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Investigating Effect of Temperature Fluctuations on Electricity Consumption in Babolsar

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ABSTRACT

One of the most important factors in energy consumption is environmental conditions. This study aims to examine the relationship between temperature and electricity consumption in Babolsar city in Mazandaran province. The main issue in this study is to find different patterns of relationship between temperature and electricity consumption in this city. Daily electricity consumption and daily temperature, were collected from 1 Jan 2010 to 31 Dec 2019, from the Electricity Department and the Babolsar Synoptic Station. Threshold regression method was used to find the breakpoints of the regression line between temperature and power consumption. Findings revealed there were 3 distinct thresholds in the relationship between consumption and temperature. The first threshold was about <20 ±3 ° C. The last threshold was 26 ±1≥ and the middle threshold was between these thresholds. The sensitivity of electricity consumption of the third threshold temperature is the most. Examination of the trends of the thresholds showed that the first and second threshold temperatures had a decreasing trend and the third threshold trend was increasing. Due to the increase in the number of temperatures of the third threshold, which electricity consumption is most sensitive to these temperatures, this case should be considered by managers in electricity management.

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INTRODUCTION

Energy is a key requirement for the survival of modern societies. The role of energy in the industrial development and economic growth of today's world is crucial. One of the most important forms of energy is electrical energy, which has an important effect on economic development, technological advances and politics. Despite human progress, in many countries, the need for electricity has not been met in many cities and villages. This form of energy cannot be stored and it is very important to manage and forecast the consumption demand [1, 2].

Undoubtedly, the demand for electricity also changes according to weather conditions [3]. Rising temperatures will increase energy demand. Higher temperatures are generally expected to increase electricity demand for cooling [4, 5]. At moderate temperatures, humans do not feel the need to generate heat by heating or expel it with the help of air conditioners. With increasing or decreasing temperature and loss of human comfort, we had to use energy to create the optimal condition by decreasing or increasing ambient temperature. It is natural that the amount of this increase in energy consumption is a function of the distance between the ambient temperature and the optimum comfort temperature (around 18°C). Conevska and Urpelainen [6] find a strong, positive relationship between electricity consumption and temperature in India. This finding indicated weather is an important consideration for electrification efforts.

Generally, in some parts of the world where the temperature is so moderate people do not use electricity to create a comfortable environment. Sultry summer weather, in particular, forces people to use air conditioners to create a comfortable environment. The

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usual expectation is that with increasing temperature, the amount of electricity consumption will increase, but in some European countries, such as Serbia [7], Germany and Sweden, the increase in electricity consumption occurs with increasing and decreasing temperature [8]. Therefore, the effectiveness of consumption is associated with low temperatures in the cold season and high temperatures in the hot season. But in some parts of the world, like Iran, electricity is mainly used for cooling, and fossil fuels are used for heating. Today, electricity consumption to cooling is increasing, which can be related to demographic, social and economic factors. The increase in consumption is due to the widespread use of electrical appliances, especially air conditioners, to cool rooms [9], population growth and change of lifestyles.

A study of the relationship between cooling degree-day (CDD) and electricity consumption in Kuwait showed that a 10% increase in CDD in the summer months is accompanied by an increase of 100 to 150 million kWh electricity consumption [10].

Yan [9] investigated the relationship between climate parameters and energy consumption in Hong Kong. This study showed that air temperature is highly correlated with electricity consumption in Hong Kong.

Ali et al. [2] have considered the socio-economic characteristics and temperature to be effective in the amount of electricity consumption in Pakistan and stated that due to the increasing trend of temperature, electricity consumption will increase in the future.

Salehizade et al. [11] with a monthly survey of temperature and electricity consumption in Fars province (Iran) found that the correlation coefficient between temperature and consumption is about 0.9. A regression study of temperature and electricity consumption in Dhaka, the capital of Bangladesh, showed that 1°C drop in temperature would reduce the city's electricity supply by about 81 MW [12]. A similar finding was also reported in a study of consumption thresholds in some Chinese cities; climate parameters explain about 0.71% of consumption variations [13]. Investigation in Taiwan using the Smooth Transition Regression (STR) method identified that the electricity sensitivity of temperature is about 25 to 27°C [14]. Today, studies of the relation between climate parameters and electricity on smaller-scale data such as daily and hourly are increasing [15].

Given the high relationship between temperature and electricity consumption and the environmental signs of global warming, the effect of temperature on electricity demand has increasingly taken precedence [4, 16]. Li et al. [17] achieved an increase in electricity consumption in China due to global warming. Parallel with the gradual alterations in temperature in Europe electricity consumption is gradually and steadily increasing [18]. Just as energy consumption mounts, the emission of greenhouse gases escalates, resulting in a growth in the Earth's temperature [19, 20].

