energy efficiency, energy audit, interactive calculator, energy consumption structure

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INTERACTIVE CALCULATOR FOR ASSESSMENT OF THE STRUCTURE OF ENERGY CONSUMPTION

Abstract

In this paper we present a simple interactive calculator, which can be used in individual flats and houses, office buildings and educational institutes such as colleges and schools, for assessment of electricity use by different categories of equipment. The user indicates only type of equipment and its approximate time of work. The program outputs the structure of energy consumption in graphic format. The results of test procedures and the ways for improvement of the program are discussed.

1. INTRODUCTION

Insufficient energy supply is a problem faced by many countries, and energy efficiency improvement is identified as the quickest and most effective solution to this problem. Many energy efficiency projects are therefore initiated to reach various energy saving targets [1]. Nowadays Russian government pays a lot of attention to solutions of the high energy intensive production system in the country, inherited from the Soviet times. In November 2009 Russian parliament adopted the law "On energy saving and energy efficiency", which established specific obligations of the federal government to co-finance the programs of Russian regions on energy efficiency. Financing of regional energy efficiency programs from the federal budget began in 2011. During 2011-2013, 66 out of 80 Russian regions were funded with 1.667 million rubles (about 40 million euro) in total, but only 18% of them have achieved expected economical results. Almost 30% of the regions were financed by the federal government only once (in 2011) and then their spending were considered ineffective.

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According to our previous study [2-3] the key factors of low efficiency of regional energy saving programs is the lack of approved standards and algorithms in the area of energy audit. In practice, both technical and economical parameters of energy audit fluctuate in a very large range. It's due not only to different complexity of the audit (the number of surveyed buildings, the number of observed parameters etc.), but also the immaturity of the market. In some regions with monopolistic market of energy service the audit for a company costs much more than paying bills for electricity and heat. For example, in Yamal-Nenets Autonomous Okrug the average cost of energy audit contract in 2011 was 185 million rubles (about 4.4 million euro) [4], while in Lipetskaya Oblast only 200 000 rubles (4800 euro).

In this situation most of the small and middle-size companies as well as government organizations are getting more and more interested in some "do-it-yourself" tools that can help to make very first steps in introduction of energy management systems and reduce the cost of professional energy audit. Especially strong need for energy audit in public sector is explained by the fact that in many regions local laws oblige state-financed organizations to reduce energy consumption by 3% every year at least during 5 years [5].

It is also well known that private consumption, especially energy consumption, is one of the largest demand classes in most economies, and is therefore responsible for a major fraction of global emissions [6]. New energy efficient home appliances can significantly reduce the energy consumption, however, the extent to which the theoretical reduction potential can be realized highly depends on individual decision processes. General population in Russia on its own has not yet embraced energy efficiency as a social value, therefore not many people are interested to invest in increasing energy efficiency of their homes and, therefore, to use algorithms for home energy audit suggested by well-known western companies such as Energy Star and others. Besides the fact that the majority of Russian urban population live in big apartment houses, managed by municipal companies and don't have much opportunities to save energy, except reduction of personal electricity use. But in some regions tariffs on electricity for population already grew to the level that makes energy saving economically reasonable.

In this paper we present a simple interactive calculator (hereinafter EnergyCalc) which can be used in educational institutes such as colleges and schools, office buildings as well as individual flats and houses for assessment of electricity use by different categories of equipment. The user indicates only type of equipment and its approximate time of work. The program outputs the structure of energy consumption in graphic format and some recommendation on how to reduce the most costly item of expenditure. The EnergyCalc is realized in the C++ programming language, following the C++98 standard. It is available for personal computers running the Microsoft Windows or the GNU/Linux operating systems.

The structure of the paper is following: in Section 2 we discuss the formulation of the problem, the methods of gathering information for in-build database in the program and describe the algorithm of calculation. In Section 3 we present the design of EnergyCalc program and describe its realization. Section 4 is devoted to discussion of the results of the tests made for the case of individual apartment, office of the middle-size company and typical public school. In Conclusions we make a short summary of main results and introduce some way for improvement of the interactive EnergyCalc.

