages of the alternative methodologies, as well as when and where to use them.

Load and energy estimations in buildings are primarily based on three methodologies: regression analyses, simulation programs and intelligent computer systems. Different methods are developed based on these foundations to fulfill the energy planner's requirements for an accommodated estimation tool. Load and energy estimation tools have different requirements in terms of input data as well as various applicabilities. All of the methods evaluated need weather data, and methods that are not primarily based on metered energy data also need sociological data.

2. Weather files and sociological factors in load and energy estimations

Energy planning, particularly load and energy forecasting, require a great amount of background information. This information includes customer type, size of the building, control and maintenance of the energy system and the allocation of different end uses, i.e. space heating, cooling, electrical equipments, domestic hot water and more. However, some of the most important factors that influence the load and energy demand are climatic parameters as well as consumer behavior.

2.1. Different representation of climatic parameters

Different climatic parameters influence the load and energy demand such as temperature level vs. space heating, ventilation and cooling; wind speed and direction vs. space heating and ventilation; solar irradiance vs. cooling and lighting; hours of daylight vs. lighting and cloud layer vs. space heating. The climate changes from place to place as well as on a yearly basis, making the generation of a common representation of the normal climate into a challenging task at any given location.

The representation of weather data can be divided into yearly weather files and simplified weather files. The most important yearly representations are test reference year (TRY), design reference year (DRY), typical meteorological year (TMY) and weather year for energy calculations (WYEC) [2,3].

TRY consists of 1 yr of actual weather data chosen from the available annual weather years recorded. The specific year is chosen based on certain criteria. Years that include months with extremely low or high mean daily temperatures are eliminated. This process is continued until 1 yr remains, and this year represents the TRY. TRY is not sufficiently accurate and, therefore, it cannot be used in energy requirements calculations exceeding several years. TRY may be applied when comparing the different designs in retrofit options [2].

A DRY is a further development of the TRY. DRY consists of 8760 sets of hourly weather data—number of hours that constitutes a normal year—for a given location. The latter year is mostly used for annual energy simulations where the computer programs can handle more than one climatic parameter. DRY includes hourly climatic parameters such as global, diffuse and direct normal irradiance, dry bulb and dew point temperature, cloud information, wind speed and direction. Like TRY, DRY is compiled from metered data at a certain location during a 12 month period. Twelve representative months are selected and adjusted giving each month a true mean value along with the variance for the main climatic parameters [3].

TMY, on the other hand, represents a constructed weather data year based on actual meteorological data. Each month consists of typical or average months from annual metered data over several years. The months selected approximate the long-term average conditions. Therefore, TMY is a compilation of 12 months that might have occurred in different years. Consequently, two adjacent months may have a "jump" in weather conditions in the transitional period. This data is smoothed using a curve-fitting technique [2].

The last yearly weather representation is called WYEC. This weather data file is constructed using months that show the closest proximity to the 30-year normal, where both temperature and solar radiation are taken into consideration. Some days and hours are replaced by corresponding data from the same month, but from a different year, to bring the weather file closer to the published 30-year normal for that month [2]. This representation is mainly used in long-term load and energy predictions due to the similarity to the 30-year normal.

Yearly representations of weather parameters require a large amount of data. The accuracy level of the climatic representation must correlate with the load and energy estimation method used by the energy planner. For example, a large amount of weather data will increase the simulation time. A possibility for reducing the simulation time might be to use simplified weather data and a corresponding method.

Westphal and Lamberts [4] present a simplified weather file with 21, 14 or only 7 days per month of data. In a case study they carried out in Brazil, they found that the difference in energy estimation between simulations using TRY and the simplified weather data file was as high as 18%. The simulation time using the simplified data was reduced as much as 50%. The simplified weather data file gave satisfactory results for buildings with low thermal mass, but the methodology presented in Westphal and Lamberts [4] revealed weaknesses when the simulation involved buildings with high thermal mass. The main weakness is that the simplified method did not take into account the influence of thermal inertia in buildings with a large thermal mass.

In some cases it is also possible to use simplified weather data such as a design day. Chou et al. [5] present a methodology for the selection of a design day weather file for energy simulations based on TMY. The selected design day is not based on the most adverse set of weather conditions, but rather on weather conditions that give a low peak, as well as few hours of load not met. Simplified weather data offers the advantage of allowing the use of less complex simulation programs. The disadvantage lies in the accuracy of the output from the corresponding simulation program.

Table 1 presents the different climatic representations introduced in Section 2.1.

The use of some of the different weather representations will be discussed in relation to the presentation of the methodologies for load and energy estimation in Section 3.

2.2. Influence of sociological factors

The amount of energy consumed is very dependent upon the attitude and awareness of the energy customers. The consumption pattern in different building types, like households, schools and office buildings, is unique for that particular building. Therefore,

Table 1
Overview of different climatic representations introduced in Section 2.1

Yearly representation	Test reference year (TRY) Design reference year (DRY) Typical meteorological year (TMY) Weather year for energy calculations (WYEC)
Simplified representation	Simplified weather file Design day

customer influence differs depending on what kind of buildings they spend their time in. Consumers will have less influence in a building with automatic control than they will have in a manually controlled building. Awareness and attitudes towards energy consumption are more evident in household consumption than in situations where many people may simultaneously have an influence on energy use, such as in office buildings.