Due to the soar in the number of energy consumers and the growing use of electrical energy in various parts of human life, it is necessary for managers and planners to pay attention to the factors affecting energy consumption. comprehensive knowledge and analysis of the relationship between electricity consumption and climate variables, especially air temperature are useful for better consumption management [1]. A lack of accurate understanding of the impact of climate on building energy consumption largely results in lower energy efficiency [13]. Uncovering this relationship with timely and accurate weather forecasting, especially in recent years with the use of new knowledge and state-of-the-art equipment with considerable accuracy, can reduce the risk of possible damage to the power system [7].

Babolsar is Located near the Caspian Sea in Iran. This city has a coastal location and is considered as a representative of temperate and humid climate. The main source of cooling for settlements in Babolsar is electricity. This study aims to investigate the relationship between temperature and electricity consumption in Babolsar to extract the temperature thresholds of electricity consumption sensitivity. The main question of this study is how and which extent temperature can affect electricity consumption in Babolsar.

MATERIAL AND METHODS

This research was conducted in Babolsar city, Iran (Figure 1). Two sets of data were collected on a daily basis from two centers: the climatic data from Babolsar Synoptic station, and power consumption data from Babolsar electricity department. The data were then arranged in a time series from January 1, 2010, to December 31, 2019. Eventually, we came up with 3618 days of the data period, missing data on few days due to technical defeciency of the system.

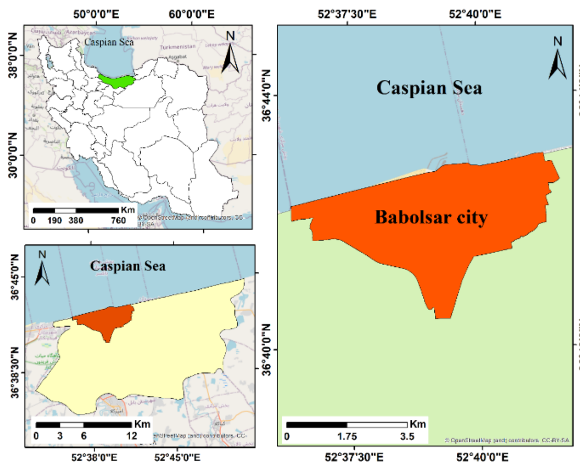

Figure 1. Babolsar location in Iran

In order to find the relationship between temperature and consumption, threshold regression analysis was utilized. The main and common form of regression when the relationship between two parameters is linear is a $\boldsymbol{y_i = \beta' x_i + e_i}$s. Sometimes, due to the multi-stage relationship between the two parameters and the nonlinear relationship, this model does not express the exact relationship between them. When the relationship to this species exists in different phases and threshold or breaking point from which the regression line becomes different is unknown. In the study of regression, one of the important issues is to recognize this change point or regime change [21]. Change point detection is also important in studying climate change [5]. When the breaking point is unknown, some other regression methods must be used to identify it. For this purpose, the threshold regression model can be used, the basis of which is expressed as follows:

$$\begin{cases} y_i = \theta_1' x_i + e_i \quad , \quad q_i \le \gamma \\ y_i = \theta_2' x_i + e_i \quad , \quad q_i > \gamma \end{cases} \tag{1}$$

where $\boldsymbol{q_i}$ is a threshold variable and is used to divide the sample into two or more groups. This threshold is the border of different regimes or classes. The random variable $\boldsymbol{e_i}$ is regression error [22]. The observed examples include$\{\boldsymbol{y_i, x_i, q_i}\}_{\boldsymbol{i=1}}^{\boldsymbol{n}}$, where $\boldsymbol{y_i}$ and $\boldsymbol{q_i}$ are real-valued and $\boldsymbol{x_i}$ is an m-vector. The threshold variable $\boldsymbol{q_i}$ may be an element of $\boldsymbol{x_i}$, and is assumed to have a continuous distribution.

The regression parameters are ($\boldsymbol{\theta}$، $\boldsymbol{\delta_N}$,$\boldsymbol{\gamma}$) and the natural estimator is least squares (LS) Let

$$S_n(\theta, \delta, \gamma) = (Y - X\theta - X_\gamma \delta)'(Y - X\theta - X_\gamma \delta) \tag{2}$$

The threshold with the least squares error is selected as the optimal threshold [23].

Due to the increasing demand to know the thresholds in regression studies, these capabilities were developed in software packages, especially econometrics and statistics such as Python, EViews and R [24, 25].