2. THE PROBLEM OF ENERGY CONSUMPTION STRUCTURE MONITORING

According to the standard ISO 50001 “Energy Management System” adopted in Russia at the end of 2012 the first step of developing energy-saving strategy is the energy survey. While a professional energy audit is the best way to determine the potential ways for reduction of energy consumption and the necessary part of the certification process, one can conduct their own simple but diligent research and spot many problems in the use of electrical equipment. The information about total electricity consumption in most cases is available because the majority of offices and homes are equipped with individual electricity meters, but the structure of energy consumption is unclear. The main problem for the average user is the lack of information about how powerful different types of office and home equipment are. In this situation users often start to save energy by ineffective methods and very soon give up.

The structure of energy consumption in offices and individual homes varies a lot. Thus, on fig. 1-2 we can see two electricity consumption structures of the same-sized families living in the same city and in similar homes. While one of the biggest parts in energy consumption for both families is a refrigerator, other “energy eaters” differ. For the first family they are lighting and TV, for the second family – electric stove, washing machine and dishwasher.

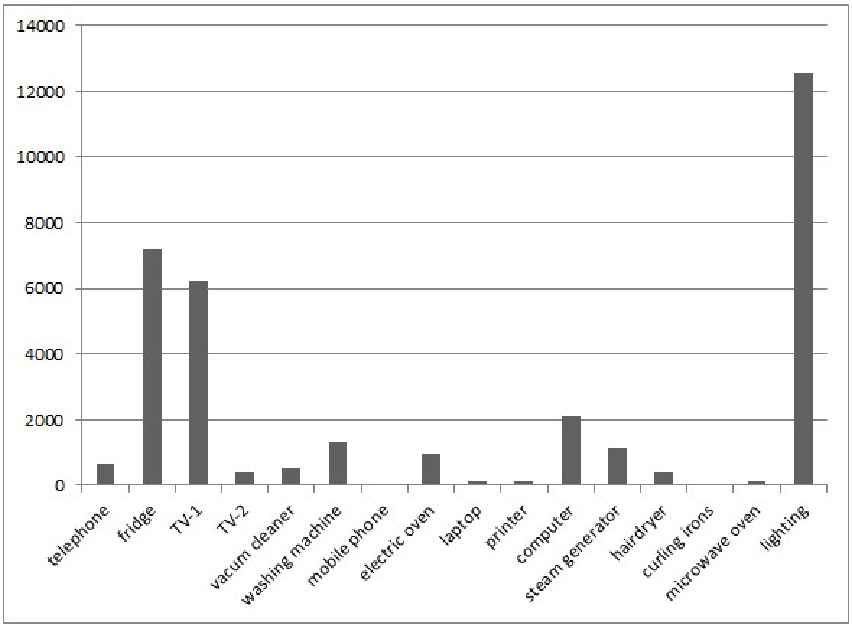


Fig.1. Weekly energy consumption structure: family 1
(Krasnodar city, 3 persons, 100 sq.m home) [source: authors own studies]

