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The analysis of municipal object’s energy efficiency with methods of system dynamics

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Kharytonov A.J. “The analysis of municipal object’s energy efficiency with methods of system dynamics” *In the article there is a question of analysis municipal object's energy efficiency with methods of system dynamics. Presently there is not universal methodology, allowing analyzing a consumption persons, directly responsible for an energy-savings – economists and managers. Data are analyzed by method of multiplicative function. Multiplicative dependence of building’s thermal consumption is got on a standard. Adequacy of this model is tested by comparing to “energy-temperature” diagram.*

Keywords: methods of system dynamics, multiplicative dependence, building’s thermal consumption, “energy-temperature” diagrams

Introduction

Nowadays, in the world there is a process of mass accumulation of information. This contributes to increased use of information technologies and increasing storage capacity. By these reasons at present there is a need to process the data and search for patterns in the data arrays. If we consider the energyы and resources consumption data on a variety of city facilities, the usual methods of analysis do not provide high quality results due to the fact that these data are stochastic and do not always lend themselves to the standard deterministic methods of analysis of energy consumption.

Scientific methods of analysis of energy and resource consumption of buildings are quite monotonous and in the bulk are based on engineering thermophysical calculations [1]. Such calculations are carried out by specialists of a corresponding profile: thermal engineering, hydraulics, electrical engineering, etc. The most qualitative data analysis is possible when the energy certificate of the building is present and the energy audit is held, but the latter is quite expensive procedure. It should also be mentioned that energy certificates for the vast majority of buildings, businesses and public-sector organizations are absent.

Currently, practically there is no simple and universal technique that allows to analyze the energy consumption of a variety of objects by persons directly responsible for energy saving – business executives, managers and system owners. Therefore, the development of new approaches in the analysis of energy and resource consumption is an actual problem.

Benchmark data

By a presidential decree no. 679/2008 of 28 July 2008 there were approved and enacted the resolution “About the decision of the National Security and Defense Council from 30 May 2008 “About the implementation of the state policy on ensuring the efficient fuel and energy resources use”. It reflects the conceptual directions of the state policy in providing of efficient use of resources and energy. One of the most important element of national energy saving policy is the creation of information systems of monitoring. In the Donetsk National Technical University in 2010, an information system for energy efficiency monitoring of municipal facilities in Donetsk was developed. It includes:

– automated workstation of data entry operator, installed at each facility;

– data transmission system to the server (the Internet access at the facility is optional);

– acquisition and data processing software installed on a server in the city council;

– constantly brimming databases of different indicators of buildings of all objects in the sphere of education.

Now the following data are collected [2]:

– administrative and engineering information for the 250 buildings of 160 schools in Donetsk;

– about 46,000 observational data of outdoor and indoor temperature of buildings during the 2008 – 2010 heating period;

– about 90,000 indications of daily consumption of electric energy;

– about 70,000 indications of daily consumption of hot or cold water;

– about 47,000 indications of thermal energy daily consumption (each indication includes coolant temperature regime, the total number and hourly mean of coolant, the total amount of heat and thermal power consumed in the period 2008 – 2010).

Statement of the problem

The aim of the work is the analysis of the energy consumption database using system dynamics methods. The study was also conducted to compare the results with the calculations, which were carried out by existing methods, based on the equations of heat balance of buildings or the resource consumption balance [5].

Data Analysis Methods

System dynamics methods allow us to study the behavior of complex systems by leveraging the capabilities of computer modeling. In contrast to the usual system dynamics modeling technologies, these methods do not require the construction of a mathematical model of the studied object in the traditional form as well as allowing us to develop computer models of the system elements and their relations.

While considering energy efficiency of buildings in the context of system dynamics, the problem is reduced to the recognition of similar images on a set of indicators for a number of consumption objects. It is necessary to choose a reference object and implement ranking of all relational objects to the current object.

An important element in this case is the selection of function class for modeling. Most often multiplicative functions are used.

A function $F(a)$ is called multiplicative if it satisfies the following two conditions: this function is defined for all positive integers and is not equal to zero at least at one a [3]. Moreover, for any positive a_1 and a_2 we have:

$$F(a_1, a_2) = F(a_1) \times F(a_2) . \quad (1)$$

It is needed to construct a multiplicative function of buildings parameters that varies little over time. The values a distinct change of which has the stochastic nature must not be included in the parameter list.

Such parameters may be those characteristics of buildings, which are controlled by energy and resource consumption, they are:

– year of construction, number of floors, height (m);

– construction area (sq. m), the total volume (cubic meters);

– total area (sq. m), heat output (Gcal / year);

– heated volume (cubic meters), heated area (sq. m);

– passport temperature of supply and return of the coolant at the object (ºC);

– the number of people present in the building during working and non-working hours.

