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RATIONALIZATION OF ELECTRICITY CONSUMPTION IN HOUSEHOLDS

Peter MORVAI*, Miroslav ŽITŇÁK, Stanislav PAULOVIČ
Slovak University of Agriculture in Nitra, Slovak Republic

With rationalization of electricity consumption, it is possible to obtain savings of electric energy in households, as well as financing and capital input for the electricity production. Rational use of appliances in the best operating modes can reduce the final consumption of electricity, representing a positive impact on improving the environment quality. The main objective of this paper was to measure the electricity consumption of appliances in various operating modes. The measured values from two energy suppliers were recorded and processed in tables and figures, from which we created a table of the financial costs necessary for operation of appliances in different modes. For the calculation of annual electricity consumption and electricity prices, an application allowing selection of individual products from suppliers with current electricity prices was designed. According to the tables of electricity prices, various modes of appliance operation allow the selection of the most preferred mode for appliance operation based on the lowest price, rational consumption and energy costs. The aim of the paper is to demonstrate the consumption and costs of operating appliances in certain operating modes, standby modes and their efficient use or functionally similar appliances for reduction of electricity consumption in households.

Keywords: electric energy; rationalization of consumption; measurement of consumption; measuring instruments; operating mode; standby mode

This paper focuses on the measurement of electricity consumption in households, finding of ways to streamline the operation of appliances in standby modes and the selectable modes. Power consumption in standby mode is decreased bellow 0.5 Wh today (Cviklovič et al., 2017). We investigate the results of choice of operating modes, impacts of the appliance location on the ambient temperature, and other possible impacts on energy consumption. With rationalization of electricity consumption, it is possible to achieve considerable financial savings (costs) and resources used for electricity production. Reducing the need for resources (wood, coal, uranium ore) can contribute to decreasing of production of harmful substances on a global scale (Ang et al., 2017).

The theoretical part deals with the objectives and importance of the power measurement, power measurement of electric current, as well as measurement of phase shift, accuracy, uncertainty and intensity of light flow (Kossiakoff et al., 2011).

The practical part includes the description of measuring instruments that were used for measuring of electricity consumption of appliances, current consumption in standby mode and hourly consumption in selected mode of operation for appliances in households. Measured data were processed in the form of tables of consumption per hour and consumption per cycle in selected operating modes. Measured data shown in tables were transferred to costs for the operation of electric appliances in each mode. For the calculation of annual electricity consumption and prices for electricity consumed, an application allowing comparison of the current electricity prices offered by suppliers was designed. Tables demonstrate the values of consumption and costs of energy consumed in each mode of operation, as well as possibilities for making of reductions in consumption by selecting the appropriate mode and location of appliances.

Material and methods

In order to meet the objective of the work, the following methodology was utilized: **Preparation and research of theory dealing with measurement of electricity consumption.**

In order to achieve the objectives, we have observed literary sources dealing with basic concepts related to:

- objectives and significance of electrical measurement, principles of analogue and digital multimeters;
- measurement of electric power in single-phase and three-phase networks, electronic power meter;
- measurement of phase shift using an oscilloscope and phase meters;

Contact address: Peter Morvai, Slovak University of Agriculture in Nitra, Faculty of Engineering, Department of Building Equipment and Technology Safety, Tr. Andreja Hlinku 2, 949 76 Nitra, Slovak Republic, e-mail: petermorvai@yahoo.co.uk

- measurement of electric current using induction and electronic electricity meters;
- accuracy of measurement, measurement uncertainty and measurement errors;
- intensity of the light flow and an example of the intensity of the light flow depending on the distance of the light source (Wulfinghoff, 1999; Gašparovič et al., 2017).

Selection of the measuring instrument

Essential criteria for selecting of electric energy meter were the technical parameters. The parameters that were significant for device selection are as follows:

- operating voltage;
- max. possible power/current load;
- min. possible power/current load;
- indication of measured performance;
- accuracy of measurement;
- requirements for ambient conditions of measurement.

Designing of application for calculation of annual consumption and the prices for electricity consumed

The „CALCULATION OF CONSUMPTION" application allows calculation of electricity consumption and comparison of electricity prices from individual suppliers at the DD1 and DD2 rates (according to the price lists for 2016). The application was created using Microsoft Visual C # software and we used it to calculate the values listed in the tables.

Measurement of consumption of light sources

This part was focused on measuring of consumption of currently available light sources with E27 and T8 threads. For measuring of consumption, we used a meter meeting the required criteria; for measuring of light flow intensity, a device UNI-T UT382 USB was utilized. Measured instantaneous consumption data were processed into the form of tables, from which the annual electricity price for model operation was calculated.

