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Load Profile of Typical Residential Buildings in Bulgaria

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Abstract. In the current market design, the increasing use of renewable energy sources for electricity generation leads to new challenges in balancing supply and demand. While households are responsible for 29% of total electricity demand in Europe, a good understanding of their consumption and load profiles is missing. Households have become one of the most crucial factors shaping the management of developments towards sustainability. The development and implementation of effective policies for promoting energy efficiency in the household sector has been an emerging target of the EU. Recent analyses of Bulgarian households show this type of housing as the most statistically significant variable to impact electricity savings. This study deals with the statistical analysis of electric consumption. Statistical evaluations of electricity consumption in a typical apartment building have been obtained in the research. Mathematical models of the investigated loads have been developed. The research is based on the periodic results and the object of investigation is a typical residential block of flats in Ruse, Bulgaria. The average daily energy consumption during the weekdays and weekends is presented and analysed in the paper.

1. Introduction

After the socio-economic changes in Bulgaria, there have been significant variations in the structure of electricity consumption. The energy consumption by households has gradually increased greenhouse gas concentrations in the atmosphere and is considered the main source of global warming. Because of global warming and the accompanying climate change, conserving electricity is imperative. Clearly, even a small reduction in the energy consumption of buildings can have appreciable economic and ecological impacts for the society [1]. Under the Energy Efficiency Directive, all EU countries are required to use energy more efficiently at all stages of the energy chain, from production to final consumption. On 30 November 2016 the Commission has proposed an update to the Energy Efficiency Directive, including a new 30% energy efficiency target for 2030, and measures to update the Directive to make sure the new target is met [2]. These documents have also been transposed into national documents (different laws, programs, etc.) Preliminary studies show that the number of studies related to the above mentioned problems is limited, making it difficult to achieve the desired goals.

The development and implementation of effective policies for promoting energy efficiency in the household sector has been one of the main targets of the EU [3]. Energy sustainability and environmental preservation have become worldwide concerns with the many performances of climate change and the continually increasing demand for energy [4].

Energy consumption is increasing in all sectors due to the rapid industrial development and population growth. The potential for household energy efficiency improvements is still high. Households, as well as the people living there, are very different and one of the important factors is to assess a consumer's behavioural aspects [5]. Usually, efficiency is defined as the actions that generate the highest outputs for a definite set of resources [6]. Various studies have been done in the field of impact of user behaviour on the total amount of energy consumption in the households [7].

Nowadays, the operation of various systems and infrastructure is based on the use of electricity, which suggests that we could not imagine life without electricity. Unfortunately, in practice, even very high efficiency of electrical equipment does not guarantee expected savings. Often people do not know or do not want to change anything in their daily routine. Inefficient use of electricity probably will lead to even more inevitable negative consequences in the future. Therefore, increased attention should be paid on finding new innovative solutions for increasing the consumers' motivation to save energy. Smart meters are contributing not only to optimizing the operation of electricity systems, but also lead to a socio-economic platform for the promotion of interactions between suppliers and consumers [5].

In Bulgaria the proportion of households and services in final energy consumption reached 37.4 % in the recent years. Since most of the energy in these two sectors is spent on heating, the influence of the characteristics of the buildings in Bulgaria on the level of energy efficiency also increases. In the future, this impact will be commensurable with the impact of the energy intensive industries. Bulgarian households fail to reduce significantly their energy consumption, despite rising energy prices and the slow growth in their income. They continue to improve their energy comfort at the expense of satisfying other necessities. If the trend of faster growth in energy prices compared to the income of households remains the same and if they do not receive any external support to improve the characteristics of buildings and appliances, it can be expected that the energy comfort of Bulgarian households will decline in the context of already reduced expenses to meet other needs. Reduced consumption of liquid fuels is caused by reduced use of private cars, due to the rapid increase in oil prices. Practically, this means fewer opportunities to travel and necessity to consider practical alternatives to preserve the mobility of Bulgarian citizens [8].

Bibliographic studies have shown that a number of educational and research organizations have been actively involved in the management of electricity consumption in public utilities. But due to differences in climatic features, the heat supply systems and the culture of behaviour in individual countries, it is not possible to use directly the results obtained for the purposes of the efficient energy consumption in Bulgaria. Therefore, specialized studies for investigation of the dynamics of electricity consumption are required. Based on this data statistical assessment of the results can be implemented.

The aim of the paper is to investigate the typical load profile of residential buildings and customers in Bulgaria. This would allow to reliably analyse the investments in renewable energy sources, energy efficiency measures, etc.

