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The impact of the mean daily air temperature change on electricity consumption

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ABSTRACT

This paper presents the analysis of the impact of weather conditions on the consumption of electricity in the City of Kragujevac (the Republic of Serbia) during the seven-year period from 2006 to 2012. It points out the mean daily air temperature as the most influential climate (meteorological) parameter, and gives an overview of deviations from the mean values compared to the reference period. Increases and decreases in the power consumption depending on the deviations of the mean daily temperature from the normal (average) values are also indicated. In periods of strong and long-lasting cold spells in the winter months, there is increased power consumption as a result of heating in residential and office buildings. During extremely hot and long summer periods, there is also a tendency of increasing electricity consumption because of home air conditioning. In the transitional seasons, especially when the remote heating system is not active, sudden and relatively long periods of cold weather also have a significant influence on increases in the electricity consumption. A timely and accurate weather forecast can certainly help prevent the electrical power system overload and reduce the risk of possible power system damages.

1. Introduction

A growing demand for energy, reductions in reserves of energy resources, primarily in reserves of fossil fuels and climate changes have resulted in an increasing number of studies on the influence of weather conditions on energy consumption.

In recent decades, we have witnessed climate changes for which most scientists believe to be of an anthropogenic origin. An enormous consumption of fossil fuels has led to significant increases in concentrations of greenhouse gases (CO_2, CH_4, NO_2, etc.) which are considered the main cause of the increase in the global average temperature. Climate changes and unpredictable weather conditions make it difficult to give good estimates of electricity consumption.

Generally, the residential sector has a significant share of the total electricity consumption. The residential sector electricity consumption is influenced by various factors such as weather, climate (zones, seasons), climate warming, residence location, residence design, occupant behaviour and socio factors.

Therefore, changes in weather conditions influence electricity consumption in residences. They often cause undesirable peaks [1] in the total electricity consumption. Valor et al. [2] examined the relationship between the changes in the daily air temperatures and the load of the electric power system in Spain. Bessec and Fouqueau [3] reported the non-linear link between the electricity consumption and the temperature in European Union. Valor et al. [2] found out that the power demand was linked to several other weather variables. Sailor and Munoz [4] found out that the power demand was linked to changes in the wind speed and direction and changes in the relative humidity. The influence of solar radiation and wind exposure of residences on the electricity consumption was documented by U.S. Energy Information Agency [5].

Sailor and Munoz [4] reported a variation in the electricity consumption for different climate zones. Lam et al. analysed [6] the impact of different seasons on the electricity consumption in the residential sector in Hong Kong. In addition, Ranjan and Jain [7] modelled the electricity consumption in Delhi as a function of different seasons (winter, summer and post-monsoon).

Climate warming has caused decrease in heating costs for both electricity users and in carbon markets in Central and North Europe according to Pilli-Sihvola et al. [8]. In Southern Europe, climate warming has brought about increases in cooling and electricity

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demand. Valor et al. [2] revealed that the sensitivity of electricity load to the daily air temperature had increased along time, in a higher degree for summer than that for winter, although the sensitivity in the winter is always more significant than that in the summer. Amato et al. [9] investigated regional electricity demand responses to climate change in the Commonwealth of Massachusetts.

The residence location influences the electricity consumption as stated by the U.S. Energy Information Agency [5]. Santamouris et al. [10] found that due to heat island effect, the cooling load of the residences centrally located in the city would be doubled, the peak electricity load for cooling tripled, and the COP (coefficient of performance) of air conditioners decreased. During winter, however, the heating load of the centrally located urban buildings would be reduced.

Tso and Yau [11] studied how the number of the household members influenced the electricity consumption in Hong Kong. The electricity consumption also depended on occupant behaviour [5,12,13]. Valor et al. [2] found a “comfort interval” and two saturation points beyond which the electricity load did not increase. Hart and Dear [14] analysed the sensitivity of household appliances use (refrigerators, air conditioners, and heating) to the electricity consumption in Sydney, Australia. In Hong Kong, Tso and Yau [11] found out that the ownership of air conditioners influenced the electricity consumption.

Ugursal and Fung [15] found that power demand was linked to the socio-cultural factors, while Valor et al. [2] found it was linked to the socioeconomic factors.

