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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

$$t_{md} = \frac{1}{24}\sum_{i=1}^{24} t_{hi} \quad (1)$$

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

$$t_{mm} = \frac{1}{n_d}\sum_{i=1}^{n_d} t_{mdi} \quad (2)$$

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:

$$y = 0.000000018384x^4 - 0.000014585x^3 + 0.0031x^2 - 0.0806x + 0.4025 \quad (3)$$

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.

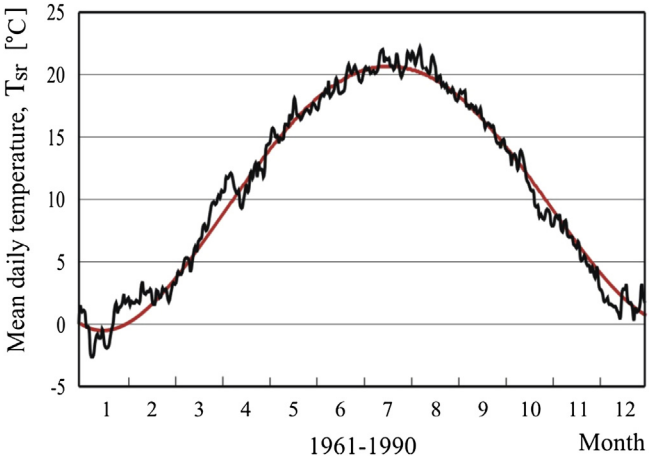

Fig. 1. The mean daily temperatures for the period 1961–1990 for Kragujevac.