2. Materials and methods

The method used to assess the load profile of a block of flats, is explained bellow. Firstly, for each day of the year the cumulative energy consumption at the n[th] hour of the day E_n, is generated according to:

$$E_n = \sum_{k=1}^{N} E_k^{hour}$$

where N is the number of apartments in the block of flats, and E_k^{hour} is the energy consumption of the k[th] apartment for a certain hour of the day.

Then the average energy consumption for every month of the year E_n^{mnt} is obtained for each hour of the day:

$$E_n^{mnt} = \sum_{l=1}^{28,29,30\ or\ 31} E_l \Big/ 28,29,39\ or\ 31$$

The experimental data is further analyzed through dividing it into weekdays and weekends. The average daily energy consumption E_n^{avg} throughout the day is estimated by using the formula:

$$E_n^{avg} = \sum_{m=1}^{K} E_m \Big/ K$$

where K is the number of weekdays or weekend days and n is again the hour of the day. The confidence interval is assessed for normal distribution with a 95% probability, based on the variation throughout the different months.

Finally, the normalized load profile for each hour of the day is estimated according to:

$$E_n^{norm} = 24. \sum_{n=1}^{K} E_n^{avg} \Big/ \sum_{p=0}^{23} E_p^{avg}$$

where p varies between 0 and 23 and represents the different hours of the day. The normalized load profile allows to visualize it on a scale whose average is 1. Such representation allows to easily apply the obtained dependencies for different consumers by multiplying them by the investigated average consumption.

3. Results and discussion

The object of the investigation is a typical block of flats in Ruse, Bulgaria. It consists of two entrances, each with 6 floors and 24 apartments, which is owned by the Municipality of Ruse. Since 2013 all the apartments have electric meters whose readings are being automatically stored in a database on hourly basis. The block is not connected to the central heating system of the town, so during the winter months the heating is done mainly by using electrical energy.

The collected data for the past years is used in the present study to analyse the load profile. The average monthly load profile for each month of the year is presented in Figures 1 and 2. It has a minimum in May, June and September and the maximum values are reached during the winter months from December to March.

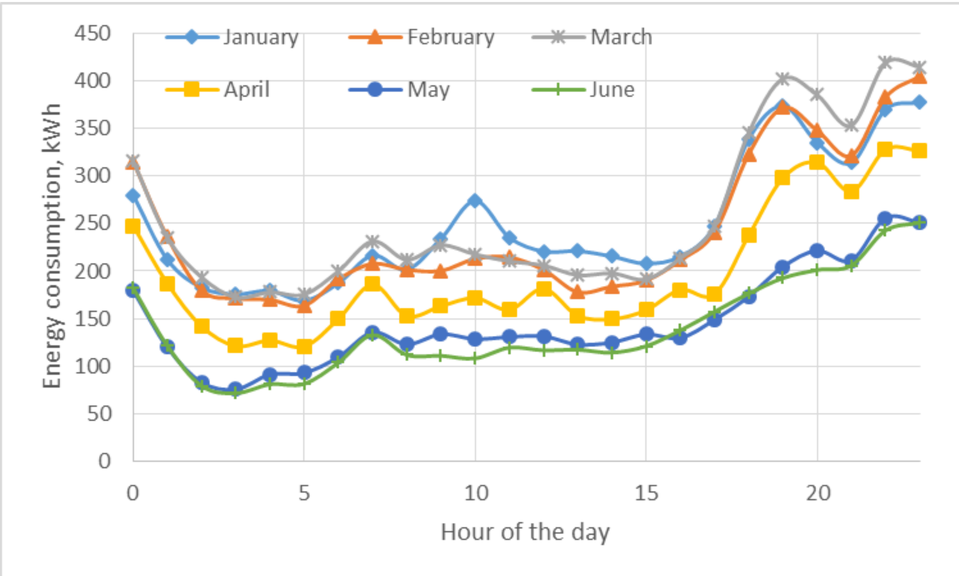

Fig. 1. Average monthly load profiles of the block of flats from January to June.