The objective of this paper is to present data on the mean temperature and the electricity consumption for a seven-year period in the City of Kragujevac and then to determine the impact of extreme changes in the mean daily temperature on the power consumption in its residential and commercial sector.

The investigation took into the account the local climate characteristics. The influence of deviations of the mean daily temperatures on the changes in the electricity consumption cannot be the same in different climate zones. There is a general approach to this investigation but the expected results would have a local character. So far, there have not been significant studies in this field in the Republic of Serbia, or in the wider area of the Balkans.

In this research, the influence of house characteristics, occupancy, and socio factors to the electricity consumption will not be presented.

2. Methods

2.1. Location

The City of Kragujevac (44.02° latitude and 20.93° longitude) has an altitude of about 200 m with a moderate continental climate with four distinct seasons. January is on average the coldest month in the year and July is the warmest. The heating season starts on 15th October and lasts for six months.

2.2. The obtained data

Temperature measurements were performed at the meteorological station of the City of Kragujevac. The station recorded variations in the mean daily air temperature for a seven-year period (from 1st January 2006 to 31st December 2012).

The mean daily temperature was calculated based on the equation

$$t_{md} = \frac{1}{24}\sum_{i=1}^{24} t_{hi} \tag{1}$$

where t_{hi} stands for the measured temperature value for each hour i. The mean daily temperatures were used to calculate the mean monthly temperature as

$$t_{mm} = \frac{1}{n_d}\sum_{i=1}^{n_d} t_{mdi} \tag{2}$$

where t_{mdi} stands for the mean daily temperature for the i-th day of the month and n_d stands for the number of days in the month ($n_d = 28$, 29, 30 or 31).

Fig. 1 shows the average values of the mean daily temperatures for Kragujevac (for the period from 1961 to 1990) for each day of the year. For further analysis, the formula of the so called “ideal” curve ($R = 0.9923$) for the average daily air temperature was obtained as:

$$y = 0.000000018384x^4 - 0.000014585x^3 + 0.0031x^2 - 0.0806x + 0.4025 \tag{3}$$

The data on electricity consumption were taken from the TS (transformer station) Kragujevac 2. This transformer station supplies the main residential area with no significant industrial plants.

The TS Kragujevac 2 delivers electrical power to the largest part of the City of Kragujevac (about 200,000 inhabitants). Since this is mainly a residential area, the ratio of residential to industrial power consumption is 9:1. TS Kragujevac 2 supplies 105,000 consumers, 98,000 of which are residential. This transformer station supplies power only to 58 industrial consumers – 57 of them are supplied with medium voltage electricity (10 kV and 35 kV) and one of them is supplied with high voltage electricity (110 kV). Public lightning has 692 connections.

It is significant to note that in the area covered by the TS Kragujevac 2, there are about 11,000 natural gas connections and 27,000 users of the district heating system.

Therefore, the structure of the electric power system of the TS Kragujevac 2 is such that the impact of the air temperature variations on the electricity consumed for heating or cooling in residential premises is high.

The price of fuels (gas, coal, fuel oil, wood, electric power) is certainly an important factor with a great influence on the intensity of the power consumption. The object of our further investigations will be to determine a more accurate correlation between the meteorological (climate) parameters and the electrical power consumption.

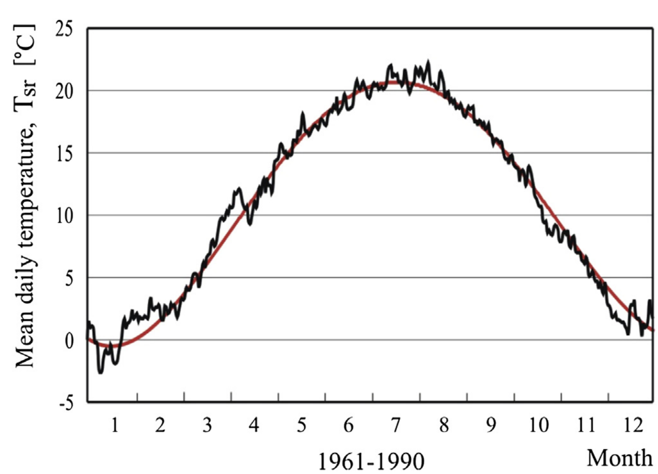

Fig. 1. The mean daily temperatures for the period 1961–1990 for Kragujevac.