The Mann-Kendall method was used to investigate the trend. According to this criterion, every term $\boldsymbol{x_i}$ ($i = 1$, N; N is the total number of terms) If ni is the number of terms which exceed xi, then the sum P is computed and in the process, τ is assessed. Then, this statistical term is compared to $(\tau)t$.

$$P = \sum_{i=1}^{n} n_i \tag{3}$$

$$\tau = \frac{4P}{N(N-1)} - 1 \tag{4}$$

$$(\tau)t = \pm 1.96\sqrt{\frac{4N+10}{9N(N-1)}} \tag{5}$$

1.96 is (Z) at 95% confidence level in the two-domain test, P is the sum of ni and N is the number of data [26].

RESULTS AND DISCUSSION

Initially, minimum, maximum and average daily temperatures were used as independent variables in the regression model and it was found that electricity consumption in Babolsar is more correlated with daily average temperature. The average temperature in Babolsar has an annual cycle (Figure 2). Electricity consumption in the warm period positively correlates with the soar in the temperature. Consumption rate in the hot months is fluctuating with temperature and in cold periods with decreasing temperature, electricity consumption chart is not consistent with temperature fluctuation. linearity between temperature and consumption does not exist, however, in cold periods.

This state represents the different effects of temperature on the amount of power consumption at different times and demonstrates that the relationship between the two variables is nonlinear. The regression line of the polynomial function for two parameters revealed a significant correlation between average daily temperature and high power consumption. This function further exhibited that at first, under about 18°C consumption doesn't have any distinct sensitivity to temperature. After this stage consumption increased with a gentle slope with temperature increasing, after passing a certain temperature with increasing temperature, the amount of electricity consumption increases with a greater and different slope. A sample of this correlation is illustrated in Figure 3; the highest R^2 between these two variables were recorded in 2010.

Having calculated the functions in different years, it was found that on overage the lowest power consumption was observed at a temperature of about 14.2°C. An increase in consumption created by the decrease in temperature is also due to the use of electric heaters. Initially, the study indicated that the relationship between temperature and electricity consumption in Babolsar is nonlinear and there are different regimes in the

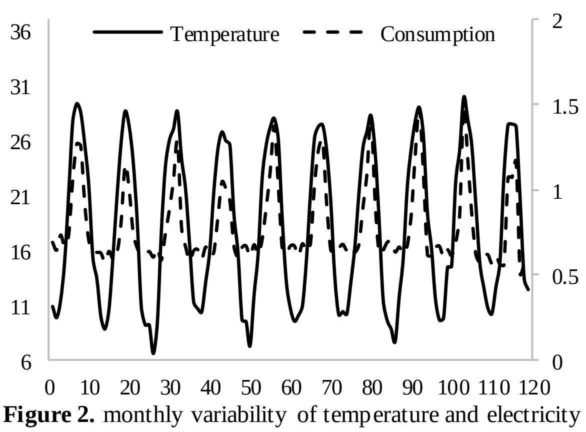

Figure 2. monthly variability of temperature and electricity consumption in Babolsar

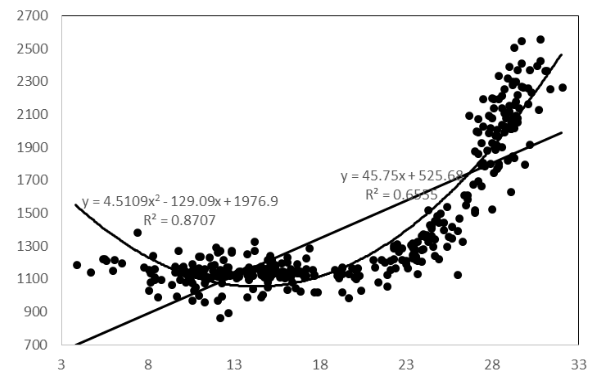

Figure 3. regression between temperature and consumption in 2010

relationship between the two variables. Thus, considering the regression line between the variables and aiming to find the points of change, the threshold regression method was used.

First, daily data for each year were separately analyzed. Finally, the total daily data for all years were used in model (Table 1).

Table 1 temperature thresholds in babolsar for electricity consumption from 2010-2019.

The results showed that in different years, the regression line has a different number of breakpoints. In 2013, the number of regimes reached 2, and in 2012 and 2017, the number of regimes reached 4. In most years, breakpoints were 3.