Price for electricity consumed in standby mode

Measurement in standby mode was aimed at processing and evaluating measured data in standby modes of the most commonly used household appliances. Measured data allow us to demonstrate hourly, daily and year-round consumption of selected appliances. Measurements were performed with a Voltcraft Energy Loger 4000 instrument.

Price for electricity consumed in individual modes of operation of appliances

This part of work deals with the processing of data measured by means of selected measuring instrument meeting the criteria for measuring of consumption. We have described the procedures and conditions for measuring of consumption of appliances, as well as processed the measured data in the form of tables and figures. Measurements were performed on the following appliances:

- Whirlpool AMC 991 air conditioning unit;
- domestic water pump Elpumps VB 50/1500B.

Optimal measurement method for measuring of electrical current of switching sources was described by Cviklovič et al. (2012). Optimized filter is very important for precision measurement of appliances current where active harmonic filter is used for power factor optimization.

Results and discussion

In order to achieve the objectives of rationalizing household electricity consumption, we recorded consumption measurements during one year and the measured data were processed in the form of tables and figures, which clearly demonstrate the consumption of the appliances in each mode of operation. Spreadsheets were processed in the form of price table showing the amount of energy consumed by the appliances. These tables show the most optimal modes of operation in terms of energy savings. Considering the light sources, the most optimal light source can be selected in terms of parameters and cost of energy consumed. The measurement accuracy of the individual measuring instruments used for consumption measurement and luminance detection is shown in Tables 1, 2 and 3. Measurement was carried out at the temperature of 21–23 °C.

Selection of the instrument and technical parameters of the instruments

When selecting a power meter, the devices were compared on the basis of the measurement accuracies declared by their manufacturer. The main criteria for selecting the appropriate instrument were the precision of instrument for measuring of small currents (standby mode), the accuracy of measurement of large currents, cos φ and the possibility of storing measurement data within the device memory or direct data transfer to the computer (Patrick et al., 2014). The devices Voltcraft Energy Loger 4000 and UNI-T UT71E met the proposed criteria. The device UNI-T UT71E was used for measuring of instantaneous power consumption in standby modes; the measuring instrument Voltcraft Energy Loger 4000 was utilized for measuring of energy consumption in kWh. Moreover, the device UNI-T UT71E was used to measure the consumption of wolfram, fluorescent and LED light sources. In regards of measuring of light sources, a device UNI-T UT382 USB luxmeter was used to measure illumination. The light flow measurement data together with the light source power measurements were processed in the form of table.

Measuring instrument Voltcraft Energy Loger 4000

The electricity consumption meter was connected between the socket and the electrical device. Using the SDHC card reader, the measured data were immediately transferred to the computer and analyzed by means of Voltsoft client software. Meter specifications are shown in Table 1.

Measuring instrument UNI-T UT71E

The parameters of the device UNI-T UT71E multimeter with optical interface for USB connection are shown in Table 2.

Measuring instrument UNI-T UT382 USB

The device LUX meter UT382 USB can measure light between 0–20,000 Lux and can be connected to a computer

Table 1 Technical parameters of the measuring instrument Voltcraft Energy Logger 4000

Measurement range	Accuracy of measurement
0–2 W	(± 15% + 1 count)
2–5 W	(± 5% + 1 count)
5–3,500 W	(± 1% + 1 count)
Running voltage	230 V/AC, 50/60 Hz
Max. possible power/current load	3500 W/15 A
Indication of measured power	0.1 W – 3500 W
Operating temperature	accuracy is valid at temperature 23 °C (± 5 °C) and at a relative humidity less than 75%

Table 2 Technical parameters of the measuring instrument UNI-T UT71E

Range		Resolution	Accuracy of measurement
Power factor	0–1	0.001	(± 2% + 10 count)
Power	0–2,500 W	0.1 W	(± 2% + 10 count)
Dignified power	0–2,500 VA	1 VA	(± 2% + 10 count)
Operating voltage		230 V/AC 50 Hz	
Max. possible power/current load		to 1150 W/5 A, permanently loaded 1150 W – 2300 W/5 – 10 A, max. 10 seconds and interval between measurements – 15 minutes	
Operating temperature		accuracy is valid at a temperature of 22 °C (±3 °C) and a relative humidity of less than 75%	

and store the measured data. Stored data from the device can be uploaded to a computer. The device accuracy for illumination measurement is 20 Lux ± (3% + 20 count), 200 to 20,000 Lux ± (3% + 8 count).