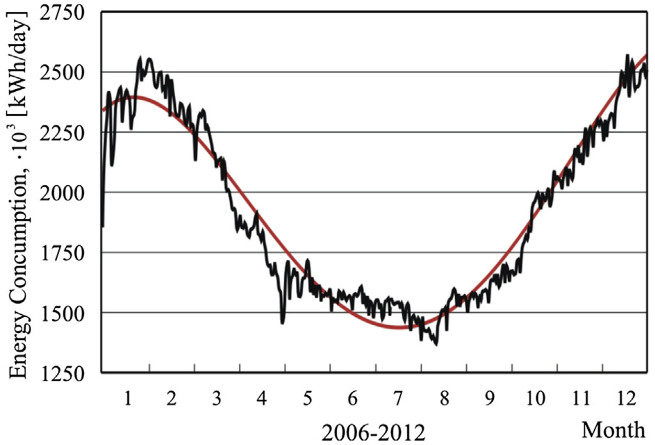

Fig. 2. The daily power consumption in the region covered by TS Kragujevac 2 during a year.

Both in the City of Kragujevac and in the whole Republic of Serbia, a relatively high percentage of inhabitants uses electrical energy as a primary source for heating, additional heating or cooling of residential and office buildings. This is due to the fact that electrical energy has for decades been one of the cheapest energy sources in Serbia. However, since production potentials of the electricity generating system of the Republic of Serbia vary by season, an urgent import of electrical energy is quite often required, especially in the winter. Therefore, it is vital to establish the correlation between the expected electricity consumption and changes in the mean daily air temperatures as precisely as possible.

3. Results

This research involved recording of average daily power consumptions in the region covered by TS Kragujevac 2 during the seven-year period. Fig. 2 shows a diagram of average daily consumptions as well as the so called "ideal" curve for that period. The function of the "ideal" dependence ($R = 0.9722$) of the daily power consumption on the ordinal number of the day in the year is also shown:

$$y = -0.0009x^4 + 0.7386x^3 - 164.6243x^2 + 6102.8023x + 2332800 \quad (4)$$

Diagrams of mean daily temperatures and daily electricity consumptions for the period from 2006 to 2012 are also given in Figs. 3–9. The gradual increase in the number of customers and in the number of electrical devices that burden the system is not considered.

4. Discussion

Figs. 3–9 shows the obvious congruence of significant changes in the average daily temperatures and the changes in power consumption. Peaks in the power consumption (circled peaks in the diagrams) correspond to the peaks in the mean daily temperatures.

In the winter months, there is a need for additional heating of residential premises. The amount of the electrical power consumed for additional heating depends on a number of factors. Based on the peak intensities in the shown diagrams (Figs. 3–9), it can be concluded that the intensity of external temperature variations is a

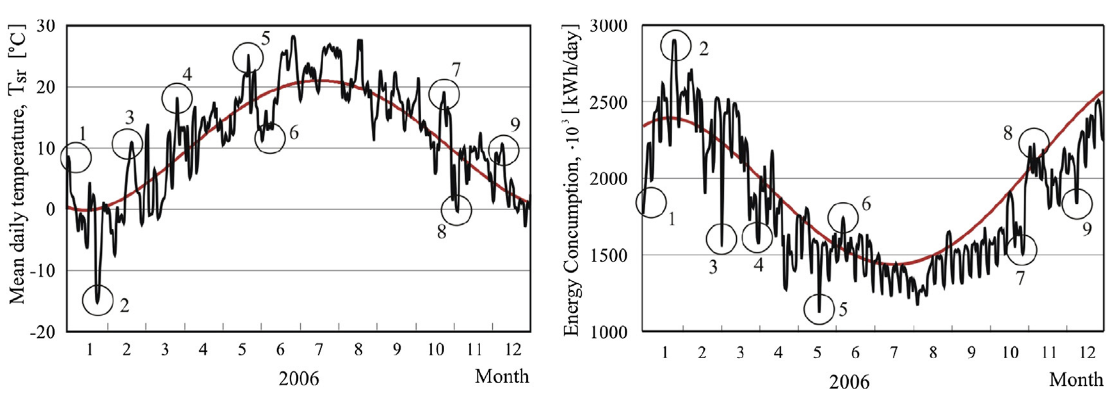

Fig. 3. Mean daily temperatures and daily electricity consumptions for 2006.

