Specific features and models of electric power consumption by household – type consumers

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In the paper, the results of analysis of the load curves for the household – type consumers fed from the LV electric power network are presented. In the study, the influence of the sunset time and ambient temperature on the electric load curves has been assessed and, consequently, the specific features of the graphs for the allocated consumer groups have been defined. Also, suitable models considering the impact of the observed factors on the electrical energy consumption have been developed. Energy consumption in the tariff zones by the consumers settled according to G12 tariff has been of special interest.

1. Introduction

Volume of the electric power sale as well as the development of the tariffs for consumers are predicted basing on the data from the electric power energy consumption recorded in the precedent years [1]. In the paper, selected results of studies on electric power consumption by chosen individual LV – fed household – type consumer groups are reported. The way of consumption of the electric power as well as administrative location of the consumer group was the main choice criterion. In addition, specific parameters of electric power load of the reported consumer groups are presented and the impact of external conditions on the load curves' run and values have been analyzed. In effect, the models mapping the relationship between the consumed power *versus* the sunset time (T_z) and temperature (ϑ) for groups evidently depended on such factors have been developed.

2. Characteristics of selected consumer groups

The input for the analysis were the power consumption time waveforms for 250 consumers settled according to the tariff G, fed from the LV network and located in the Wielkopolskie province [2]. The period under consideration was 2003 to 2006.

General description of the consumer groups under consideration with specific features underlined is presented in Table 1.

In Table 2, specific parameters of the annual waveform for considered consumer groups are listed: A_r – yearly power consumption, P_{dmax} – maximum recorded value of active power, T_s – peak power consumption period.

Lower values of T_s are for users with electric room heating. Also, the town–located consumers show higher T_s values than the rural ones with similar features.

Table 1. Specific features of selected consumer groups

Tariff group and consumer type	Consumer description		Group code
M – town-located W – rural	Electric water heater is in use	Electric room heating is in use	
G11 M	NON	NON	G11 M1
	YES	NON	G11 M2
G11 W	NON	NON	G11 W1
	YES	NON	G11 W2
G12 M	NON	NON	G12 M1
	YES	NON	G12 M2
	YES	YES	G12 M3

Table 2. Specific parameters of annual waveform

Consumer group code	P_{max} kW/consumer	A_r kWh/consumer	T_s h
G11 M1	0,74	2536	3450
G11 W1	0,84	2715	3251
G11 M2	2,24	5376	2400
G11 W2	2,84	6390	2250
G12 M1	1,37	5259	3836
G12 M2	1,97	6841	3471
G12 M3	4,09	10503	2568

3. Influence of external conditions

3.1. Scope of the study

Waveform and parameters of the electric power consumers depend on many factors describing both the consumer and the external conditions [3].

The study was mainly focused on how the sunrise and sunset times as well the air temperature affect the energy consumption. As the sunrise and sunset show a high linear relationship, the study has been limited to the analysis of the sunset

time influence on the shape and values of the electric power consumption by consumers. Moreover, the study has shown a nonlinear dependence between the average monthly values ϑ and the time T_z [4].

Regarding the high recurrence of the load waveform features in the selected consumer group in the successive years of recording, the averaged mathematical models mapping the influence of the factors taken into account (T_z i ϑ) can be developed for the entire period of observations.

3.2. G11 tariff group consumers

By the consumers that do not use the electric power for heating purposes (G11 M1 and G11 W1), a stronger dependence between the electric load's daily variations during the year and the T_z, variations is observed than for other consumers settled according to the G11 tariff [3] – Fig. 1.