Description of application "CONSUMPTION CALCULATION"

The application "CONSUMPTION CALCULATION" was developed and programmed in the Microsoft Visual C # programming language. This application allows the calculation of the annual electricity consumption and prices from individual electricity suppliers at DD1 and DD2 tariffs. This application was used to facilitate calculations of the costs of electricity consumed by appliances in individual modes of operation. The calculations are processed in the form of energy price tables. This application is shown in Fig. 1.

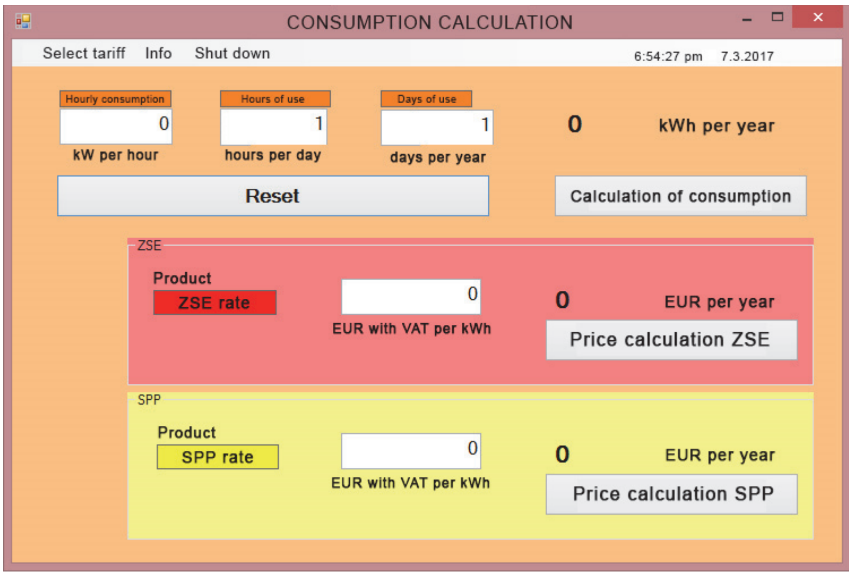

Fig. 1 Application "CONSUMPTION CALCULATION"

Measurement of consumption of light sources

Instantaneous consumption of light sources, which is also the hourly consumption, was measured on the light sources shown in Table 3. This table shows light source data and allows selection of a suitable source with regard to optimal consumption, light intensity and price. In order to measure the light intensity, a reference distance of 1m has been determined. Source consumption per year is calculated for 24 hour, 365 days per year utilization.

The costs for consumption of light sources from Table 3 provided by different suppliers are processed in the form of Table 4. Model operation represents the 6 hour power supply per day 365 days per year for 10 pcs of light sources. Prices are processed for two suppliers at the tariff DD2.

In relation to commercial buildings, lighting typically accounts for 20–50% of total energy consumption. In residential buildings, the figure typically is 10% or less. The percentage of lighting energy that can be saved is typically large. Contemporary lighting

Table 3 Measured values of the light sources E27 a T8 from the Table 4

Measured values for light sources E27						
Appliance/ Bulb/TYPE	**active power P (W)**	**consumption (kWh/annum)**	**illumination E (Lux)**	**power factor cos φ**	**apparent power Q (VA)**	**price included VAT 20%, €**
Wolfram – Techlamp A55	56.9	521.22	85	0.99	59.5	0.42 – 0.79
Halogen – OSRAM ECO PRO	51.4	402.96	20	0.99	51.4	2.34
Fluorescent – OSRAM DULUX MINI TWIST	23.9	209.36	108	0.63	37.6	4.79
Fluorescent – Kanlux ETU-MSS	23.3	204.11	110	0.65	35.7	5.38
LED – EMOS A60	7.8	68.33	127	0.61	12.7	6.86 – 8.71
LED – ORO FIGO-BZ	10.5	91.98	179	0.55	18.9	5.77
LED – EMOS A70	14.8	129.65	266	0.60	24.6	7.15
LED – PHILIPS CORE PRO	15.5	135.78	356	0.57	27.1	12.54
Measured values for light sources T8						
Appliance/Bulb/TYPE	**active power P (W)**	**consumption (kWh/annum)**	**illumination E (Lux)**	**power factor cos φ**	**apparent power Q (VA)**	**price included VAT 20%, €**
Fluorescent – Narva LT 36W/865	35.1	307.48	721	0.96	36.2	2.69 – 5.30
LED – Greenlux 22W/840	21.6	189.22	754	0.95	22.6	35.96
LED – Greenlux 20W/840	17.6	154.18	467	0.62	28.2	16.30
LED – Panlux 20W/840	20.1	176.08	508	0.92	21.70	17.45