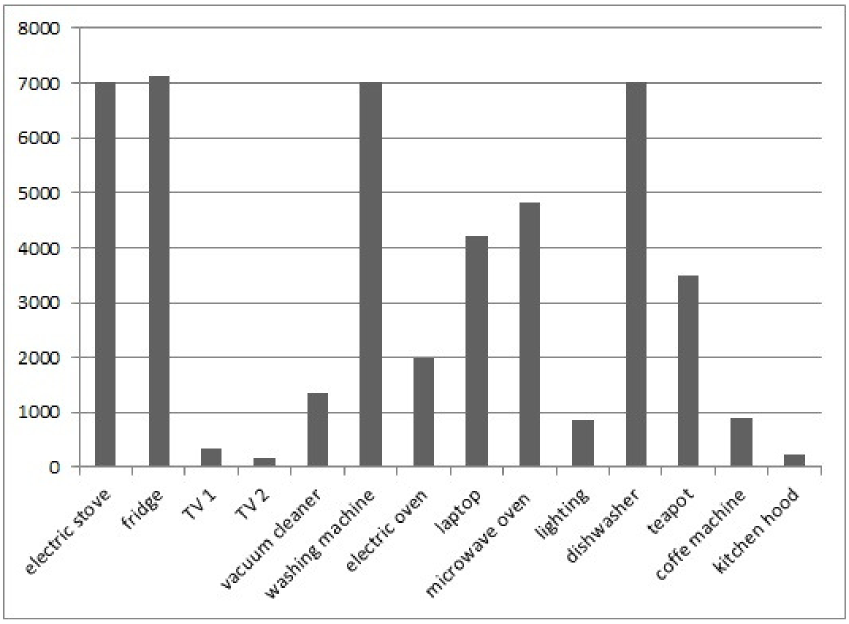


Fig. 2. Weekly energy consumption structure: family 2
(Krasnodar city, 3 persons, 100 sq.m home) [source: authors own studies]

The similar difference can be seen in the energy structures of offices. The main reason for this variation is not only different life style of the people and different commercial activities of the companies, but also the attitude towards energy efficiency and income level. Low energy prices cause the lack of incentives to improve energy efficiency for wealthy people and companies. The level of energy efficiency of household and office equipment has practically no effect on the price, therefore the majority of the buyers do not pay much attention to energy efficiency indicators and tend to choose more powerful and functional home and office appliances. Permanent growth of prosperity of the middle class Russians is primarily reflected in the acquisition of durable goods, including a variety of new types of household and office equipment.

Nowadays the study of the influence of the demographic, socioeconomic, and housing characteristics variation in household energy consumption became very popular in different countries (see, for example [7-10]), but still not in Russian economic literature. Therefore it was not possible to rely on results of previous studies and it was necessary to select a new way to investigate the structure of energy consumption of the households.

With this in mind we have abandoned the idea of using the typical structure of energy consumption as a pattern of the EnergyCalc and have used instead a case-study method for gathering the information about the possible set of home and office appliances. According to [11], a case study is an empirical enquiry that investigates a phenomenon in a real life context. In order to avoid volunteer bias in residential energy efficiency studies, we have used the results of [12] and provided volunteers with a short questionnaire that takes at most 1 minute to complete before the study about their intentions to enroll. A case-study was conducted for 7 households, 4 offices of SMEs and two public high schools in Krasnodar city, Krasnodar region, Russia. The following information at each object was collected:

- list of appliances,
- appliances' brand and year of manufacture,
- users' satisfaction with the quality (including energy efficiency) of appliances and their plans to purchase new kinds of equipment.

Then the information about appliances' energy consumption was collected from the sites of most popular Russian Internet stores and the official sites of equipment's manufacturers. For majority of appliances energy consumption is measured as power (Wt); for washing machines and dishwashers the energy consumption for the cycle was measured. If the energy consumption of appliance depends on the class of energy efficiency or on the presence some special functions, several modification of the same appliance were indicated in the list. All collected information was presented in the form of database, which later on will be built-in inside of EnergyCalc.

The process of calculation the energy consumption was organized as it is presented in the table below.

Tab. 1. Methods of energy consumption structure assessments

Object	Input parameters	Data base parameter	Calculation formula
Home and office appliances, except washing machines and dishwashers	Time of use (hours in a week), class of energy efficiency (if possible)	Power, Wt	Time×Power
Washing machines and dishwashers	The number of uses in a week	Energy consumption for a cycle (ECC), Wt	Number×ECC
Lighting in the public high schools (class-rooms)	The number of class-rooms, the time of lighting	Average energy consumption (AEC) for lighting a class-room	Number×Time× AEC
Lighting in the public high schools (halls)	The floor area of halls, the time of lighting	Average energy consumption (AEC) for lighting a sq.meter	Area×Time×AEC
Running the average school kitchen	The number of days in a week than the kitchen works	Average daily energy consumption (ADEC)	Number×ADEC