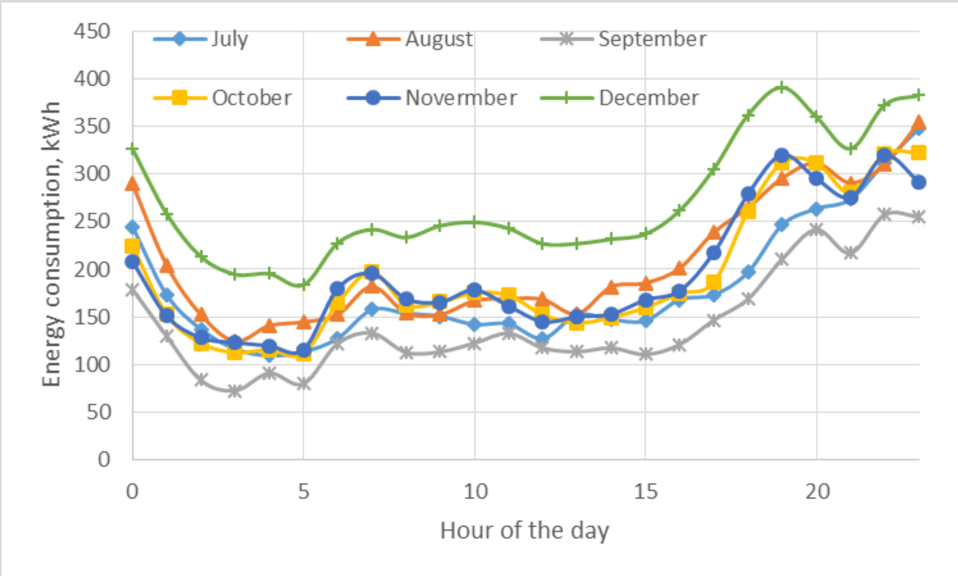

Fig. 2. Average monthly load profile of the block of flats from July to December.

The average daily energy consumption during the weekdays and during the weekends is presented in Figures 3 and 4 respectively. The figures also show the confidence interval for the different months with a 95% probability. As expected, during the weekdays (Fig. 3) there is a peak of the energy consumption at 7:00h when people wake up and prepare to go to work. The consumption starts to increase again after 18:00h when people return home and has peaks at 20:00h and 23:00h.

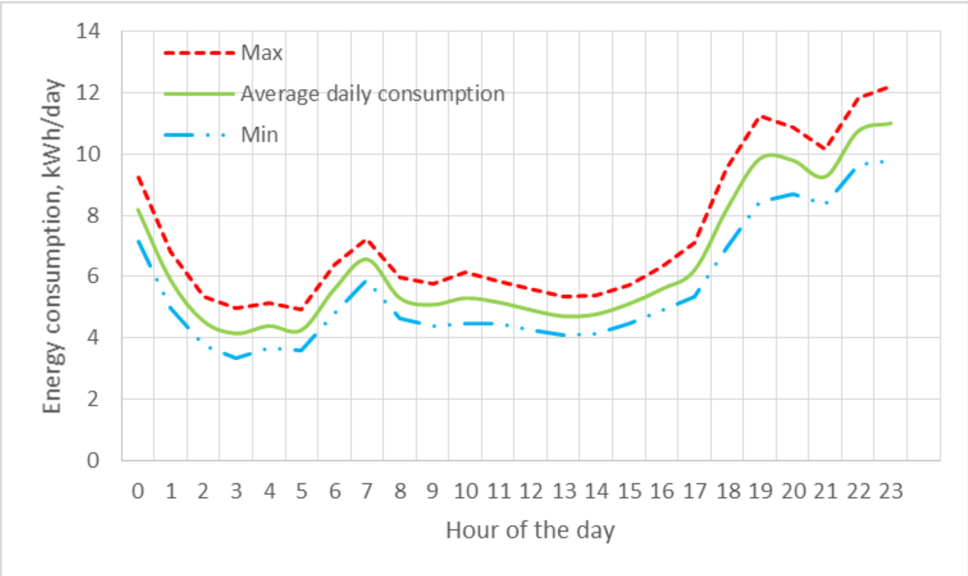

Fig. 3. Average daily energy consumption during the weekdays and the variation throughout the different months.

The situation is slightly different during the weekends (Fig. 4), when the morning peak is at approximately 11:00h, which is explained with the fact that people wake up later than usual. The other two peaks are again at 20:00h and 21:00h.