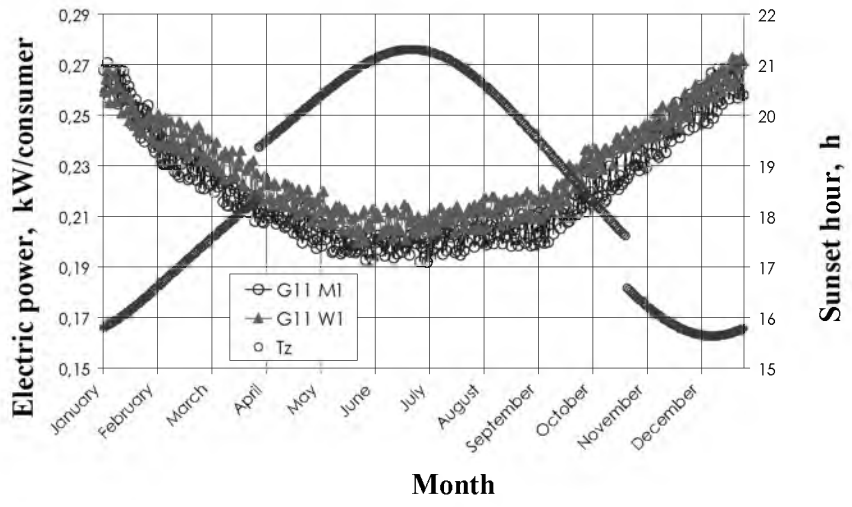

Fig. 1. Yearly variation of daily electric load in the G11 M1 and G11 W1 consumer groups and of sunset time (2004)

Such a conclusion is confirmed by the discussion of the correlation coefficient – Fig. 2. For the consumers belonging to the G11 M1 and G11 W1 groups, the coefficient values are evidently higher at the sunrise and sunset hours.

For consumers that do not use the electric power for heating purposes, the curve mapping the influence of the sunset hour on the energy consumption becomes a linear function. For illustration, a graph of relationship between the power consumed from the sunset by the G11 M1 group and G11 W1group consumers, for one year of recording, is presented in Fig. 3.

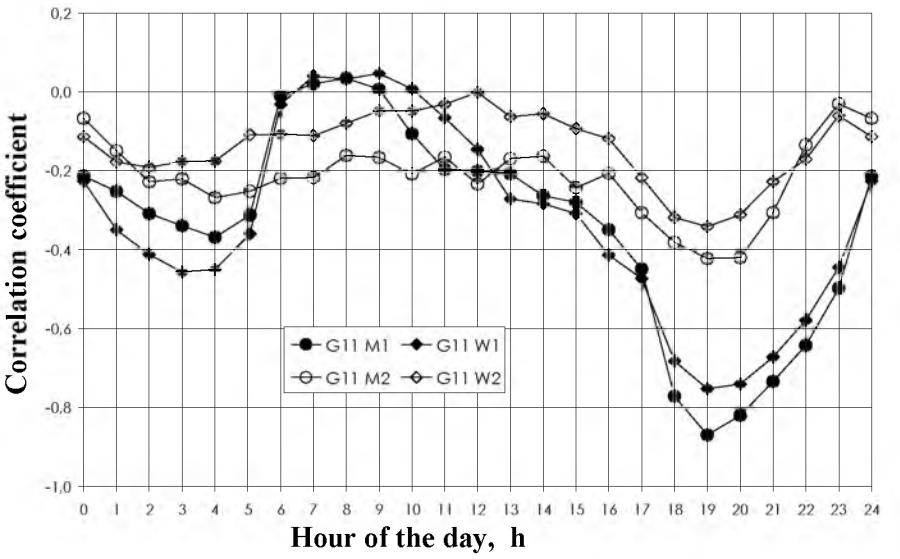

Fig. 2. Daily variation of correlation coefficient between the G11 group consumers and the sunset hour (2006)