The attribute options for construction of a multiplicative function must be reliable, independent and directly affect on the consumption of the selected resource.

Subsequent analysis of the data and the estimation of the parameters that affect the energy consumption showed that for the analysis of heat consumption must be considered the year of construction of the building, heated area and the number of people in the building. This allows us to form a following multiplicative function:

$$T = a\frac{x_1}{x_{1_0}} \cdot \frac{x_2}{x_{2_0}} \cdot \frac{x_3}{x_{3_0}} , \quad (2)$$

where a – constant, x_1, x_2, x_3 – parameters of studied objects, x_{i_o} – parameters of reference object.

To calculate the multiplicative function reference object – a building, characterized by some typical characteristics – is needed. As a reference, the worst or the best building in terms of thermal energy consumption, the building with the smallest heated area or building, selected according to other criteria, could be taken.

For the analysis, as the reference object school no. 9 of Voroshilov district has been chosen. It is characterized by a high specific consumption of thermal energy. Thus, the multiplicative function for analysis of resource and energy consumption will be as follows.

$$T = 100\% \cdot \frac{H_x}{H_c} \cdot \frac{A_x}{A_c} \cdot \frac{Y_x}{Y_c} , \quad (3)$$

where H_x, A_x, Y_x –number of people in the building, area of heated space and year of the construction of test buildings, H_c, A_c, Y_c – the corresponding parameters of the reference object. The calculated values of the multiplicative function (3) for the selected objects of one of the Donetsk' districts are given in Table 1.

Table 1. – Calculated values of multiplicative functions for the objects of Voroshilov district

Name of the school	Total amount of people	The total area of the buildings, sq. m	Average year of buildings	Volume, cu. m	T Index, calculated relatively to the school no. 9
School no.3	483	3176	1936	15355	22,12
Gymnasium no.15	299	2323,4	1952	7434,9	10,10
Gymnasium no.18	449	4449,3	1938	15573	28,84
Educational complex KORN	280	2295	1990	6770,3	9,52
Educational complex no.5	960	8907	1964	32265	125,13
School no.9	876	7749	1977	30996	100
Educational complex	738	3690,7	1950	40280	39,57
Lyceum no.22	526	3069	1939	46649	23,32
Educational complex no.1	1194	1132	1965	30959	19,79
School no.13	535	3500	1961	57275	27,36
DSPMS no.17	850	1652,9	1964	24123	20,56
School no.2	475	4169	1939	60040	28,61
School no.14	687	4049,4	1955	60741	40,52

Table 2. – The ratio of annual consumption of the selected objects to the annual consumption of the reference object for the different base years

Name	Actual consumption of thermal energy, Gcal for year				The normalized thermal energy consumption in relation to the school no. 9			
	2010	2009	2008	2007	2010	2009	2008	2007
School no.3	200,36	264,19	295,73	348,80	0,28	0,37	0,42	0,49
Gymnasium no.15	265,07	328,26	417,13	488,88	0,37	0,46	0,59	0,69
Gymnasium no.18	305,97	328,07	350,17	372,27	0,43	0,46	0,49	0,52
Educational complex KORN	356,08	329,00	372,71	369,23	0,50	0,46	0,52	0,52
Educational complex no.5	1135,18	810,98	1064,1	1317,3	1,60	1,14	1,50	1,85
School no.9	808,00	710,81	884,99	1059,7	1,14	1,00	1,25	1,49
Educational complex	930,00	930,00	1095,1	1150,2	1,31	1,31	1,54	1,62
Lyceum no.22	422,45	481,92	498,51	374,11	0,59	0,68	0,70	0,53
Educational complex no.1	431,91	628,60	656,10	796,39	0,61	0,88	0,92	1,12
School no.13	397,66	347,43	398,25	381,70	0,56	0,49	0,56	0,54
DSPMS no.17	562,46	479,04	480,14	383,76	0,79	0,67	0,68	0,54
School no.2	374,49	409,30	481,94	355,39	0,53	0,58	0,68	0,50
School no.14	453,26	425,13	490,32	376,43	0,64	0,60	0,69	0,53
School no.19	457,77	490,00	610,00	248,36	0,64	0,69	0,86	0,35
School no.56	474,22	330,00	200,00	60,52	0,67	0,46	0,28	0,09
School no.117	279,10	390,00	450,00	543,93	0,39	0,55	0,63	0,77

Energy consumption assessment

For the analysis the change dynamics of the parameters during yearly intervals have been considered.

