Analysis of the influence of the installation of a dishwashing machine on household energy sources consumption in urban power supply systems

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Abstract. The subject of the research is the interconnection between the installation of a dishwashing machine in a household and the change in consumption of such primary resources as electric energy, cold and hot water. Applicability of this research is defined by the high growth of various electric appliances in the households, and the dishwashing machine has one of the highest tempos of the increase over the last decade. The results of this research allow esteeming the future change in the structure of consumption of energy sources by the households in terms of mass implantation of dishwashing machines in our daily life. Several methods of estimation have been reviewed of how the installation of the dishwashing machine impacts on energy sources consumption in the household. Mathematical descriptions and the rationale for the statistical data analysis methods of household energy sources consumption, which were used are explained. Based on the analysis of statistical data over 5 years before the installation of the dishwashing machine, the consumption of the sources is forecasted for the sixth year upon condition that there is still no dishwasher. At the beginning of the sixth year, the dishwashing machine was installed in the observed household. Forecasted values of household sources consumption for the sixth year have been compared with actual values which were obtained after installation of the dishwasher in the household.

1. Introduction

The subject of the research is the interconnection between the installation of a dishwashing machine in a household and the change in consumption of such primary sources as electrical energy, cold and hot water.

Two methods could be used for the analysis of the impact of an electric appliance (a dishwashing machine) on the household sources consumption [1-7].

The first one is a comparison of actual water and electricity consumption data when washing dishes by hand with the actual resources’ consumption by the dishwasher in one working cycle. As far as resource counters are placed at the input of the household, it is necessary for arranging the research to exclude any outside consumption of sources. On the contrary case, it may deform daily life source consumption. Besides, cold and hot water consumption when hand dishwashing dramatically depends on the temperature and pressure of water. The consumption highly varies both in time of a day and in the season of a year. The consumption of electrical energy when hand dishwashing also has a random character. Putting the light on in the kitchen is defined by the cloud coverage, the time of day and the...
season. Turning on other electric appliances along with the process of hand dishwashing, such as TV set, depends on the content of TV programs. Also, the consumption of electrical energy by other members of the family depends on whether the dishes are washed by hands or not. Typical water counters have a rather excellent measurement inaccuracy while measuring small volumes of water which are used for hand dishwashing. That is why, despite the seeming simplicity of this method, it doesn’t allow getting verifiable results.

The second one is the analysis of monthly average data on the consumption of the household resources. These data were obtained based on measurements of the resource counters at the input of the building. The basis of this method is a comparison of actual household resource consumption with the forecasted household resource consumption. The actual consumption is obtained after the installation of the dishwasher. The forecasted consumption is obtained, while the dishwasher is not provided. It is based on actual measurements of the resource counters for the period before the installation of the dishwasher. The household with known counters measurements was picked for the realization of this method. These monthly measurements were recorded of the hot and cold-water counters since 2012. In January 2017, the dishwashing machine was installed in this household.

It is necessary to notice that the state of life of this household and its electric appliances during the research years were permanent. During 2017, the type of lighting devices was also changeless. Elsewise, it would be impossible to define which effect bring the installation of this dishwashing machine in the change of consuming sources.

As a result, for the primary data for the analysis of energy and water consumption are taken monthly measurements from two-stage electrical energy counter and the measurements of the cold and hot water counters. All counters are placed at the input of the household, and the measurements were taken since 2012 for 2017. The dishwashing machine was working predominantly at night.

2. The results of forecasting
The average monthly consumption of resources was defined for each year over the observed period equal to 1 year. It is needed to draw a trend line (approximating connection) for the data over a period from 2012 to 2016 (the period with no dishwasher in the household). The most widespread method for this is the least square adjustment method. Coefficients of the trend line equation are determined in a way that the sum of squared deviations of actual values would be minimal from theoretical values [1-7]:

$$\sum_{i=1}^{n} (y_i - \bar{y}_i)^2 \rightarrow \text{min}$$

where $y_i$ is an actual value of the variable, $\bar{y}_i$ is the estimated value of the variable calculated from the trend line equation.

Linear dependences were taken for the trend line dependences. They suit well for the best description of a simple linear data set. These linear dependences are typical for electric power consumption over the years (figure 1). Cold and hot water consumption is also characterized by linear change except for 2015 and 2016. Meanwhile, forecasted values of polynomial dependences can be significantly overstated as the pattern of the curve change for the future period is unpredictable. That is why we pick linear dependences for the trend line.

The following type of equation shall be used for calculating the points of the linear trend:

$$\bar{y}_i = a + b \cdot x_i$$

where $b$ is a slope of a straight line, $a$ is a bias.