The results showed that the sensitivity of electricity consumption in Babolsar mainly has three main breakpoints. According to the threshold regression results, at temperatures below the comfort temperature (around 20°C), power consumption is inversely related to temperature. From this temperature to around 27°C, this relationship has another regime. Mainly in this temperature range, for every one-degree-Celsius increase in temperature, based on the obtained results, 224 amps were added to the consumption load in Babolsar. At temperatures above 27 degrees, with a change in the slope of the regression function, this value exceeds about 227 amps. On the other hand at temperatures above 27 degrees, with a change in the regression slope, this value increases to about 230 amps for 1°C. This threshold (80°F or 26.6°C) is that point heatstroke or sunstroke is imminent when the temperature reaches this level [27].

$$\begin{cases} y = -2.40T + 1445.246, & \mathrm{T} < 23 \\ y = 224.5T - 3741.210, & 23 <= \mathrm{T} < 26.9 \\ y = 226.9T - 3654.963, & 26.9 <= T \end{cases} \quad (4)$$

To anticipate the future condition, the trend of temperature thresholds to which power consumption is sensitive was examined using the Mann-Kendall test (Table 2).

According to the data size, $(\tau)t$ is equal 0.173 and according to τ obtained for temperature thresholds, $\mathrm{T} < 23$ and $23 <= \mathrm{T} < 26.9$ have a significant decreasing trend and $26.9 <= T$ has a significant increase in trend from 1960-2019 (Figure 4).

To further clarify the issue and to know more precisely the critical times for better management of power supply sources, the amount of mode and temperature deciles were extracted. These data showed that mainly from June to September, the highest repetition of temperatures above the second and third thresholds occurs in this city, and during this period, the most probable increase in consumption load occurs (Table 3). The red color cells indicate the months in which there is a sensitivity to consumption with the temperature at the second threshold (23<=T<26.9). Yellow Cells indicate the third threshold (>=26.9) condition in months.

Table 1. Temperature thresholds in babolsar for electricity consumption from 2010-2019

Year	Threshold				R-squared
	1	2	3	4	0.92
2010	<22	22<=T<27	27<=	-	0.91
2011	<21.9	21.9<=T<27	27<=	-	0.92
2012	<19	19<=T<23.8	23.8<=T<26.5	26.5<=	0.88
2013	<22.3	22.3<=T	-	-	0.90
2014	<21.8	21.8<=T<26.5	26.5<=	-	0.88
2015	<21.3	21.3<=T<26.7	26.7<=	-	0.90
2016	<22.4	22.4<=T<26.9	26.9<=	-	0.94
2017	<21.8	21.8<=T<27.65	27.65<=	-	0.95
2018	<16.9	16.9<=T<23.9	23.9<=T<26.5	26.5<=T	0.89
2019	<19.3	19.3<=T<24.95	24.95<=	-	0.69
2010-19	<23	23<=T<26.9	26.9<=T	-	0.92

Table 2. Man-Kendal Test results for different temperature thresholds in Babolsar

Threshold	Temperature	Tau	Trend	
1	<23	-0.4994	Descending	▼
2	23<=T<26.9	-0.2701	Descending	▼
3	>=26.9	0.54689	Ascending	▲

By calculating the deciles, more division was done to determine the time and possible effect of power consumption from temperature. According to this, June to September there is more corrlation between temperature and electricity consumption.

