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### Heat/cold generation

# Method for load modelling of heat and electricity demand

L. Pedersen, R. Ulseth,
Norwegian University of Science and Technology, Trondheim/Norway

# Method for Load Modelling of Heat and Electricity Demand

Linda Pedersen, PhD-student
Rolf Ulseth, Associate Professor
Department of Energy and Process Engineering, The Norwegian University of Science and Technology
Address: Kolbjørn Hejes vei 1b, N – 7491 Trondheim
Phone: +47 73 59 32 32
E-mail: linda.pedersen@ntnu.no , rolf.ulseth@ntnu.no

**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.

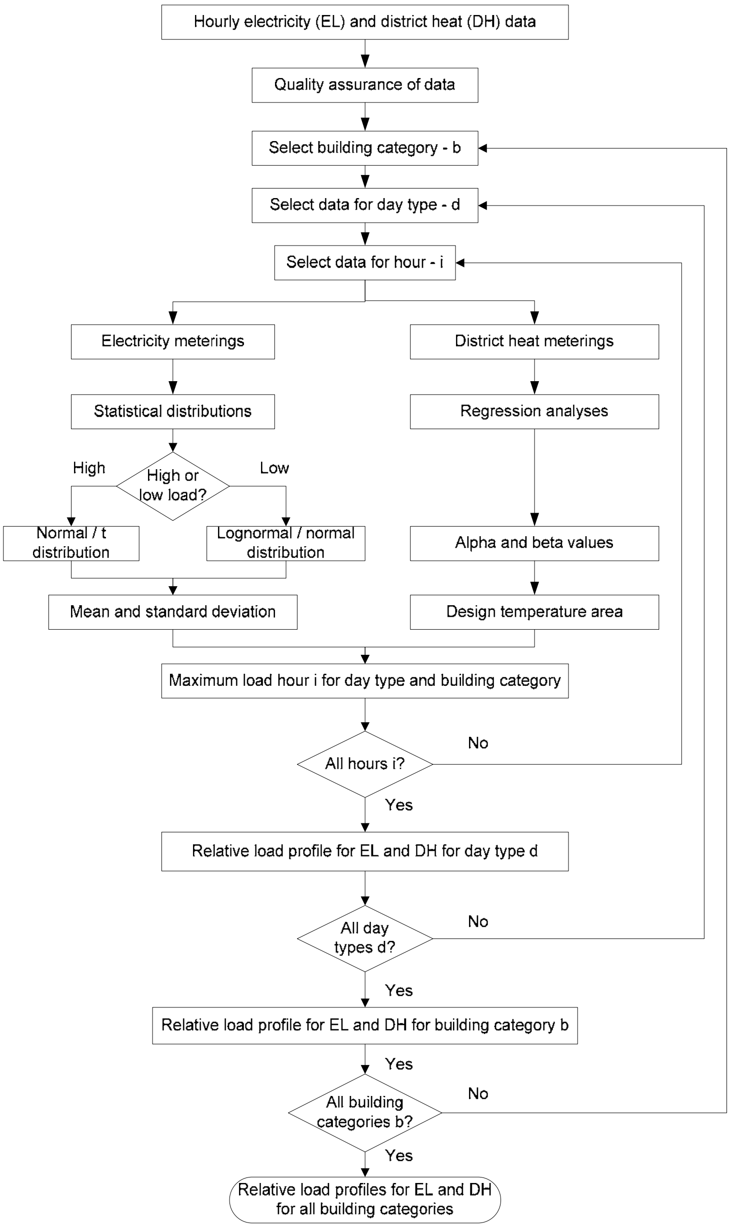



*Figure 1 Flow chat of load modelling for mixed energy distribution systems.*

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]

$\alpha_j$ Specific regression coefficient [W]

$\beta_j$ Specific regression coefficient [W/K]

$\theta_{mdt}$ 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.