Aune [6] has performed several field surveys and in-depth interviews with several people in different Norwegian households in order to characterize different consumer groups. She has learned that attitude and consumption do not necessarily coincide, and that the way the consumers think they use energy might not be reflected in the actual consumption.

The actual energy consumption also depends upon the culture. Wilhite et al. [7] have learned that the Norwegian energy culture is intensive in relation to space heating and lighting, while the Japanese people use less energy for space heating and lighting. Therefore, this results in a higher energy bill for Norwegian households in terms of space heating and lighting consumption. The Japanese, on the other hand, have a very energy intensive and extremely important bathing culture, which means that domestic hot water use accounts for a large part of their energy bill. Differences in culture, attitudes and building practices are important, and should be considered when estimating loads and energy consumption. Some methods, like the energy-signature method [8], take this into consideration, while some building simulation programs concentrate mainly on the building's physical behavior. According to Richalet et al. [9], a methodology for load and energy estimations should be based on measured energy data, because the real behavior of the building can differ significantly from its design due to the operation of the building's energy system.

3. Different methodologies for load and energy estimations

Computers and computational expansion over the last 40 yr have led to the rapid evolution and improvement of calculation methods for load and energy estimation [10]. This section presents an investigation of the different methodologies being applied today, with descriptions of selected methods.

The meteorological and sociological factors described in Section 2 will be discussed later in this section in relation to the impact the different factors have on load and energy estimations.

3.1. Overview of the methodologies

Based on an analysis of selected articles involving load and energy estimations, load and energy estimations can be described as primarily based on three methodologies: statistical approaches/regression analyses, energy simulation programs and intelligent computer systems.

3.1.1. Statistical approaches/regression analyses

A statistical approach to load and energy predictions is based on large amounts of hourly metered energy consumption data. The probability sample must have a high level of statistical significance in order to meet the accuracy requirements of the stakeholder/energy planner.

Load and energy predictions are mainly based on linear or multivariate regression analyses. A regression analysis expresses the mathematical correlation between different factors, if a correlation in fact is present. This analysis also gives an indication of the quality of the correlation between various energy consumption measures, and climatic parameters such as load and outdoor temperature [11].

The representations of climatic as well as sociological parameters are very important in terms of regression analyses. Consumer behavior is more or less reflected in the hourly metered energy data, but the weather data should be presented as a yearly representation of climate at the specific location.

Examples of load and energy estimation methods based on statistical methodology and regression analyses are USELOAD [12], computational demand analysis (CDA) [13,14], the Finnish load model [15] and energy-signature [8].

3.1.2. Energy simulation programs

Simulation programs are "…an attempt to emulate the reality" [10]. Consequently, energy simulations in buildings require a large amount of data, both precise weather parameters and detailed description of the buildings. Simulation programs mainly model the energy conservation in the buildings including transmission, ventilation and infiltration losses. In addition, the model must factor in domestic hot water consumption as well as lighting, electrical equipments and internal heat gains [10].

Energy simulation programs are mainly based on two different modeling techniques: a response function method (analytical method) or numerical methods. The response function method solves linear differential equations that include time invariant parameters, while numerical methods handle nonlinear, time varying equation systems. Even though programs based on the response function method are often easier to validate, the numerical methods are preferred because they can solve the equations simultaneously, handle complex flow path interactions and accommodate time varying system parameters [10].

The primary numerical method is a nodal network representation of the building. This means that the whole building, or one specific room, is divided into segments where each segment is represented by one node. Energy conservation equations are developed for each node, and the entire nodal network is solved simultaneously. Many simulation programs are based on the nodal network model, but the differences lie in the solution techniques [10].

Examples of load and energy simulation programs based on nodal networks are ESP-r [10], EnergyPlus [16] and engineering method (EM) [13].

3.1.3. Intelligent computer systems

The last methodology for load and energy estimations presented in this review article is called intelligent computer systems, or artificial intelligence, and the systems consist of expert systems and artificial neural networks. Both computer systems go beyond straightforward programming. Expert systems "make decisions" based on an interpretation of data and a selection among alternatives. Neural networks (NNs) are trained in relation to a set of data until the network recognizes the patterns presented. The artificial NN may then make predictions based on new patterns [17].

The latter system is the most suited for load and energy estimations because it is able to handle incomplete data which might result from metered energy data and some climatic parameters. NNs can also solve nonlinear problems as well as "…exhibit robustness and fault tolerance" [17].

An example of a load and energy estimation method based on intelligent computer systems is presented by Aydinalp et al. [13] concerning the prediction of energy demand in Canadian households. They call the method NN.

3.2. Comparison of the different methodologies

The methodologies presented differ in many ways in terms of what kind of input data they require, and when and where to use them. This section provides a short discussion of the input data, with a special emphasis on meteorological representations as well as a discussion of when and where to use the different methodologies.