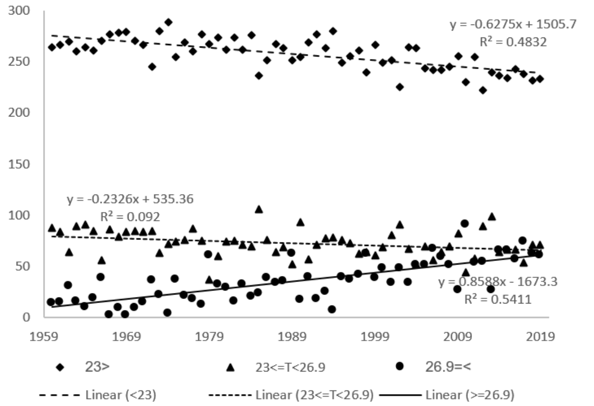

Figure 4. trends for different threshold in Babolsar 1961-2019

Table 3. Different deciles and mode of temperature in Babolsar

Decile	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	6.9	5.5	8.5	12.1	18.4	23.8	25.7	25.5	22.4	15.8	10.6	7.8
2	7.8	6.8	9.9	13.2	19.7	24.6	26.5	26.5	23.3	17.6	11.8	8.4
3	8.6	8	10.5	13.9	20.6	25.1	27	27.1	24	18.5	12.9	9.3
4	9.1	8.8	11.2	14.5	21.3	25.4	27.3	27.6	24.5	19.1	13.7	10
5	9.6	9.3	11.6	15.1	21.9	25.9	27.9	28	25	19.5	14.2	10.7
6	10.2	9.9	11.9	15.8	22.3	26.3	28.2	28.4	25.4	20.3	14.8	11.4
7	10.6	10.3	12.4	16.5	23	26.8	28.6	28.7	26	21.1	15.2	12.1
8	11.2	10.8	13.1	17.3	23.7	27.3	29.1	29.1	26.7	22	16	12.7
9	12.2	11.5	14.9	18.8	24.6	28	29.8	29.7	27.7	23.6	17.6	13.9
10	15.9	16.5	22.9	28	30.5	29.8	31.5	31.1	29.9	27.5	20.5	17
Mode	9	10.4	11.6	16	22.6	25.3	27.9	27.6	24.9	19.1	15	10.8

CONCLUSION

The role of environmental factors, especially climate, on energy consumption is considerable. Given the importance of environmental factors effects over energy consumption, exploring the relationship between energy and weather parameters gains prominence. Using daily electricity consumption and temperature data in Babolsar, the present exploration revealed that in the warm period, flactuations in electricity consumption are associated with temperature. Polynomial function showed this function can explain a large part of the relationship between power consumption and temperature in Babolsar. By this function, it was determined that there is generally the lowest power consumption close to 14°C. Distance from comfort temperature to lower temperatures until 14°C reduces consumption. Again, as the temperature decreases from 14°C, the amount of power consumption increases with decreasing temperature. The temperature and consumption regression line typically start to change slope from a particular threshold and passes different phases of increase in consumption per change in the average daily temperature. Using the threshold regression method, it was found that there are usually several points of change in the regression line between temperature and electricity consumption in Babolsar. The most important temperature to which electricity consumption is sensitive it is the temperature of about 27, after this threshold usually it is very possible humans get heatstroke. Examination of different temperature deciles based on daily data in different months of the year showed that 80% of the temperatures of July and August are higher than the third temperature threshold, which has the highest correlation with Babolsar electricity consumption. According to the results, July and August are the most significant months in which Babolsar electricity consumption is the most sensitive to air temperature. Consumption sensitivity in Babolsar is also much more pronounced due to the use of electrical energy for cooling. In the cold season, unlike some European countries, lowering the temperature has very little effect on electricity consumption. Consumption sensitivity points in Babolsar start about 20 ± 3 which from this temperature onwards, consumption reacts to temperature changes and increases. Due to the high sensitivity of electricity consumption to temperatures above 27 and considering the frequency of these temperatures is increasing significantly due to global warming, it is necessary to consider solutions. The first is reduction of fossil fuel consumption in order to reduce greenhouse gas emissions. The second is, we should be ready for more electricity consumption in the future from now. This readiness can be as different ways, equipping the necessary infrastructure for energy supply and increasing the efficiency of cooling devices.

Undoubtedly, in the future, smart electricity meters will replace today's meters. By knowing the critical temperatures for consumption, it is possible to include in the future electricity meter program sensitivity to specific temperatures instead of specific hours to increase prices, thus encouraging consumers to reduce consumption at critical temperatures instead of specific hours.

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Persian Abstract

چکیده

یکی از مهمترین عوامل در مصرف انرژی شرایط محیطی است. مساله اصلی در این بررسی یافتن الگوهای مختلف ارتباط میان دما و مصرف برق در شهر بابلسر است. مصرف روزانه برق از اداره برق و دمای روزانه از ایستگاه سینوپتیک بابلسر از ۱ ژانویه ۲۰۱۰ تا ۳۱ دسامبر ۲۰۱۹ جمع‌آوری شد. برای یافتن نقاط شکست خط رگرسیون بین دما و مصرف برق از روش رگرسیون آستانه‌ای استفاده شد. یافته‌ها نشان داد که ۳ آستانه مشخص در رابطه بین مصرف و دمای بابلسر وجود دارد. اولین آستانه به دست آمده دمای حدود۳±۲۰> درجه سانتیگراد است. آخرین آستانه ۱±۲۶≤ است و آستانه میانی مرز این دو است. بیشترین حساسیت مصرف برق دما در آستانه سوم است. بررسی روند آستانه‌ها نشان داد که درجه حرارت آستانه اول و دوم روند کاهشی داشته و آستانه سوم در حال افزایش است. با توجه به افزایش فراوانی دمای آستانه سوم که مصرف برق بیشترین حساسیت را به این دما دارد، این مورد باید، مورد توجه مدیران در زمینه مدیریت برق قرار گیرد و با دانستن دماهای موثر بر مصرف راهکارهایی نظیر افزایش قیمت در هنگام وقوع این دماها برای کاهش مصرف اقدام نمود.