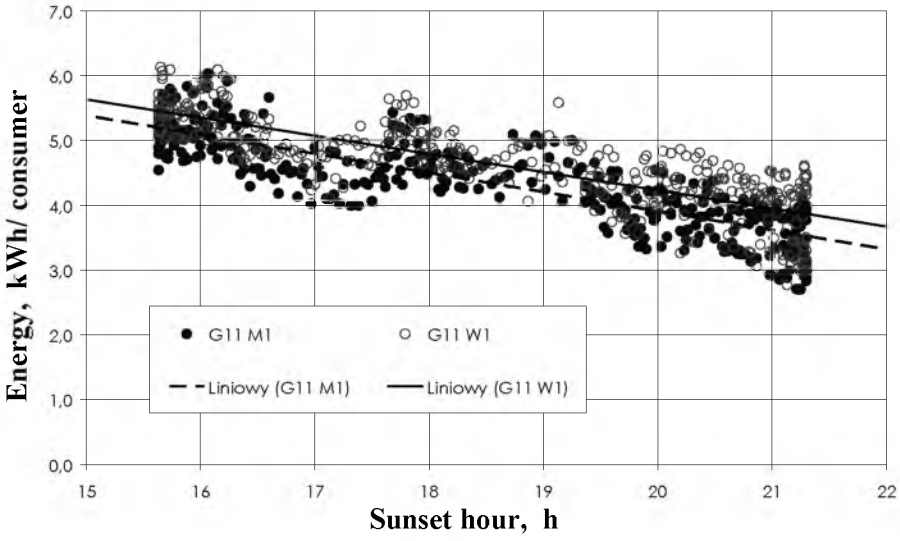

Fig. 3. Energy consumed daily by the G11 M1 and G11 W1 group consumers, from sunset hour (2006)

For entire observation period, the linear relationship between the energy consumed by these consumer groups from the sunset can be described by the formulas:

– for consumers belonging to G11 M1 group (where R^2=0,73):

$$A = 9{,}97 - 0{,}310 \cdot T_Z \tag{1}$$

– for consumers belonging to G11 W1 (where R^2=0,68):

$$A = 9{,}79 - 0{,}200 \cdot T_Z \tag{2}$$

where: $T_Z \in \left(15^{40} \div 21^{14}\right)$.

For consumers belonging to the G11 M2 and G11 W2 groups, influence of T_z on the electric load curve is evidently weaker. The influence of the sunset hour to the load values is noticeable during summertime. For these consumer groups, the evident relationship between consumed electric energy and the air temperature is noticeable when the temperature is lower than 15 °C – Fig. 4. In this range, a linear influence of the air temperature on the load parameters can be assumed.

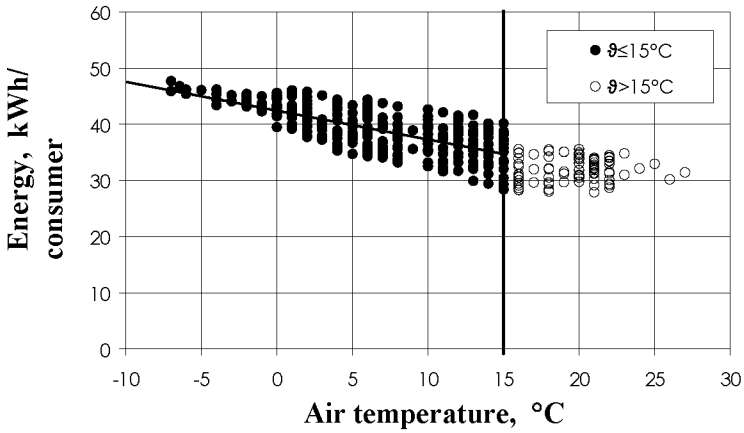

Fig. 4. Electric energy consumed daily by the G11 W2 group consumers *versus* air temperature (2006)

Averaged relationships between the consumed energy and the air temperature (for $\vartheta \leq 15$ °C), for complete period of observations can be expressed by a linear function in the forms:

– for consumers belonging to G11 M2 (where R^2=0,658):

$$A = 23{,}73 - 0{,}9255 \cdot \vartheta \tag{3}$$

– for consumers belonging to G11 W2 (where R^2=0,815):

$$A = 42{,}167 - 0{,}5178 \cdot \vartheta \tag{4}$$

3.3. G12 tariff group consumers

The waveform of the energy consumed by the G12 group consumers is significantly affected by the air temperature (ϑ). Also, a noticeable influence of the sunset hour on the G12 M1 consumer groups can be seen in the hours when the

expensive energy zone is involved. Such a conclusion is confirmed by the analysis of correlation coefficient between the consumed active power and the sunset hour – Fig. 5.