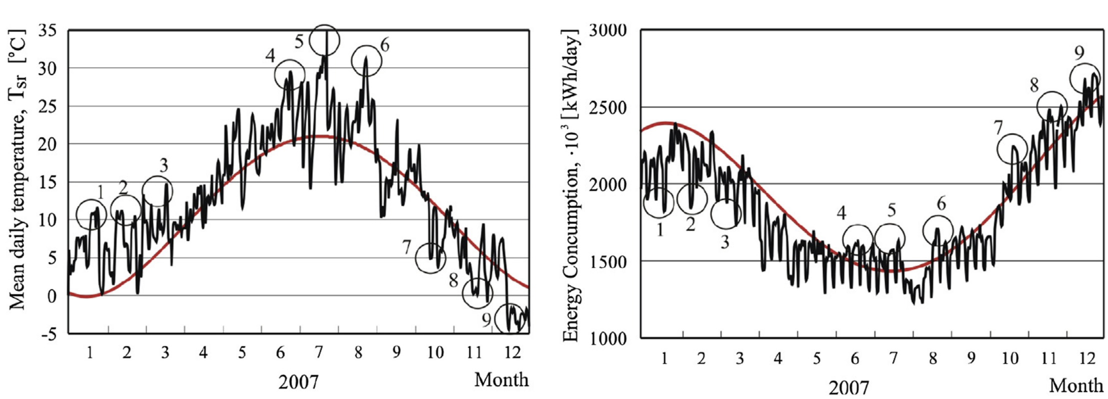

Fig. 4. Mean daily temperatures and daily electricity consumptions for 2007.

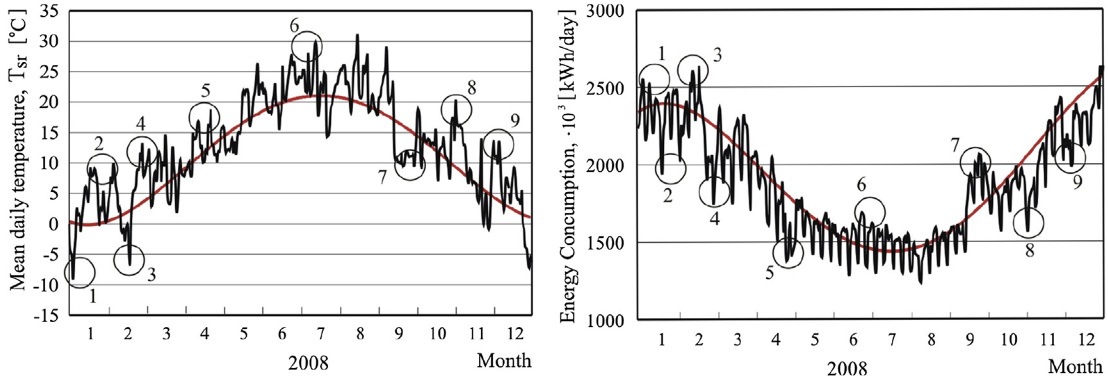

Fig. 5. Mean daily temperatures and daily electricity consumptions for 2008.

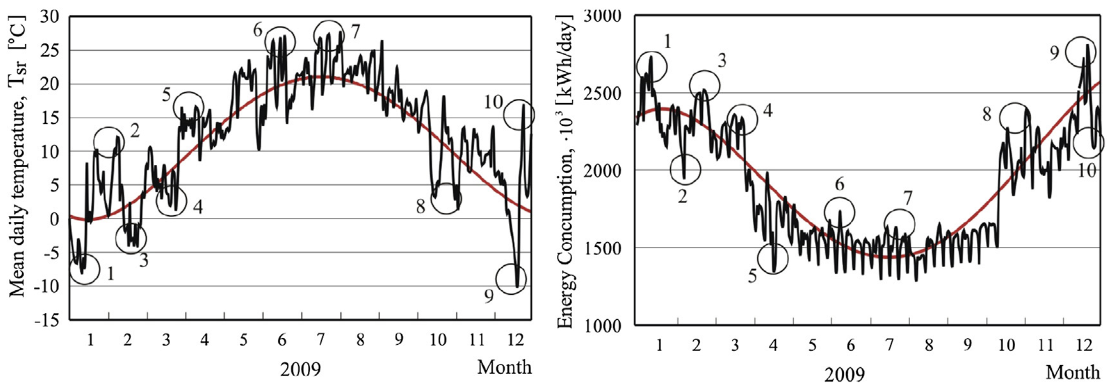

Fig. 6. Mean daily temperatures and daily electricity consumptions for 2009.