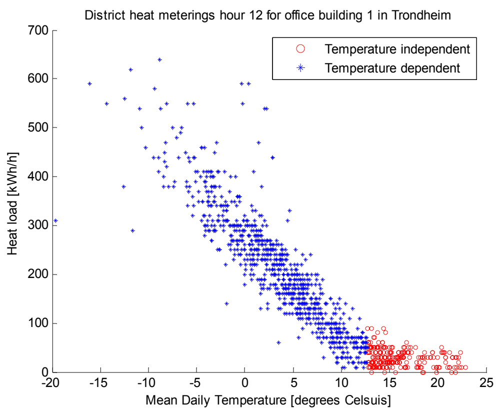



*Figure 2 Scatter plot of hourly district heating consumption.*

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 $\beta$ 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 $\alpha$ and $\beta$ values are calculated using the method of least squares.

The temperature dependent season is found by calculating $\beta$ 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 $\beta$ 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 $\beta$ values are allowed to vary $\pm$1 %, the largest corresponding temperature span occurs from 12.7°C to 9°C.

When the temperature band is found, the $\alpha$ values within the temperature band are controlled and should be relatively constant within the band. The $\alpha$ values specify where the regression line crosses 0°C. High $\alpha$ 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.

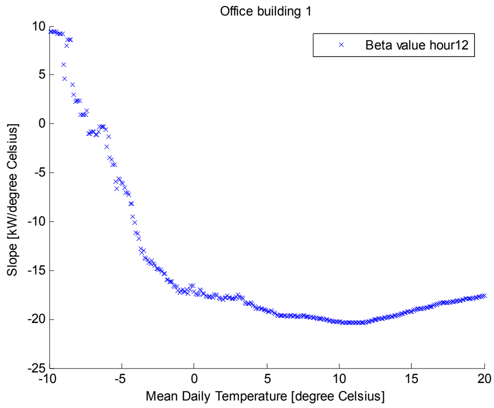



*Figure 3 β values for office building 1*

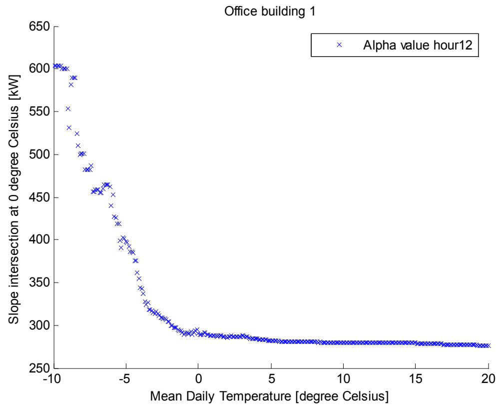



*Figure 4 α values for office building 1*

Every building category will be assigned their unique $\alpha_j$ values and $\beta_j$ 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;

$\mathbf{A} = [\alpha_1\ \alpha_2\ \alpha_3 \ldots \alpha_{23}\ \alpha_{24}]$
$\mathbf{B} = [\beta_1\ \beta_2\ \beta_3 \ldots \beta_{23}\ \beta_{24}]$

**A** and **B** inserted into equation 1 for each day type gives;

$$\mathbf{\Phi}_\mathrm{n} = \mathbf{A} + \mathbf{B} \cdot \theta_{mdt} \qquad \text{Equation 2}$$

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, $\Phi_B$, is chosen according to equation 3;

$$\phi_B = \frac{1}{24}\sum_{j=1}^{24}\phi_{M,j} = \frac{DailyConsumption(kWh)}{24} \qquad \text{Equation 3}$$