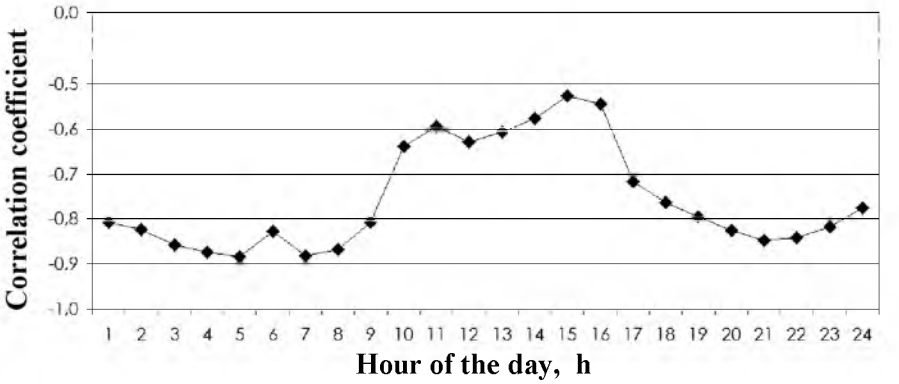

Fig. 5. Daily variation of correlation coefficient: load of the G12 M1 group consumers and the sunset hour (2004)

High values of the heating devices (compared to the power installed in the household for lighting purposes) results in the fact that the load graph for the consumers using electricity for heating purposes (G12 M2 and G12 M3) is strongly influenced by the air temperature – Fig. 6.

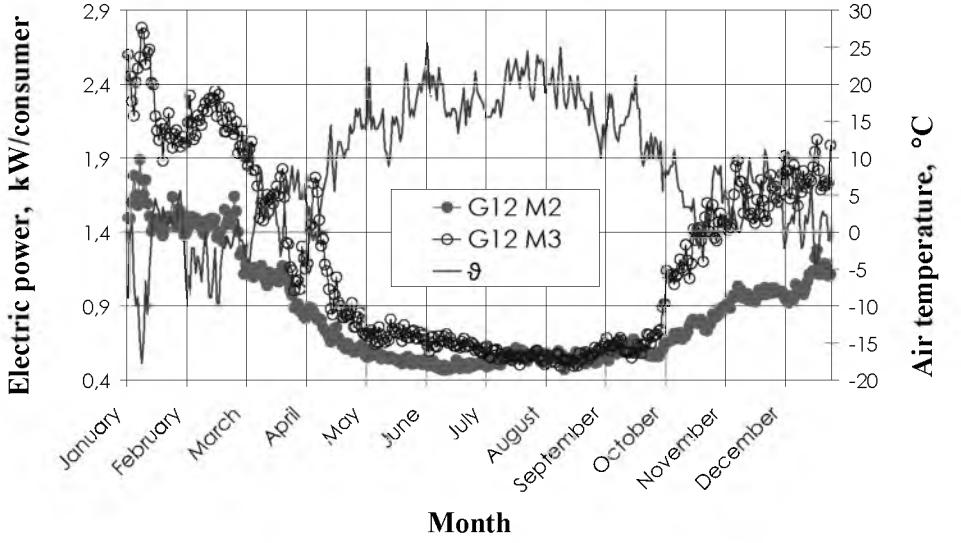

Fig. 6. Yearly variation for consumers belonging to the G12 M2 and G12 M3 groups and the average temperatures during a day (2003)

The conclusions are confirmed by the analysis of the daily variation of the correlation coefficient between average energy in the particular hours of the day and the average air temperature – Fig. 7. High correlation coefficient value in all hours of the day indicates that the air temperature has a strong impact all day long by the considered consumer groups (in both the *cheap* and the *expensive* energy time zones).