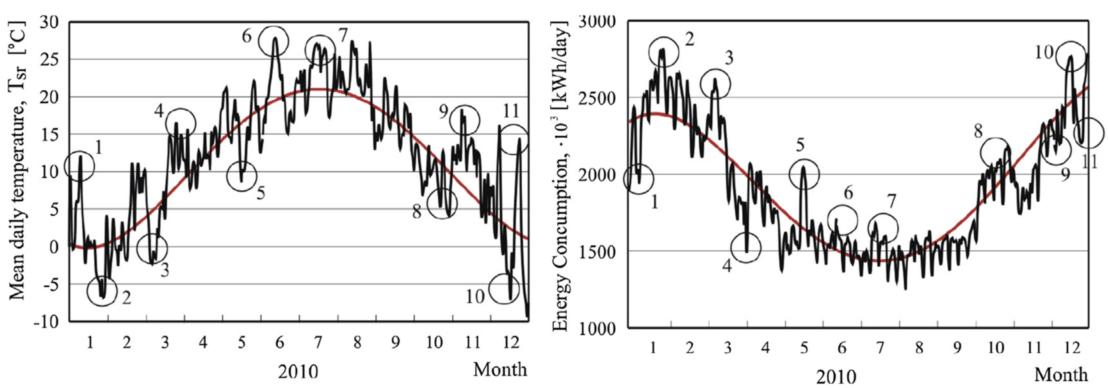

Fig. 7. Mean daily temperatures and daily electricity consumptions for 2010.

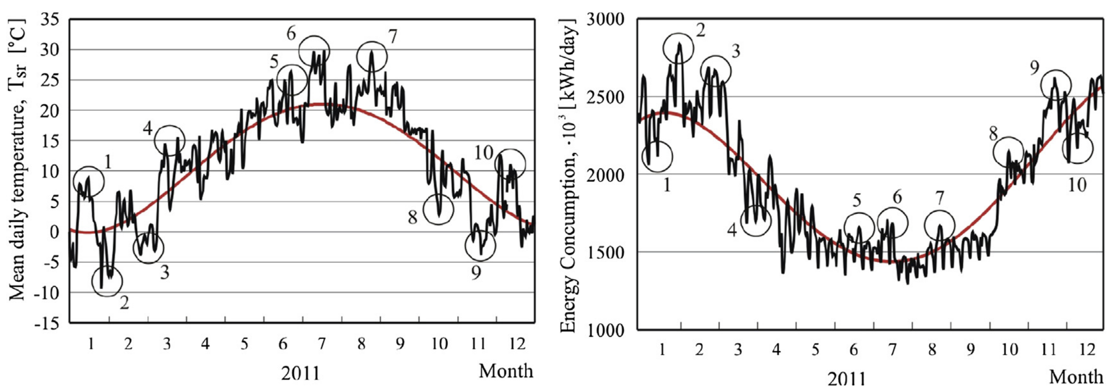

Fig. 8. Mean daily temperatures and daily electricity consumptions for 2011.

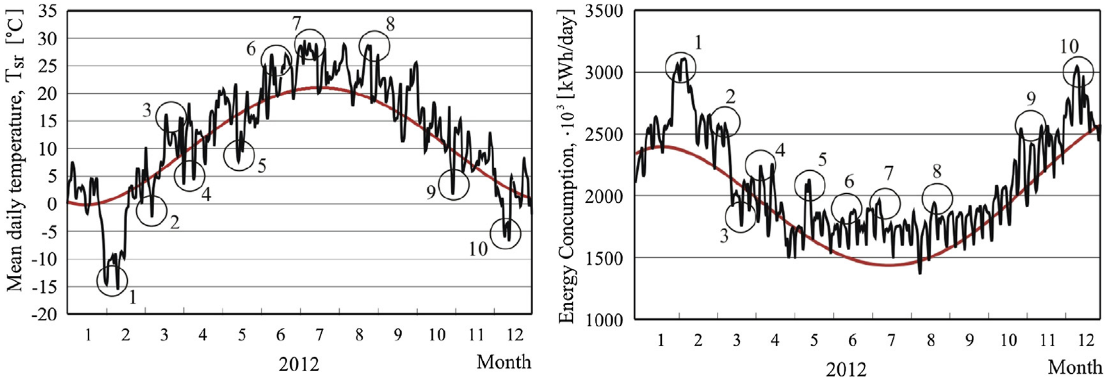

Fig. 9. Mean daily temperatures and daily electricity consumptions for 2012.

predominant factor with a great influence on the quantity of the additionally consumed electrical power.