For each year and for each resource the empirical measure t was built (Table 2). This measure determines the ratio of annual consumption to the annual consumption of the reference volume of the same resource for the selected base year:

$$t = \frac{C_x}{C_c}, \quad (4)$$

where C_x – resource consumption of the analyzed object in a given year; C_c – resource consumption for the base year of the reference object.

The dependence of the parameter t from T is called normalized consumption. In Figure 1 the

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scatter diagrams of the normalized consumption for different years are shown.

The obtained model of thermal energy from the indicators of objects (persons, area, and year of construction) allows to determine the state of the object based on actual consumption of thermal energy. However, the problem of the optimal choice of attribute indicators and reference objects for the described analysis still remains.

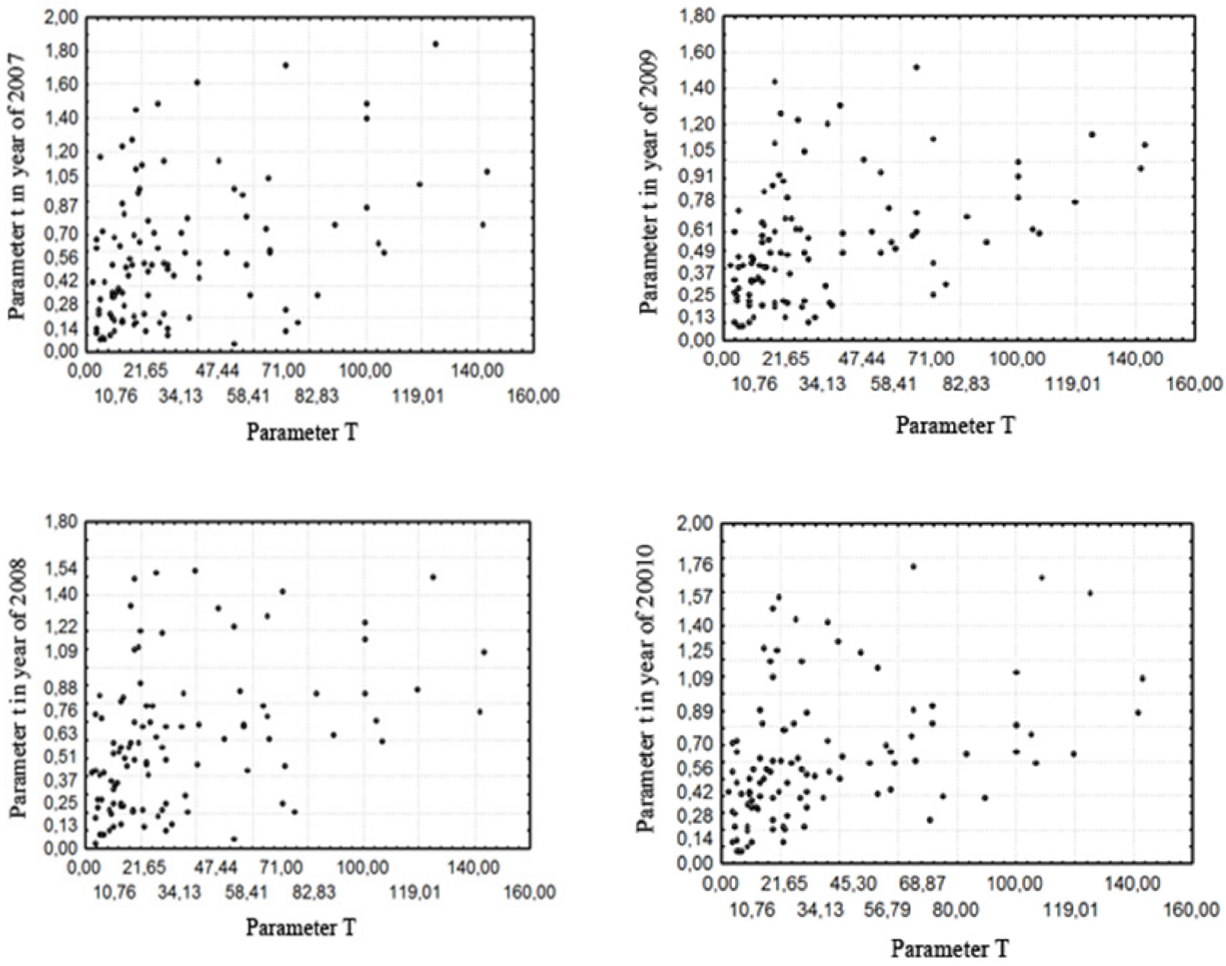

Figure 1. – The distribution of the normalized thermal energy consumption in relation to the consumption of thermal energy of the school no. 9

