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Calculation method for electricity end-use for residential lighting

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ABSTRACT

Knowledge of the electricity demand for different electrical appliances in households is very important in the work to reduce electricity use in households. Metering of end-uses is expensive and time consuming and therefore other methods for calculation of end-use electricity can be very useful. This paper presents a method to calculate the electricity used for lighting in households based on regression analysis of daily electricity consumption, out-door temperatures and the length of daylight at the same time and location. The method is illustrated with analyses of 45 Norwegian households. The electricity use for lighting in an average Norwegian household is calculated to 1050 kWh/year or 6% of total electricity use. The results are comparable to metering results of lighting in other studies in the Nordic countries. The methodology can also be used to compensate for the seasonal effect when metering electricity for lighting less than a year. When smart meters are more commonly available, the possible adaption of this method will increase, and the need for end-use demand calculations will still be present.

1. Introduction

The importance of improved energy efficiency for climate change mitigation and environmental protection in general is commonly known. Energy efficiency has become a vital part of the energy strategy of many countries. Knowledge of energy by end-use is vital to be able to calculate energy saving potentials of different end-uses. The development of cost-effective policy measures depends on realistic calculations of the amount of energy used for different purposes, such as the calculation of the effects of new standards in the US demonstrated by Rosenquist et. al. [1] and the impact of "phase-out" regulations of lighting markets studied by IEA [2]. The potential of energy savings in European households has been calculated to 48% of the electricity use based on extensive measurements [3].

Lighting energy consumption can be reduced by energy efficiency improvements associated with the choice of lamps and by behavioural changes, decreasing the use of artificial lighting. Domestic lamp types include the traditional incandescent tungsten filament lamps (GLS (general lighting service)), HL (halogen lamps) and the more efficient CFL (compact fluorescent lamps). GLS and HL accounted for approximately 72% of market share of the European Union in 2010. Regulations are in force to reduce the use of GLS in the European Union. The CFLs are up to 80% more efficient and durable compared to the GLS and the HL are approximately 50% better than GLS [4]. The energy savings of the first EU Eco design directive is calculated to reduce the European residential electricity consumption with 39 TWh in 2020 [5].

This study is part of the research project «Electricity Demand Knowledge» (ElDeK) [6]. The main objective of the project is to increase the knowledge concerning the electricity demand for different electrical appliances in households. A major part of the project is metering of electrical appliances in households. In this paper a study focussing on the electricity used for lighting in households is presented. It is difficult to measure all electricity used for lighting because of the large number of lamps. In addition, the metering equipment available in this project, as in many other metering projects, is not suited to measure lamps without a socket. Due to the large variations in daylight length it is reasonable to believe that the electricity for lighting varies with the time of the year, but the period for metering of end-use demand is often limited, in this case to four weeks for each customer. The electricity for lighting will also probably vary with the location of the metred household. The differences in day-light length varies a lot in many countries and in Norway it varies from no day-light during the winter and no darkness during the summer in the north of Norway to 6 h day-light as a daily minimum in the south of the country and 18 h at the most. A method for calibration of metering of less than a year due to the time of the metering period and the location of the customer would therefore be of interest. Electricity is used for space heating to a large extent in Norway and since this also varies with

Abbreviations: CFL, compact fluorescent lighting; DSO, distribution system operators; GLS, general lighting service; HDD, heating degree days; HL, halogen lamps.

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the season, it makes it difficult to calculate the electricity used for lighting. Norwegian households behave less energy efficient particularly with electricity use for lighting than most European countries due to low electricity prices and because electricity used for lighting partly contributes to space heating. A calculation method based on information of daily electricity use, outdoor temperature and hours of daylight is presented in this paper and the results are compared with previous knowledge of electricity for lighting in the Nordic countries. In addition a method for calibration of the seasonal effect of metering of lighting is suggested.

Numerous models for electricity demand forecasting and load profiles exist [7–12]. More specifically, examples of models of residential lighting demand are the model of Stokes [13] being able to represent load variations on fine time-scales to support investigations into the effects of low voltage urban electricity networks of future wide-scale uptake of solar technologies; the model of Richardson [14] with an objective to provide high-resolution electricity demand profiles at the individual dwelling level, based on information of active occupancy profiles and outdoor irradiance data. Widén presents a stochastic bottom-up model based on domestic occupancy patterns and solar irradiance data giving load curves that can be used in simulation of distributed photovoltaics [15]. Common for these methods and the method of this paper, is the linkage of electricity use for lighting with daylight availability. A major difference is the objective of the models, since the objective of the method of this paper not is to provide load curves for individual dwellings but to allocate the share of total electricity use being used for lighting in large group of dwellings in an easy, fast way. The method presented is simple to apply if daily electricity use of households is available. Full scale implementation of smart metering technology is going on in many countries and in Norway all customers will have this equipment by the end of 2018 [16]. These smart meters will make it possible to register the electricity consumption on a more detailed time level than before and thus improve the knowledge of the electricity consumption of individual customers, as illustrated by Kavousian et.al. [12]. However, the use for calculation methods for lighting demand will remain.