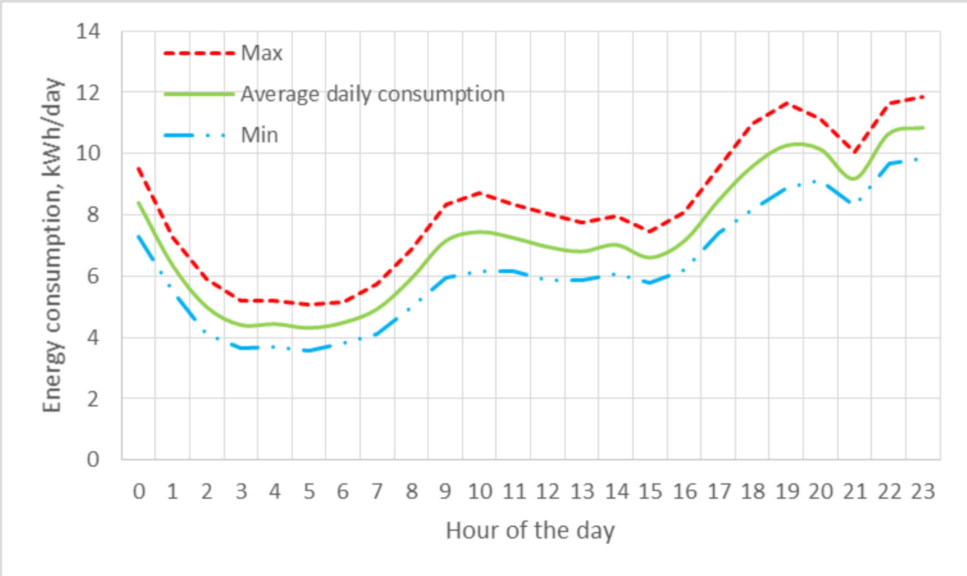

Fig. 4. Average daily energy consumption during the weekends and the variation throughout the different months.

The load profile has been normalized for three situations: during the weekdays, during the weekends, and on average (Fig. 5). The average one has one morning peak at 7:00h, caused by the weekdays, another smaller peak at 11:00h, caused by the weekends, and two significantly higher peaks, at 20:00h and 23:00h.

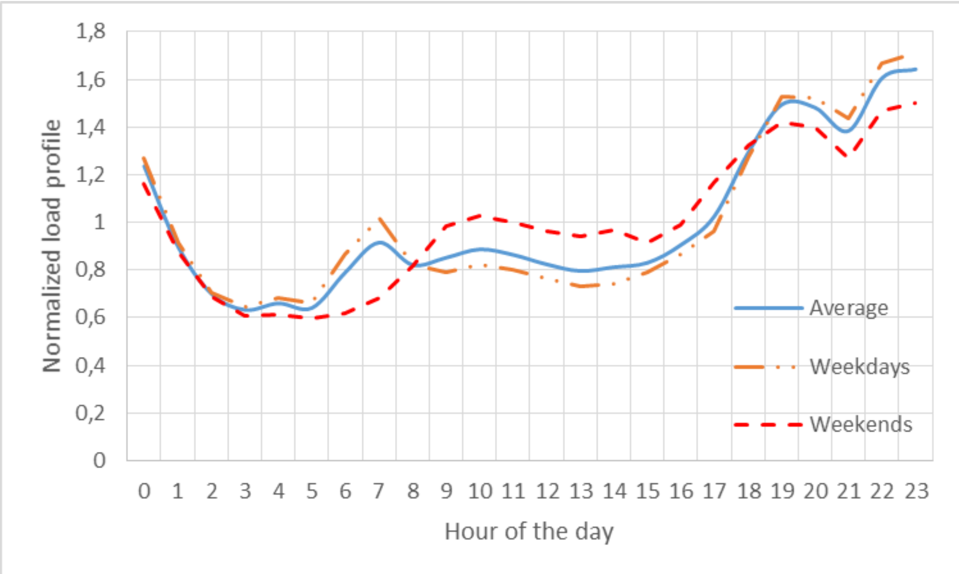

Fig. 5. Normalized load profile during the weekdays, weekends, and on average.

The obtained results show some similarities with studies in other countries [7], yet the peaks are happening in a different timeframe. On the one hand, in Bulgaria, the noon peak from the weekends is not so pronounced, and is approximately 1 hour earlier. On the other hand, the evening peak in Bulgaria is significantly higher and longer. Such a difference can be explained with the different culture and lifestyle.

4. Conclusions

This study presents an analysis of experimental data from 48 apartments in a Bulgarian block of flats, located in the city of Ruse. Hourly data of the energy consumption of each apartment since 2013 have been used for the analysis.

The obtained results demonstrate that during the weekdays there is one peak, early in the morning, around 7:00h, and then other two peaks at 20:00h and 23:00h when people spend their time at home.

During the weekends, the morning peak shifts to 11:00h, and the evening peaks remain the same. The average normalized load profile has been obtained in this study. The load profile has four peaks – at 7:00h, 11:00h, 20:00h, and at 23:00h, and the last two peaks are significantly higher. The results show that a substantial amount of the energy (more than 50%) is consumed during the dark hours of the day when there is no solar light.

The results provide some interesting data about the lifestyle in Bulgaria and show some differences from similar studies conducted in other countries. These results can be used to design renewable energy systems at residential buildings, to perform cost-benefit analysis of different energy saving investments, to design smart grids, and others.

5. Acknowledgment

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