According to the least square adjustment method:

$$F(a,b) = \sum_{i=1}^{n} (y_i - \bar{y}_i)^2 = \sum_{i=1}^{n} (y_i - (a + b \cdot x_i))^2 = \sum_{i=1}^{n} (y_i - a - b \cdot x_i)^2 \rightarrow \text{min}$$

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Next, you need to define the values of \( a \) and \( b \) at which the function \( F(a,b) \) can reach a minimum. You should determine partial derivatives \( \partial F(a,b) \) with respect to \( \partial a \) and \( \partial b \), and equate them to zero.

\[
\begin{align*}
\frac{\partial F(a,b)}{\partial a} &= -2 \cdot \sum_{i=1}^{n} (y_i - a - b \cdot x_i) = 0 \\
\frac{\partial F(a,b)}{\partial b} &= -2 \cdot \sum_{i=1}^{n} [(y_i - a - b \cdot x_i) \cdot x_i] = 0
\end{align*}
\]

The linear approximation coefficients are determined after having solved the obtained equations:

\[
a = \frac{n \cdot \sum_{i=1}^{n} y_i - \sum_{i=1}^{n} x_i}{n} ; \quad b = -\frac{n \cdot \sum_{i=1}^{n} x_i \cdot y_i - \sum_{i=1}^{n} x_i \cdot \sum_{i=1}^{n} y_i}{n \cdot \left(\sum_{i=1}^{n} x_i\right)^2}
\]

According to the results of constructing approximating dependences of average monthly source consumption over a period before the installation of the dishwasher (2012-2016), forecasted resource consumption for 2017 is defined by extending trend line (figures 1 and 2). The difference between actual average monthly source consumption for 2017 (after installation of the dishwasher) and forecasted resource consumption for 2017 based on retrospective data over 2012-2016 (before the installation of the dishwasher) is the effect from the installation of the dishwasher.

**Figure 1.** Average monthly electric power consumption for years.
3. Analysis of the results

The inaccuracy of the forecast, which is shown in Figures 1 and 2, is defined for the determination accuracy of calculation of the forecasted value of average monthly energy sources consumption for 2017 upon the condition with no dishwasher in the household. There was taken standard inaccuracy showing the accuracy of estimation of average, and it is not a parameter of dispersion.

The standard inaccuracy depends on the dispersion of the data set $\sigma^2$ and the sample size $n$. The formula gives it:

$$S = \frac{\sigma}{\sqrt{n}},$$

In turn:

$$\sigma = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} (y_i - \bar{y}_{\hat{x}})^2},$$

where $\sigma$ is the value of the standard deviation of the data set; $n$ is a sample size (number of values in a series), $y_i$ is an actual value of the variable, $\bar{y}_{\hat{x}}$ is an estimated value of the variable calculated from the trend line equation [4].

According to the results of constructing approximating dependences (figures 1 and 2) the difference between the average monthly source consumption for 2017 (if there is no dishwasher in the household) and actual values for 2017 (if there is a dishwasher) is defined. The results are presented in Table 1.

![Figure 2. Average monthly water consumption for years.](image-url)
Table 1. The decrease in the average monthly source consumption after the installation of the dishwasher.

| Resource     | Electricity at daytime | Electricity at nighttime | Cold water | Hot water  |
|--------------|-------------------------|--------------------------|------------|------------|
| Difference in consumption | 20.8 ± 1.9 kW·h       | −7.1 ± 1.7 kW·h          | 0.69 ± 0.13 m³ | 0.33 ± 0.16 m³ |

Actual average monthly electric power consumption at daytime for 2017 (after the installation of the dishwasher) is less than forecasted value. The difference between the actual and forecasted power consumption at daytime in 2017 is more than a measurement inaccuracy of this resource. It means that the dishwasher has an impact on the power consumption at daytime.

Actual average monthly electric power consumption at nighttime for 2017 is more than the forecasted value. The difference between the actual and forecasted power consumption at nighttime in 2017 is more than a measurement inaccuracy of this resource. It means that the dishwasher has an impact on the power consumption at nighttime.

Actual average monthly cold-water consumption for 2017 is less than forecasted value. The difference between the actual and forecasted cold-water consumption in 2017 is more than a measurement inaccuracy of this resource. It means that the dishwasher has an impact on cold-water consumption.

Actual average monthly hot water consumption for 2017 is less than forecasted value. The measurement inaccuracy is marginally less than the difference between the actual and forecasted consumption of this resource. This is the fact of the abrupt change of hot water consumption over 2015-2016. However, it was noted that the dishwasher has an impact on hot water consumption.

4. Conclusion
Statistical data for resource consumption of the household were analyzed before and after the installation of the dishwasher. Household resource consumption forecast was made without the dishwasher in the household. There was conducted a comparative analysis of forecasted resource consumption (with no dishwasher) and actual consumption (with the dishwasher).

The following main conclusions are obtained based on the analysis. After the dishwasher installation:

1. The average monthly electric power consumption at daytime decreased by (20.8 ± 1.9) kW·h and at nighttime increased by (7.1 ± 1.7) kW·h. A daily decline in consumption is due to the lack of necessity of turning on electric lighting and other electric devices in the kitchen for hand dishwashing. The work of the dishwasher explains the power consumption increase at nighttime in “delayed start” mode;
2. Cold and hot water consumption has decreased by (0.69 ± 0.13) m³ and (0.33 ± 0.16) m³ respectively because the water usage for hand dishwashing is more than for machine dishwashing.

Therefore, filling up of our life with the dishwashers won’t lead to the resource consumption increase in urban power supply systems. On the contrary, it helps to reduce resource consumption.

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