As seen from the table, the structure of the energy consumption in private apartment and office is calculated by multiplying the operation time of each device on its output. The algorithm for public high schools is slightly different, because the main part of the school building usually is occupied by the typical school classrooms with the same lighting systems, what can be used as a measureable unit in the process of energy consumption evaluation. Another measurable unit in school's energy consumption can be a school kitchen, which has standard equipment, purchased by municipalities at the same manufacture through tender system (most of the public schools in big cities have about 1 thousand students of different age from 6 to 17 and cook a standard lunch set for all students every day, except Saturdays and Sundays). Halls and gyms in school also have standards of lightings on one square meter and usually are equipped with the fluorescent lighting. The parameters of all other appliances in a school building such as air conditioning, computers, projectors, musical equipment, interactive whiteboards, plasma screens and others are included in build-in database. Their energy consumption is calculated similar to the case of office and apartment.

Proposed way of estimation the structure of energy consumption is simple for the user, because all he needs is to monitor the time of different equipment operation for several days (about a week). Then the user can run the EnergyCalc, get the structure of energy consumption and the estimation of total electricity spending, which one can compare with the meter‘s records. If the calculated and actual readings vary greatly, it may indicate that the user does not take into account some items of equipment or underestimates the time of their use. If the readings are the same, the user can analyze the real energy consumption structure and select the most reasonable ways to optimize it.

3. CODE AND DESIGN

The EnergyCalc program is realized in the C++ programming language, following the C++98 standard. It is currently available for personal computers running the Microsoft Windows or the GNU/Linux operating systems. However, there are builds of the program possible for other operating systems, such as Apple OS X, as well as a mobile version for Android and iOS. EnergyCalc uses the Qt libraries (version 5.2.0) and was created using the Qt Creator development environment, which is part of the Qt project. The program provides a user interface in two languages, English and Russian.

The main program window is a selection dialog, which provides buttons to choose the environment energy calculations should be performed within, such as home, office or public school (fig.3). This is necessary due to the different types of electrical appliances typically used within these environments and therefore different measureable units.

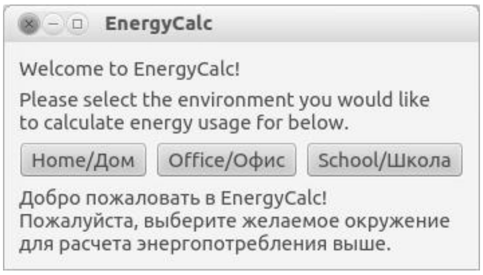


Fig. 3. Selection dialog [source: authors own studies]

After the desired environment has been selected, the program will attempt to read the data for this environment's typical appliances from files in its' directory. If this succeeds, the user should be presented with a dialog similar to the one below (fig.4).