The amount of input data required by the methodologies differs according to the accuracy level of the calculations. A regression analysis primarily needs load meterings, weather characteristics and some background information on the metered buildings [12,14]. Simulation programs, on the other hand, do not need load meterings, but weather characteristics and detailed information on the buildings are extremely important. The latter methodology also requires information about the behavior of the consumers, i.e. sociological parameters [10]. Intelligent computer systems process metered load data, weather characteristics, sociological parameters and background information of the buildings. The more accurate information provided to the intelligent computer system, the better results the solution algorithm will give [17]. This is also true for regression analyses and simulation programs, because rubbish in equals rubbish out.

All three methodologies can provide both short-term and long-term predictions for load and energy demand depending on the accuracy of the input parameters. Long-term predictions are the most interesting from the energy planner's point of view. The uncertainty factor concerning the input parameters is distinctive in terms of the climatic representation. The yearly representations of weather parameters discussed in Section 2.1 are most interesting in relation to simulation programs and intelligent computer systems, but yearly representations are also used in regression analyses. TRY is most suitable for short-term predictions of load and energy demand because of its real representation of weather characteristics. DRY has manipulated real data and may be used in both short-term and long-term predictions. TMY and WYEC consist of constructed data representing long-term average climatic parameters. As a consequence, TMY and WYEC are most suited for long-term load and energy predictions [2,3].

The methodologies presented are further developed into more specific load and energy estimation tools, but the applicability is based on the program foundation. Regression analyses are primarily used in load and energy estimations involving several customers, i.e. energy planning for a specific development area where there are many end-users [15]. Because of the detailed nature of simulation programs, the application of this load and energy estimation tool is used with one or just a few large customers. Simulation programs are, therefore, mostly used in retrofitting of already existing buildings [10]. The application of intelligent computer systems are somewhere in between regression analyses and simulation programs [13].

3.3. Exemplification of methods for energy and load estimations

A summary of the specific methods developed for load and energy estimations presented in Section 3.1 is listed in Table 2 in relation to the methodology they are based on.

The different methodologies will be exemplified through CDA, EM and NN.

3.3.1. CDA

CDA is based on a regression method, and the regression level is on the end-use and not the total energy demand [13]. The different appliances (electrical equipment, cooling and heating devices) at the customer level are summed up to estimate the total energy demand for that particular customer. Energy consumption, electrical appliances, demographic features, energy market prices and weather data are necessary when applying the CDA method. The method alone is relatively inexpensive and this results in less precise estimates for the different end uses [14].

3.3.2. EM

EM is presented in an article by Aydinalp et al. [13], and the method is based on the development of a database for the residential sector in Canada. The database is representative for the national housing stock concerning energy demand. The energy demand for the houses in the database is estimated using a simulation program. Detailed descriptions of the houses in the database are necessary. The advantage of using this

Table 2
Overview of different methodologies and corresponding methods for load and energy estimations

Methodology	Method
Statistical approach/regression analyses	Energy-signature *Conditional demand analysis—CDA* Finnish load model USELOAD
Energy simulation programs	*Engineering method–EM* ESP-r EnergyPlus
Intelligent computer systems	*Neural networks– NN*

method is EM's ability to evaluate different energy efficiency upgrade scenarios. The simulation program requires weather data files representing long-term averages.

3.3.3. NN

The third method introduced in Section 3.1 is the NN method. This is an information-processing method inspired by the way the human brain processes information. NNs "…are considered to be intuitive because they learn by example rather than by following programmed rules" [13]. Other advantage of using NNs is that they can handle noise and incomplete data, and they can perform predictions at high speed [17]. This method also requires weather characteristics including heating and cooling degree days as well as other climatic parameters [13].

3.3.4. Comparison of the different methods

The different methods have different capabilities, but each of them can be used in load and energy demand modeling for different customers. EM is the most detailed and flexible model and, consequently, this model requires detailed data and engineering expertise to be developed. The CDA-based model, on the other hand, does not require as detailed data, but the number of buildings in the database has to be large because of the regression analysis. The model cannot provide as much detailed information and flexibility as EM. The NN method is still at the development stage, but this approach is very promising in terms of energy demand modeling. The NN model is situated somewhere between EM and CDA in terms of development and use [13].

4. Conclusion

Many methods exist for making load and energy estimations, but they are all primarily founded on three different methodologies. The first methodology, regression analysis, is mainly based on large amounts of metered load data, long-term weather characteristics and some information about the buildings being modeled. A statistical approach is most suitable for large development areas and long-term estimates of the expected load and energy demand. The second methodology, an energy simulation program, requires detailed information about the buildings and sociological parameters, as well as a thorough representation of weather data, i.e. weather representations like DRY or TMY. Simulation programs are founded on the transfer function method or the numerical method. The latter method is the most widespread, and this approach is suitable for short- or long-term load and energy simulations in one or a few buildings. The third and last methodology, intelligent computer systems, is primarily based on neural networks that process information based on the way the human brain function. Intelligent computer systems require metered load data, weather parameters and building information. Based on this information, the neural network is trained until the pattern in the dataset is revealed. Neural networks may be used for both short- and long-term predictions of load and energy, and this approach is proper for one building or several buildings.

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