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;

$$\phi_{R,j} = \frac{\phi_{M,j}}{\phi_B} \qquad \text{Equation 4}$$

## 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.

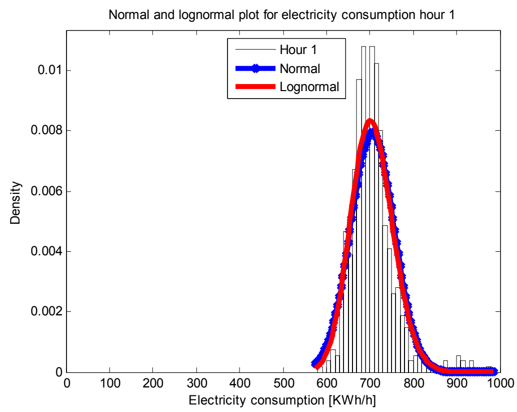



*Figure 5 Normal and lognormal plot low load*

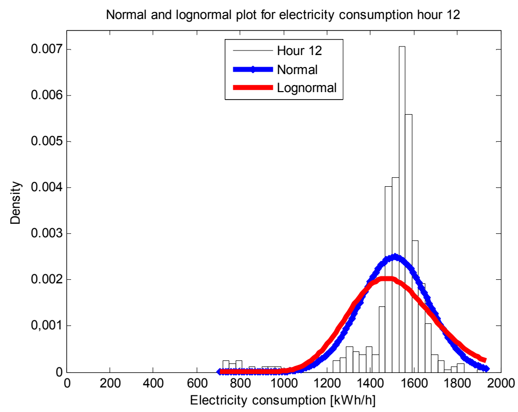



*Figure 6 Normal and lognormal plot high load*

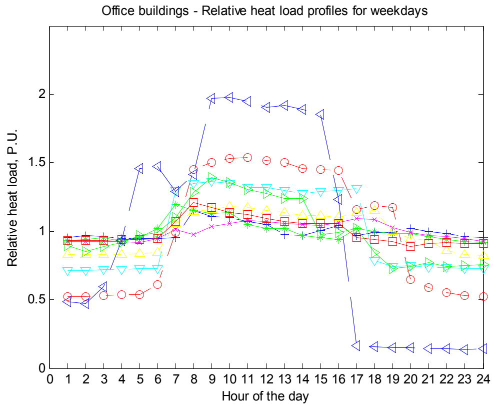
As a result, the electricity load is modelled using a normal distribution for all hours in this paper. The graphical method of a normal test plot has been applied in order to investigate the electricity load's goodness of fit in relation to normal distribution, but the plots themselves will not be presented 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 %.



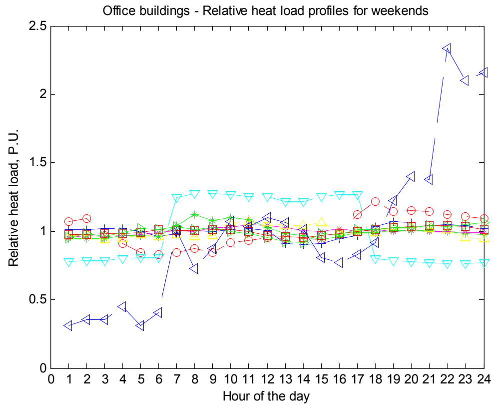
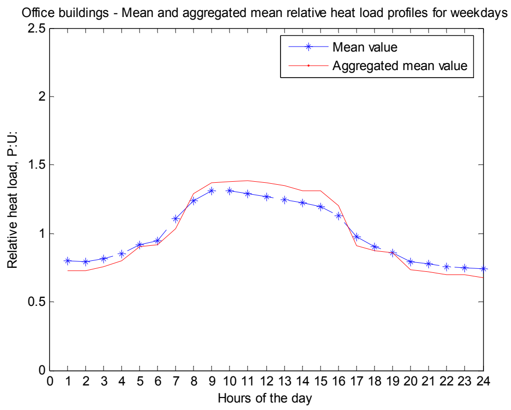




*Figure 7 Relative heat load profiles for nine office buildings weekdays*

*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.