Table 4 Consumption rates of light sources in the model operation

	6 hours × 365 days × 10 pcs × tariff DD2 (€)			
	EON classic	**SPP standard price**	**SPP one energy**	**SPP two energies**
Wolfram – Techlamp A55	148900	148227	146208	143531
Halogen – OSRAM ECO PRO	134.507	133.900	132.076	129.658
Fluorescent – OSRAM DULUX MINI TWIST	62.543	62.261	61.413	60.288
Fluorescent – Kanlux ETU-MSS	60.973	60.698	58.871	58.775
LED – EMOS A60	20.412	20.319	20.043	19.676
LED – ORO FIGO-B2	27.477	27.353	26.980	26.487
LED – EMOS A70	40.562	40.378	39.828	39.099
LED – PHILIPS CORE PRO	40.562	40.378	39.828	39.099
Fluorescent – Narva LT 36W/865	91.852	91.437	90.192	88.541
LED – Greenlux 22W/840	56.524	56.269	55.503	54.487
LED – Greenlux 20W/840	46.057	45.849	45.224	44.396
LED – Panlux 20W/840	52.599	52.361	51.648	50.703

conversation programmes reduce the energy consumption by less than a half (Wulfinghoff, 1999).

Table 3 with real measured values for T8 light sources indicate that the compact fluorescent light Narva LT 36W consumes more electric power than the LED light Grenlux 22W/840 (T8 fluorescent tubes with the similar illumination) by 62.5%. The fluorescent light bulb Kanlux ETU-MSS consumes more electric power than the LED EMOS A60 (E27 light bulbs with the similar illumination) by 198.7%. It is evident from the comparison between light sources that the amount of energy within the range from 62.5% to 198.7% can be saved by means of new technologies (Light Emitting Diode).

Price for electricity consumed in standby modes

The procedure is to measure and record the main and auxiliary currents in both running and standby modes (CIBSE, 2015). Measurements were performed on household appliances (18 pcs of commonly used appliances). The measured values were processed to daily, two hundred-days and

Table 5 Consumption and price for electric energy used by appliances in standby mode

Electricity consumption (kWh)	For 24 hours	For 200 days	For 365 days
	0.6936	138.72	253.164
Price for electricity consumed (€)			
Tariff DD2 – EON classic	0.0828	16.5759	30.2510
Tariff DD2 – SPP standard price	0.0825	16.5010	30.1143
Tariff DD2 – SPP one energy	0.0813	16.2762	29.7042
Tariff DD2 – SPP two energies	0.0798	15.9783	29.1604

year-round electricity consumptions of all examined appliances. These data are shown in Table 5.

Price for electricity consumed in individual modes of operation of appliances

Most complex systems include a number of operating modes in order to respond efficiently to differences in their environment or operating status (Kossiakoff et al., 2011).

According to Clements-Croome and Derek (2013), more and more intelligence is being designed into buildings, systems and appliances and even clothing. The manufacturers such as Aga, LG, Samsung and Magimix develop cookers, fridges and toasters with sensors that are enhancing efficient home management systems. The ABI research predicts that these developments are likely to rapidly become part of everyday life, and the energy consumption of appliances would be about half of the entire energy consumed by a typical home.

a) Measurement and price for electricity consumed by Whirlpool AMC991 air conditioning unit

In regards to measuring of consumption per 1 hour on the Whirlpool air conditioning unit, the consumption was determined in the individual modes of operation. The modes of operation are as follows: fan 1st, 2nd, 3rd stage, cooling, dehumidification, heating. The outside air temperature was also recorded during heating and cooling. By changing the outside temperature, air conditioner consumption has increased. Measured values are shown in Fig. 2.