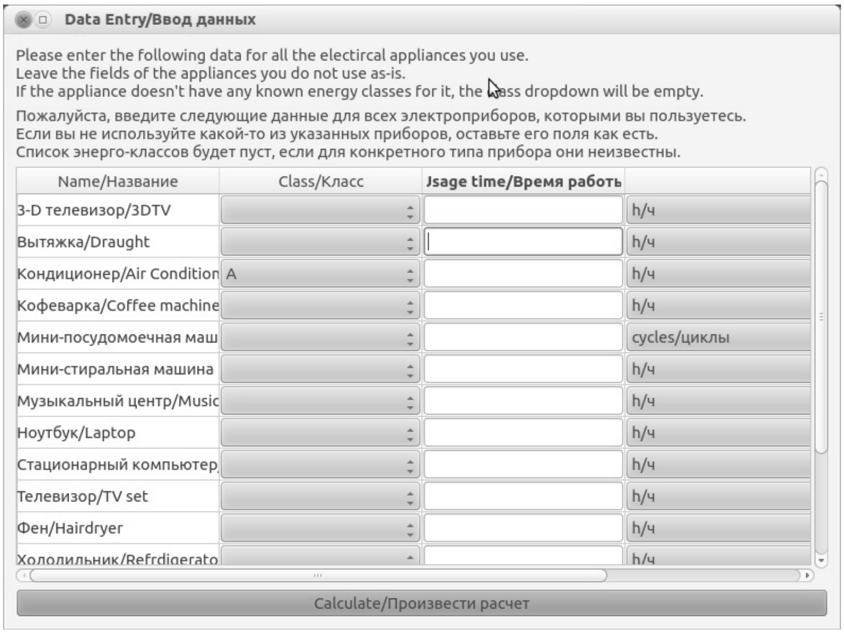


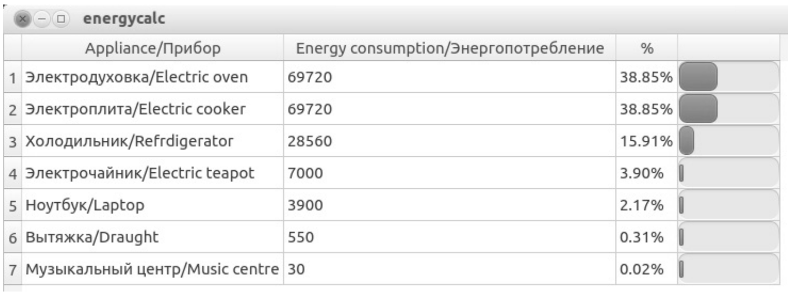
Fig. 4. Input window [source: authors own studies]

Here, user should specify how many hours in a selected time period (usually week, but it also can be day or month) he uses specific appliances presented in the list. For some appliances (e.g. hairdryers), it may be more convenient to specify the time in minutes, in that case, the user can modify the right-most column to specify that he wants to imput minutes rather than hours for those appliances. Also for some appliences such as washing mashines or dish washers user specify the number of uses in the monitoring period.

If known, energy-saving classes may also be specified. However, this isn't possible for all appliances. For those which have no known energy saving classes, this place in the list will be empty.

As soon as user specifys the operating times for all the appliances, he clicks the Calculate button below the table. The program will then sort all electrical appliances by the amount of electircal power consumption, and output the result in number and graphic formats (fig.5).

Note, that in some situations, such as a failed installation, accidental installation to a system-only directory, or accidental deletion or damage of the programs' data files (having the “.energy” file extension), the program may fail to load information required to allow data entry for some or all types of environments. A program reinstallation should fix the issue. In case this happens, an error dialog will be shown.



energycalc

	Appliance/Прибор	Energy consumption/Энергопотребление	%
1	Электродуховка/Electric oven	69720	38.85%
2	Электроплита/Electric cooker	69720	38.85%
3	Холодильник/Refrdigerator	28560	15.91%
4	Электрочайник/Electric teapot	7000	3.90%
5	Ноутбук/Laptop	3900	2.17%
6	Вытяжка/Draught	550	0.31%
7	Музыкальный центр/Music centre	30	0.02%

Fig. 5. Output window [source: authors own studies]

4. TESTING PROCEDURES AND RESULTS

Testing procedures were conducted on the same objects as case-study. The main purpose of testing the EnergyCalc was to determine how the number of appliances and their year of production as well as the duration of monitoring period affect the accuracy of calculation of total electricity consumption. For this calculated results were compared with the meter's records. Another purpose of testing was to determine how easy the user can get input parameters and to what extent he is satisfied with results of monitoring experiment. The responders have estimated these two parameters in Likert scale from 1 to 5 (1 – not satisfied at all/ very difficult; 5 – totally satisfied/ very simple) [13]. The tests' results are presented in the table below.

Tab. 2. The results of testing procedures

Object	The number of appliances (measurable units)*	Average time of operation (year)	Duration of monitoring, days	Mistake, % (the difference in calculated and real readings)
Household 1	17	3	7	5%
Household 2	13	4	7	5%
Household 3	18	2	7	7%
Household 4	18	4	7	5%
Household 5	19	3	11	9%
Household 6	19	3	7	5%
Household 7	20	2	10	10%
Office 1	17	7	14	10%
Office 2	10	5	7	11%
Office 3	17	7	7	13%
Office 4	12	5	7	9%
School 1	20	3	5	15%
School 2	20	4	10	10%

* All appliances of the same kind such as lamps, computers or laptops of the same power were considered as one measurable unit

Analyzing the data at the table, we can see that the lowest level of mistake is achieved in households. However, neither the number of appliances under monitoring, nor their year of production or time of observation did not significantly affect the accuracy of the results.