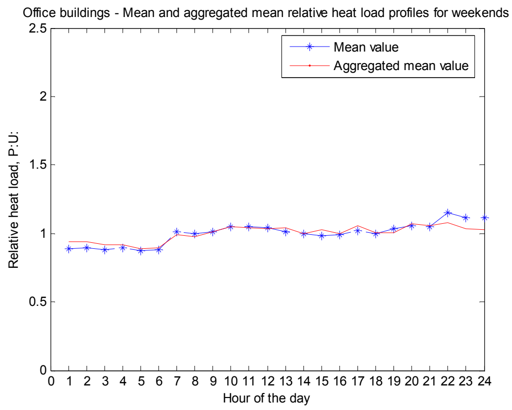




*Figure 9 Mean and aggregated mean relative heat load profiles for office buildings weekdays*

*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.

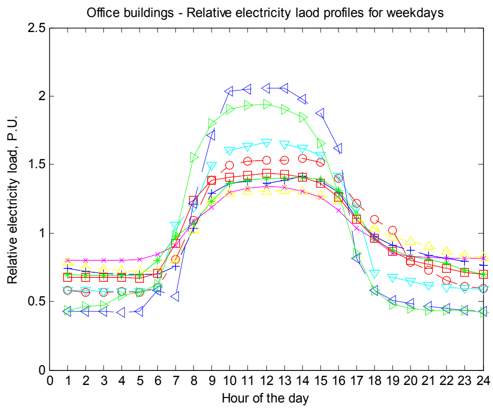



*Figure 11 Relative electricity load profiles for nine office buildings weekdays*

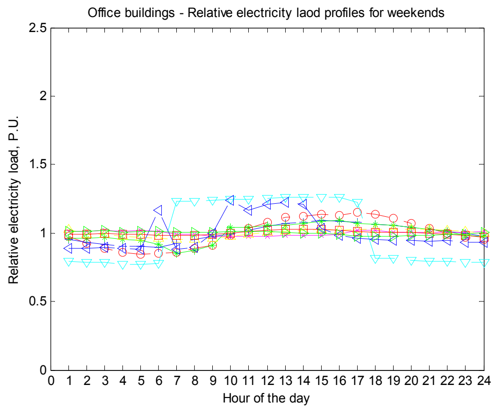



*Figure 12 Relative electricity load profiles for nine office buildings weekends*

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.

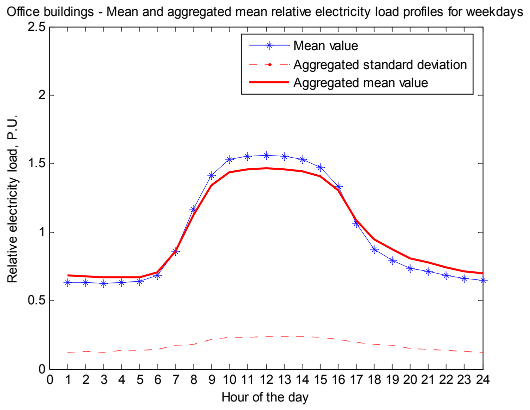



*Figure 13 Mean and aggregated mean relative electricity load profiles for office buildings weekdays*

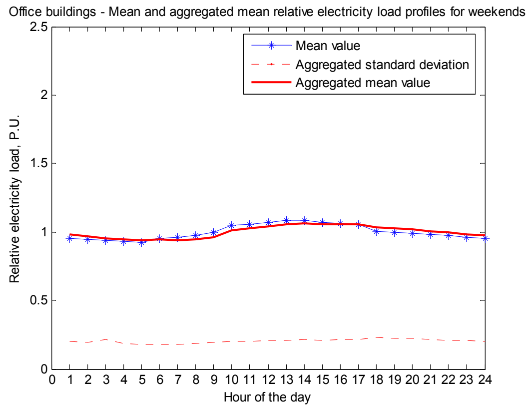



*Figure 14 Mean and aggregated mean relative electricity load profiles for office buildings weekends*

## 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 ν (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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