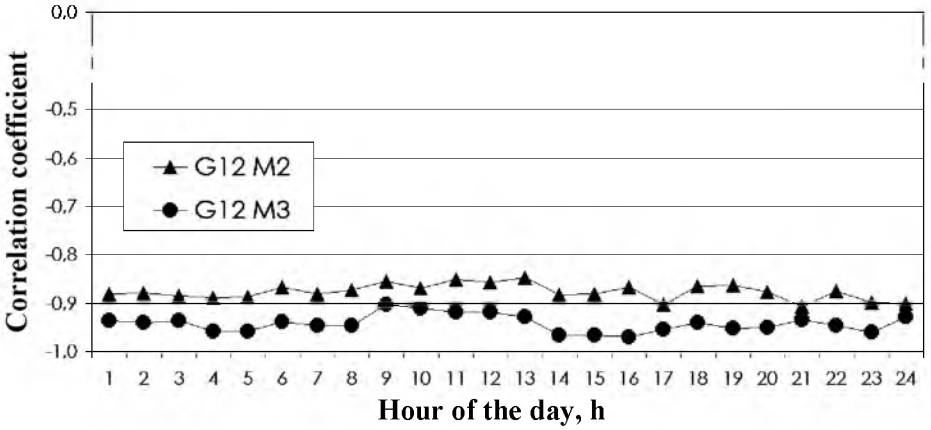

Fig. 7. Daily variation of correlation coefficient: load of the G12 M2 and G12 M3 groups and the air temperature (2005)

The influence of the air temperature on the consumed energy value is the most noticeable by the consumers belonging to the G12 M3 group characterized by the highest values of consumed power comparing to the other consumer groups. The correlation coefficient value calculated for the year reaches the highest value and is r_{xy} = -0,918 whilst for G12 M2 is r_{xy} = -0,863. Influence of the air temperature is noticeable when it is lower than 15 °C. For the entire registered time period, influence of the air temperature (when $\vartheta \leq 15$ °C) on the consumed energy volume can be expressed using the linear function in the forms:

– for consumers belonging to G12 M2:

$$A = 24{,}4 - 0{,}592 \cdot \vartheta \tag{5}$$

– for consumers belonging to G12 M3:

$$A = 45{,}2 - 1{,}69 \cdot \vartheta \tag{6}$$

Influence of the air temperature on the values of energy consumed in the zones of the G12 tariff is different in two groups under consideration. In figures 8 and 9, examples of dependence between the energy consumed in the S I zone (*expensive* energy) and the S II zone (*cheap* energy) and the air temperature for selected year of observation are shown.

For entire observation period, a linear dependence energy consumption in tariff zones *versus* air temperature is expressed by the formulas:

a) for consumers belonging to G12 M2:

– for S I:

$$A_d = 13{,}09 - 0{,}276 \cdot \vartheta \tag{7}$$

– for S II:

$$A_d = 11{,}21 - 0{,}308 \cdot \vartheta \tag{8}$$

b) for consumers belonging to G12 M3:

– for S I:

$$A_d = 21{,}29 - 0{,}753 \cdot \vartheta \tag{9}$$

– for S II:

$$A_d = 23{,}09 - 1{,}04 \cdot \vartheta \tag{10}$$

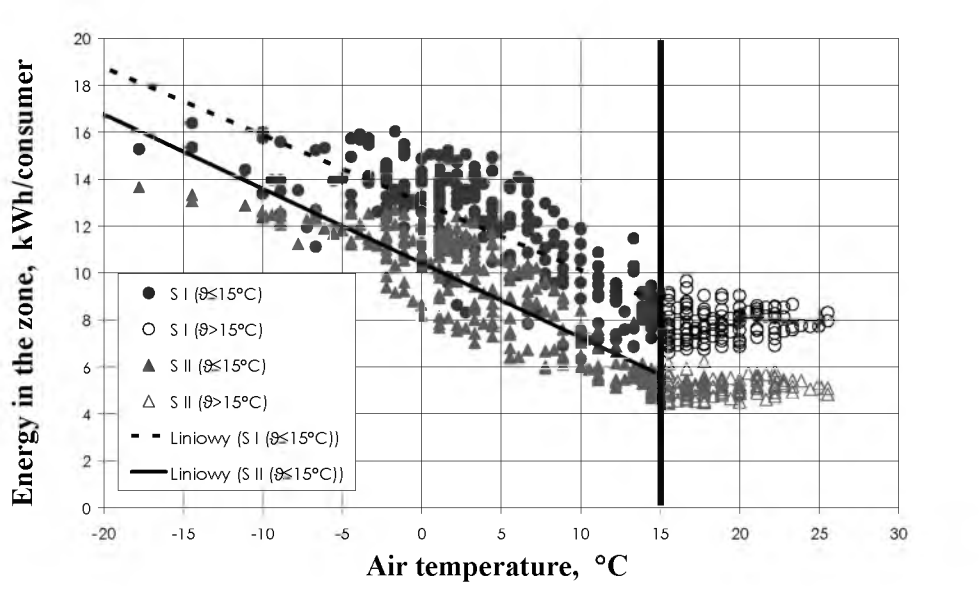

Fig. 8. Electric energy consumed by the G12 M2 group consumers in different tariff zones *versus* air temperature

For consumers belonging to G12 M2 group, energy consumption in the S I zone is always by 5 to 10 % higher than in the S II zone – Fig. 10. And, in wintertime, for consumers belonging to G12 M3, the energy consumption in the S II zone is by 2 to 9 % higher than in the S I zone – Fig. 11. It can be seen that the power consumption by the G11 M3 group consumers is higher in the S II zone than in the S I zone when the temperature falls below 5 °C (Fig. 9).

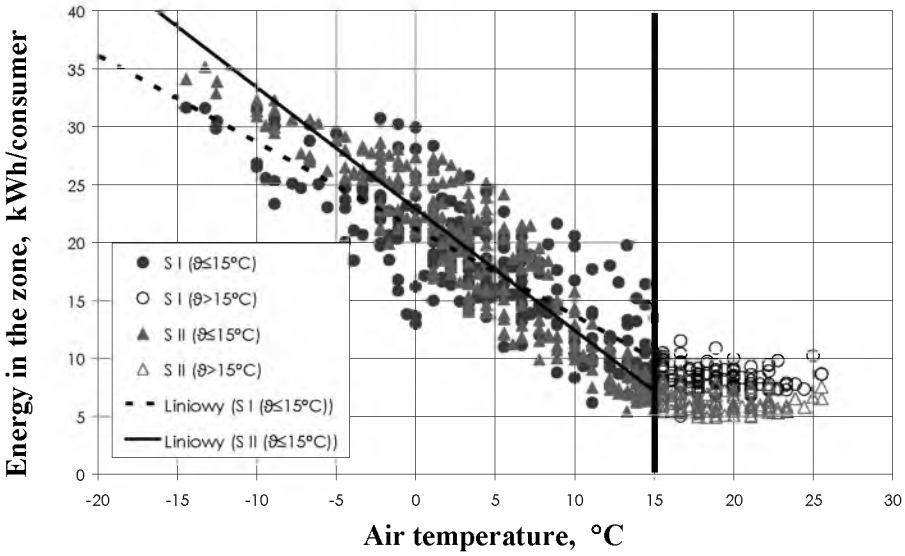

Fig. 9. Electric energy consumed by the G12 M3 group consumers in different tariff zones *versus* air temperature

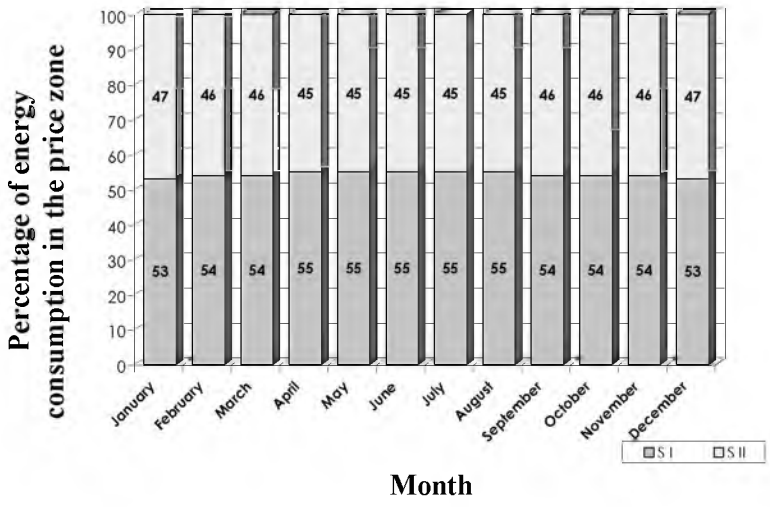

Fig. 10. Monthly share of the energy consumption by the G12 M2 consumers in the (S I, S II) price zones