The level of mistake for offices is almost twice higher, which can be explained by insufficient quality of monitoring procedure (not all types of devices and their differences in power are included in the list), but also by the fact that that not all the energy consumption issues came to the attention of persons, who conducted monitoring.

There is not enough data to do some statistically proved conclusions about the accuracy of calculation for public schools, but it seems that the longer duration of monitoring cause better results.

The level of satisfaction with results and evaluation of simplicity of monitoring are presented on figure 6. It is interesting, that the level of satisfaction has a negative correlation with the accuracy of calculation. It happens mostly because owners (or managers) of complicated objects for monitoring such as SMEs offices and public schools are more interested in some tools that are quite simple in operating and can give them a glimpse which investment decision will be more effective for energy saving.

Most of responders also have noted that the process of monitoring helped them to realize how much they can improve their daily patterns of energy consumption; some decided to switch to use of energy saving light bulbs and others – to use day/night tariff meters. One office manager has observed unrecorded electricity consumption. Another firm started to consider implementing environmental standards and motivating workers with pro-social preferences, because they have found that "green employees" report a signifycantly higher perception of usefulness and equitable recognition at work during experiment (that fully correspond to the results of the study [14]).

These results of testing process show that participating in energy efficiency studies can be considered as a high influencing social interaction which helps to form of consumer perceptions and preferences for pro-environmental technologies [15].

Test procedures were helpful as well in terms of gathering user feedback for further improvement of the program. Thus, some users noted that they prefer to use similar program on their mobile phones.

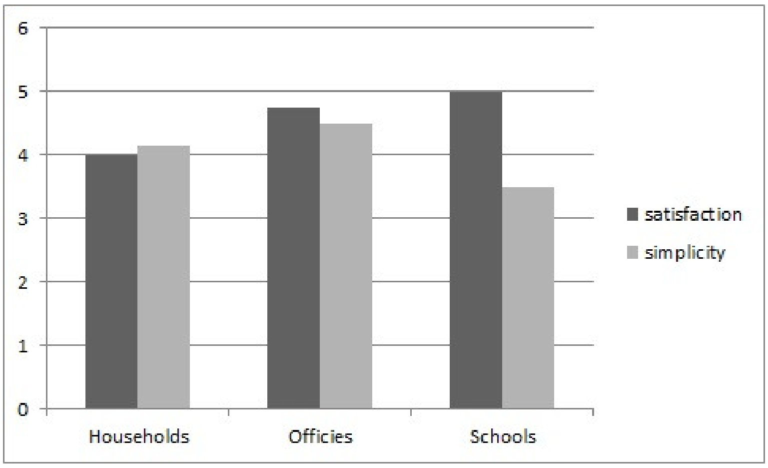


Fig. 6. Opinions of the respondents on satisfaction and simplicity with results of monitoring procedure [source: authors own studies]

Based on the results of test procedures it was decided to present the calculator for home and office in a form of mobile application. Current version of the program will be supplemented with practical recommend-dations on energy saving and put to one of the regional Internet portals on energy efficiency as open access software. It will not only give advantages in distributing the program, but will also (in case the user's consent) help to collect statistics on the energy consumption structure of households and offices. The use of the Cal-culator at the regional level will help to gather statistical data that can supplement and clarify the results of studies conducted by government agencies, which sometimes use outdated methods of data collection that do not meet the requirements of modern realities [16].

5. CONCLUSIONS

Resent significant increase in electricity tariffs and the growing popularity of energy-saving technologies in Russia initiate the interest to the problem of energy consumption monitoring. While a professional energy audit currently is very expensive, owners of small and middle-sized companies as well as regular householders demonstrate a high level of interest to use some "do-it-yourself" tools that can help to make very first steps in introduction of energy management systems and reduce the cost of professional energy audit.