Table 1 shows the number of minimum and maximum power consumption peaks by season, marked as period A, period B, period C and period D.

The highest frequency of the power consumption peaks is recorded for the periods A and B, then for the period D and finally, the lowest frequency is registered for the period C.

Diagrams in Figs. 10–13 show how the changes in the daily electricity consumption (ΔEC) depend on deviations of the mean daily air temperatures from the average values obtained (Δt) using the formula (3). For the periods A, B, C and D, dependences $\Delta EC = f(\Delta t)$ are shown. Optimum regression models are used to describe the functional dependence for each of the characteristic periods.

Table 1
Power consumption peaks by season.

	Period A	Period B	Period C	Period D	Σ
2006	4	3	1	1	9
2007	3	3	0	3	9
2008	5	2	1	1	9
2009	5	3	0	2	10
2010	4	4	1	2	11
2011	3	4	0	3	10
2012	2	4	1	3	10
Σ	26	23	4	15	68
%	38.2	33.8	5.9	22.1	100

Period A: 1st December – 28th/29th February (heating season, cold period).
Period B: 1st March – 15th April & 16th October – 30th November (heating season, moderately cold period).
Period C: 16th April – 31st May & 1st September – 15th October (non-heating season, moderately warm period).
Period B: 1st June – 31st August (cooling season, warm period).

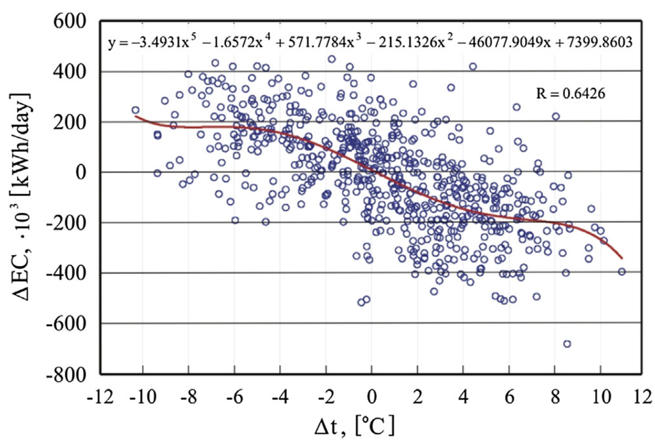

Fig. 11. Dependence of the change in the electricity consumption on the deviation of the mean daily air temperature – period B.

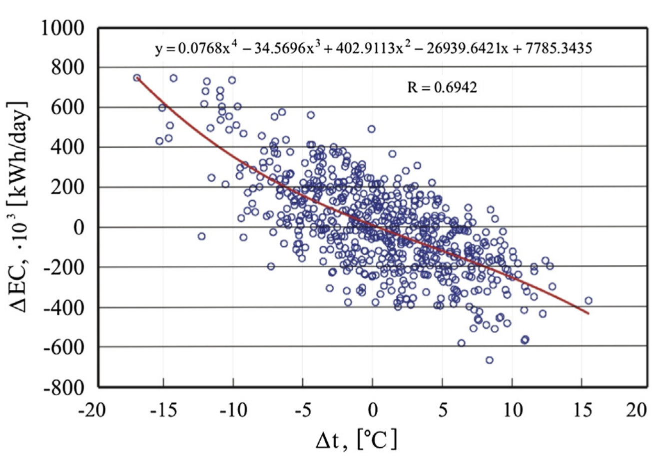

Fig. 10. Dependence of the change in the electricity consumption on the deviation of the mean daily air temperature – period A.