This study is also related to the economic work on estimating end use consumption with conditional demand models where total consumption per measurement period is disaggregated into consumption by end use. Conditional demand studies include Parti and Parti [17] and Tiedemann [18].

Section 2 presents the methodology and Section 3 the data used. The results of the analyses are presented in Section 4 and discussed and compared with other studies in Section 5. Finally, Section 6 concludes.

2. Methodology

The methodology used is regression analysis of daily measurements of total household electricity consumption during a year in combination with information of daylight and measured temperatures/heating degree days at the same time and location. The hypothesis is that the seasonal difference in daylight is reflected in the seasonal variation of electricity use and this seasonal difference can be used for quantification of the electricity used for lighting. The intention is to find a simple, easily applicable method.

The average hours of daylight and darkness are presented in Fig. 1 together with the normal HDD (heating degree days) as a daily average per month at Oslo. The HDDs of each month divided by the number of days in that month are presented to illustrate the differences of a normal day at different times of the year. The figure illustrates the nonconforming of daylight and energy demand for space heating. An example of this is the comparison of data for May and September, with similar values of HDD (6.3 and 6.2 respectively) and with larger difference in hours of darkness (7.2 and 11.5 respectively).

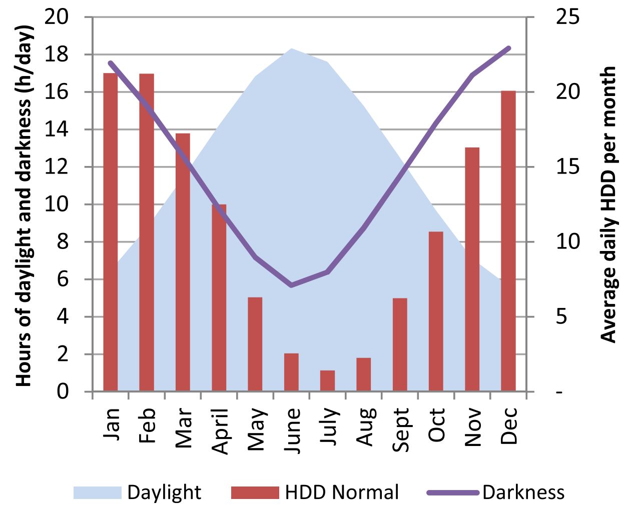

Fig. 1. Average daily hours of daylight, darkness and heating degree days (HDD) per month in Oslo.

By analysing days with low share of electricity for space heating and varying hours of daylight, the theory is to calculate the electricity used for lighting. The coefficients for calculation of the electricity use will be calculated:

$$E = a\mathrm{HDD} + b\mathrm{D} + \mathrm{constant} \quad (1)$$

where

E = electricity use (kWh/day)
a = coefficient for space heating
HDD = number of heating degree-days (Heating Degree Days)
b = coefficient of darkness
D = darkness (hours without daylight)
constant = electricity use independent of outdoor temperature and daylight/darkness (kWh/day)

The coefficients a and b and the constant of Eq. (1) are calculated with regression analysis of corresponding data of daily electricity consumption, number of HDD (heating degree-days) and hours of darkness.

There are several possible problems with the method used. First, the electricity used for lighting is rather small and might be difficult to separate from other end-uses. Electricity used for space heating is a large part of total electricity use in most Norwegian households and the demand for energy for space heating does to a large degree coincide with the demand for lighting. Electricity used for space heating may be calculated based on information of the outdoor temperature, but the use of fire wood will interfere with the calculation and no information on the energy use from wood is available for the analysed data. Also other heat sources such as the use of heat pumps and boilers/stoves will cause problems. The sun radiation contributes to space heating particularly in the spring and this will also make it difficult to separate the electricity used for lighting. Finally, some lighting is independent of daylight because not all rooms have windows (stairway, hallway, bathrooms etc.). Lighting is also in use at sunset/sunrise and when the weather is bad (dark clouds). This indicates that there is a demand for lighting also when there is no darkness. At the same time there is not demand for lighting during all hours with darkness because the households are not occupied all this time due to non-domestic