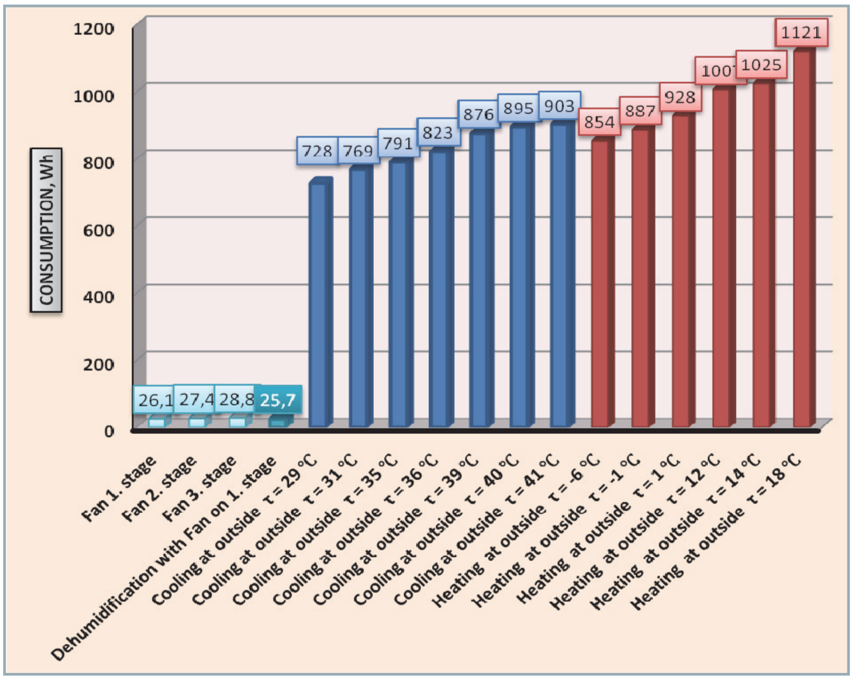

Fig. 2 Measurement of consumption in different operating modes (depending on the outside temperature τ) on Whirlpool air conditioner AMC991

A difference of 12 °C for cooling represents the difference of 35 kWh (4.0315 € for "DD2 two energies") and a difference of 20 °C for heating represents the difference of 53.4 kWh (6.1509 € for "DD2 two energies") for 200 hour of operation. Optimal location for air conditioning outdoor unit is out of the range of solar radiation (the north side of the object or permanent shade).

b) Measurement of the consumption of domestic water pump Elpumps VB 50/1500B

Measurements were carried out at an outside temperature of 21 °C. Two measurements of consumption were performed under the same conditions. The only difference was the connection of pump to outlet. The pipes of size 1/2" and 3/4" have been selected. The goal was to fill a 200-liter container and observe consumption for individual pipeline dimensions. The results of measurements are provided in Table 6.

The possibility of power consumption rationalization by means of appropriate choice of inner diameter of the outlet pipe for the water pump is confirmed in Table 6. The difference in consumption for 1/2" and 3/4" pipes for 200 cycles (40 m^3) represents a saving of 37 kWh (4.4 € for "DD2 two energies").

According to Patrick et al. (2014), the exact power consumption of any appliance should be found on the manufacturer's tag identifying the electrical characteristics of the device. It is evident from Table 6 and Fig. 2 that the exact power cannot be determined. The power consumption of appliance varies with the outside temperature changes (Fig. 2) and choosing of the appropriate component of appliance

Table 6 Consumption measurement in each condition for the water pump Elpumps VB 50/1500B

Pipe size	Power factor cos φ	Max current value I (A)	Max. voltage value U (V)	Consumption per cycle (kWh)
Output pipe size 1/2"	0.96	13.13	243.4	0.153
Output pipe size 3/4"	0.96	10.83	239.2	0.079

(Table 6). Due to these reasons, it is recommendable to ensure that the manufacture's tag provides information on the minimum and maximum potential consumption of appliance (then it would be possible to calculate the minimum, maximum and average consumption per hour, day, month, year and cycle).

Conclusion

Growth in the use of electrical equipment leads to increased electricity consumption, which is linked to increased emissions as well. Due to this reason, newly developed electrical equipment should satisfy the rising demands for energy efficiency and environmental friendliness. Energy users need three things to maximize their ability to save energy and money on their electricity bills: the consumer empowerment triad of information, pricing options, and automation. Information necessary for comprehension of issue should come as first from these equals, because it represents the starting point for intelligent efficiency. Time-based pricing provides additional financial incentive to lower peaks, and automation allows for "set-and-forget" energy management in our busy world. But information remains the key to all of these. Education should be included in all consumer energy initiatives (Sioshansi, 2013).

The aim of the paper was to achieve rationalization of household electricity consumption and demonstrate possible reductions in electricity by using different types of light sources (the choice of optimal source according to luminescence, consumption and cost for consumed electricity), as well as to point out achievable savings in standby and in individual modes of operation on selected appliances. Recording measurement data and their consequent processing allows us to evaluate the consumption of appliances in the selected modes of operation. According to the measurement results, it is possible to consider which modes are optimal for saving electricity. Indoor and outdoor temperatures influence the electricity consumption. By measuring the consumption we showed that appropriate appliance components can have considerable impact on final appliance consumption, as demonstrated on the domestic water pump using a suitable piping cross-section. Optimal location of the outdoor unit of the air conditioner away from the range of solar radiation can save energy as well (the north side of object or permanent shadow).

The significance of the paper lies in demonstration of potential options for consumption reduction of appliances in households in the Slovak Republic and abroad as well.

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