By the use of presented EnergyCalc one can calculate the structure of energy consumption of a household, office or typical public school and see it both in graphic and number formats. Testing procedures helped to figure out that the lowest level of mistake is achieved in households (average 7%), while the level of mistake for offices is almost twice higher. The results of monitoring for public school have the mistake about 15%, but they can be improved with increase of time for monitoring.

Test procedures were helpful in terms of gathering user feedback for further improvement of the program. Based on their results it was decided to present the calculator for home and office in a form of mobile application

REFERENCES

[1] XIAOHUA XIA, JIANGFENG ZHANG.: *Mathematical description for the measurement and verification of energy efficiency improvement.* Applied Energy, Vol. 111, 2013, pp. 247-256.

[2] RATNER S.: *The implementation of state policy in the field of energy efficiency.* Economic Analysis: Theory and Practice, No. 29, 2013, pp. 21-28. (in Russian)

[3] RATNER S., IOSIFOVA L.: *Evaluating the effectiveness of regional energy efficiency programs (the case of Krasnodar region).* Regional Economy: Theory and Practice, No. 35, 2013, pp.43-49. (in Russian)

[4] Official site of energy audit: [electronic resource]. (http://www.energo116.ru) [date of access: 21.12.2013]

[5] Russian Federation Government Decree of October 21, 2011 No. 1843 -r on the distribution of subsidies granted in 2011 from the federal budget of the Russian Federation to co-finance expenditure commitments associated with the implementation of regional programs in the field of energy conservation and energy efficiency.

[6] GROGER M., SCHMID V., BRUCKNER T.: *Lifestyles and Their Impact on Energy-Related Investments Decisions*. Low Carbon Economy, No. 2, 2011, pp. 107-114.

[7] VALENZUELA C., VALENCIA A., WHITE S., JORDAN J. A., CANO S., KEATING J., NAGORSKI J., POTTER L. B.: *An analysis of monthly household energy consumption among single-family residences in Texas, 2010.* Energy Policy, Vol. 69, 2014, pp. 263-272.

[8] CHOONGWAN KOO, TAEHOON HONG, MINHYUN LEE, HYO SEON PARK.: *Development of a new energy efficiency rating system for existing residential buildings.* Energy Policy. Vol. 68, 2014, pp. 218-231.

[9] IN-AE YEO, SEONG-HWAN YOON, JURNG-JAE YEE.: *Development of an urban energy demand forecasting system to support environmentally friendly urban planning*. Applied Energy, Vol. 110, 2013, pp. 304-317.

[10] BOTETZAGIAS I., MALESIOS C., POULOU D.: *Electricity curtailment behaviors in Greek households: Different behaviors, different predictors.* Energy Policy, Vol.69, 2014, pp. 415-424.

[11] YIN R.: *A case study research: Design and Methods*. Thousand Oaks, CA: Sage, 2002.

[12] DAVIS, A.L, KRISHNAMURTI, T.: *The problems and solutions of predicting participation in energy efficiency programs*. Applied Energy, Vol. 111, 2013, pp. 277-287.

[13] ALLEN E., SEAMAN C.: *Likert Scales and Data Analyses*. Quality Progress, 2007, pp. 64-65.

[14] LANFRANCHI J., PEKOVIC S.: *How green is my firm? Workers' attitudes and behaviors towards job in environmentally-related firms.* Ecological Economics, Vol. 100, April 2014, pp. 16-29.

[15] AXSEN J., ORLEBAR C., SKIPPON S.: *Social influence and consumer preference formation for pro-environmental technology: The case of a U.K. workplace electric-vehicle study.* Ecological Economics, Vol. 95, 2013, pp. 96-107.

[16] FOULDS C., POWELL J.: *Using the Homes Energy Efficiency Database as a research resource for residential insulation improvements.* Energy Policy, Vol. 69, 2014, pp. 57-72.