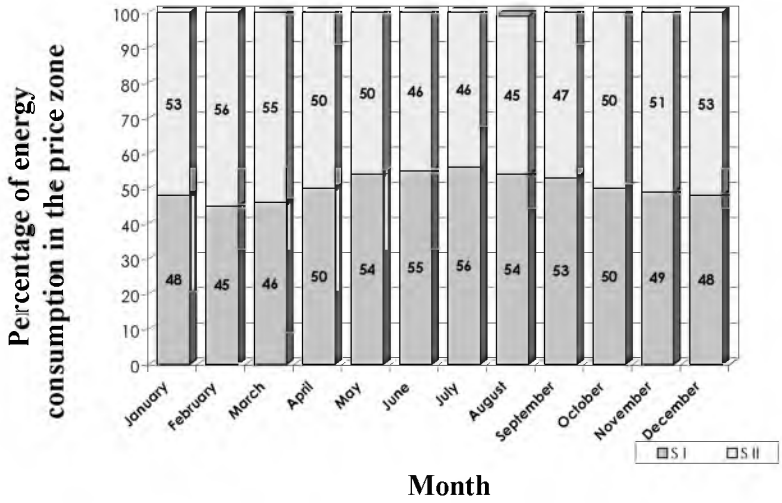

Fig. 11. Monthly share of the energy consumption by the G12 M3 consumers in the (S I, S II) price zones

4. Conclusion

The analysis has shown a diversified impact of external conditions, i.e. sunset hour and air temperature, on the values and shape of the power consumption graphs for the house–hold type consumers.

A sunset hour is a significant factor affecting the power consumption graph for consumers settled according to the G11 tariff; and it is especially marked by the consumers belonging to the G11 M1 and G11 W1 groups which do not use the electricity for heating purposes. To some extent, the air temperature's influence is noticeable in the G11 M2 and G11 W2 groups when the air temperature falls below 15 °C. For temperatures over 15 °C, the sunset hour's influence on the energy consumption is prevailing.

For consumers belonging to G12, the air temperature's influence on the consumed energy is prevailing. However, for G12 M1 consumer group, the sunset hour's influence is also noticeable in the *expensive* energy price zone (afternoon, as the T_z is involved) when the air temperature exceeds 15 °C.

Strong and very strong influence of the air temperature on the consumed energy value is observed by the G12 M2 and G12 M3 consumer groups.

In tables 3 and 4 (G11 consumers and G12 consumers, respectively), results of assessment of the influence of the considered conditions on the values presented on the graph of electric power consumption are listed. The assessment has been carried out according to the Guilford scale [5].

Table 3. Influence of external conditions on the energy consumption by consumers belonging to G11 tariff

Group code	T_z	ϑ*
G11 M1	strong	no influence
G11 W1	strong	no influence
G11 M2	weak	weak
G11 W2	weak	weak

- *– when value $\vartheta > 15$ °C, no influence of the factor is observed (unnoticeable influence)*

Table 4. Influence of external conditions on the energy consumption by consumers belonging to G12 tariff

	T_z			ϑ		
Group code	All day around (24h)	S I	S II	All day around (24h)	S I	S II
G12 M1	weak	moderate*	no influence	moderate	weak	strong
G12 M2	no influence	no influence	no influence	strong	strong	strong
G12 M3	no influence	no influence	no influence	very strong	very strong	very strong

S I – in the hours the expensive *energy is involved,*
S II – in the hours the cheap *energy is involved,*
** – mostly noticeable in the summertime (15-22)*

Developed models and study results for successive years are recurrent and can be helpful when estimating the energy consumption by particular consumer groups regarding the external conditions.

References

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