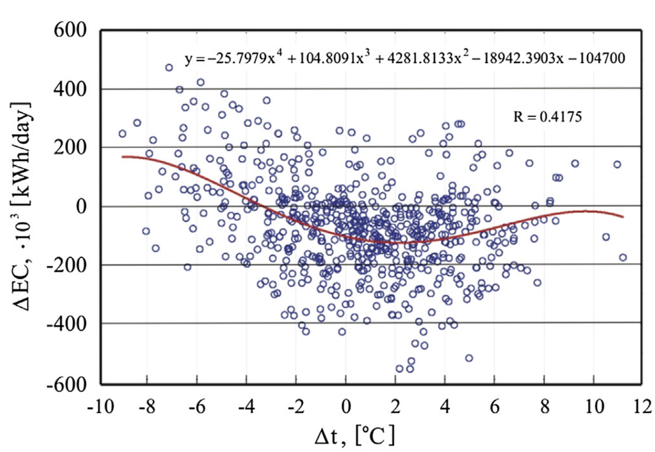

Fig. 12. Dependence of the change in the electricity consumption on the deviation of the mean daily air temperature – period C.

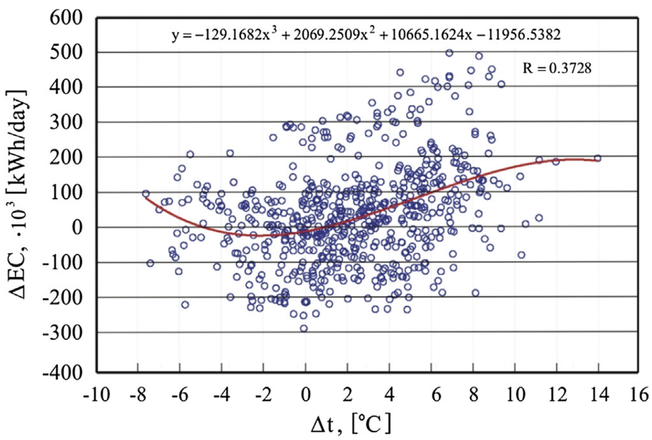

Fig. 13. Dependence of the change in the electricity consumption on the deviation of the mean daily air temperature – period D.

A dramatic decrease in the electricity consumption that correlates with increases in Δt (Fig. 10) is characteristic for the winter period A. For the rest of the heating season (period B) which is characterised with somewhat warmer weather, the curve ΔEC = f(Δt) is similar but with a slightly less inclination.

On the other hand, a middle zone with negative deviations in electricity consumption is noticed in diagrams in Figs. 12 and 13. Extreme temperatures cause increases in the electricity consumption. In the zone of high temperature deviations, this increase is higher for negative deviations in the period C. During the period D, the electricity consumption increases significantly for higher positive temperature deviations.

The length of strong cold spells and the length of warm spells in the winter months also influence the electric power consumption. Other factors that influence the intensity of power consumption peaks include usage of fuels, periods of major religious and state holidays, prices of fuels, construction characteristics of the buildings, etc.

Due to obvious climate changes, periods of extremely hot weather in summer have become both more frequent and longer. During these periods, air conditioners are intensively used for cooling in residential premises; therefore, electrical power consumption is significantly increased.

In transient periods (autumn and spring), when the remote controlled heating system is not active, there is an increased risk of overloading the electric power system.

Geographic location and the climate zone influence the overall dependence of the electric power consumption on different weather conditions.

It is observed that there are high peaks in the power consumption associated with high (summer) and low (winter) temperature peaks.

There are also some variations in the power consumption for minor changes in the air temperature, but they could hardly affect the operation of the electric power system.

5. Conclusion

It is obvious that there is a strong correlation between changes in the external temperature and electricity consumption in the residential and commercial sector. Based on the diagrams of the power consumption for the seven-year period (2006–2012) for the City of Kragujevac, it can be concluded that there is high electricity consumption in the residential and commercial sector as a response to extreme changes in the mean daily air temperature.

Based on the data on the mean daily temperature values gathered at a particular location and based on the corresponding daily electric power consumption, reliable regression models can be obtained. These regression models describe the dependence of these two values for different characteristic periods during a year.

Electricity distribution companies could benefit a lot from more accurate and reliable predictions of electric power consumption based on weather (temperature) forecast. Lower air temperatures (in winter) present a greater danger to operation of the electric power system because the system is already heavily loaded in winter. A timely and accurate weather forecast followed by an appropriate response from both those in control of the power system and the consumers can certainly contribute to electricity savings and prevent power system damages with serious consequences.

Acknowledgement

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