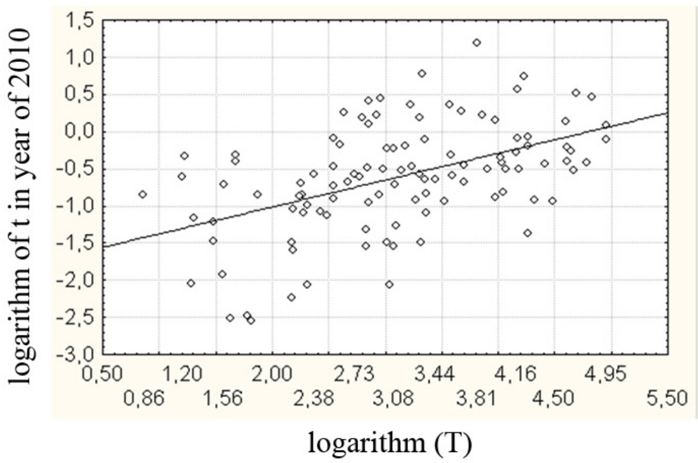

Figure 2. – Distribution of the natural logarithm of the normalized indicators of consumption in relation to the natural logarithm of the heat consumption of the school no.9, 2010

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In the analysis of energy consumption it is necessary to check the linearity the dependencies (Figure 2). Due to this it is vital to construct a linear function of following type:

$$\ln(t) = A + B \cdot \ln(T), \quad (5)$$

where A, B are coefficients.

Figure 2 shows that the logarithmic relation is expressed by a linear relationship.

The analysis of distribution graphs of the indicators of the thermal energy normalized consumption relative to the thermal energy consumption of the reference building for each year (Figure 1) shows that the obtained coefficients are stable over time. The dynamics of changes ratios is similar to the dynamics of changes in average temperature of the environment and indicates the independence of unstable factors in the maintenance of internal heat.

Function test of the model

To verify the functionality of the model we have to apply objects of public sector facilities to the analysis of its heat demand. For the analysis of these objects the method of charting the "energy-temperature" actual heat load and the required heat load, calculated according to the heat balance equations based on real data is used. More details about this technique can be found in [1]. For the analysis we selected objects that have sufficient volume of data for analysis. As it is seen from the graphs above, the difference between necessary and the average daily consumption of thermal loads shows the deviation in the supply of heat energy to various buildings in the upward or downward. According to data provided by the enterprises supplying heat, heat is supplied to all schools according to the temperature graphs, so this indicator is taken to determine the heat loss of buildings. Let’s define the place of the schools above in the distribution of the normalized heat, leaving out only the objects in the distribution of Kiev and Voroshilov district, and select individually the objects with positive and negative difference between needed and consumed daily average thermal loads.

The resulting distribution shows the relationship between the normalized distribution of heat and the calculation of the data by the method of charting “energy-temperature”, which proves the efficiency of the model.

Conclusions

According to the results of the automated information system of monitoring of energy efficiency of municipal facilities in Donetsk database with indexes of consumption of energy and resources was accumulated. The data were analyzed using the theory of multiplicative functions. The dependence of the heat consumption of the buildings from the reference object is obtained. The adequacy of this model is tested by comparing it with the method of diagrams "energy-temperature".

The resulting multiplicative relationship can replace the database of indexes of energy and resource consumption by the base of models with the values of consumption and the parameters of the equation of the linear dependence of the natural logarithms of multiplicative function indicators. It allows to analyze energy and resource consumption, using only the data of consumption and omit static data and object parameters.

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Харитонов А.Ю. «Анализ энергоэффективности муниципальных объектов с помощью методов системной динамики». *В статье рассматривается вопрос энергоэффективности анализа муниципальных объектов с помощью методов системной динамики. В настоящее время не существует универсальной методологии, позволяющей анализировать потребление электроэнергии лицами, непосредственно ответственными за энергосбережение – экономистами и менеджерами. Данные анализируются методом мультипликативной функции. Мультипликативная зависимость теплового потребления здания была взята за стандарт. Адекватность этой модели проверена путем сравнения с диаграммой «энергия-температура».*

Ключевые слова: методы системной динамики, мультипликативная зависимость, тепловое потребление здания, диаграмма «энергия-температура»

Харитонов А.Ю. «Аналіз енергоефективності муніципальних об'єктів за допомогою методів системної динаміки». *У статті розглядається питання енергоефективності аналізу муніципальних об'єктів за допомогою методів системної динаміки. Нині не існує універсальної методології, яка дозволяла би аналізувати споживання електроенергії особами, які безпосередньо є відповідальними за енергозбереження – економістами та менеджерами. Дані аналізуються методом мультиплікативної функції. Мультиплікативна залежність теплового споживання будівлі була взята за стандарт. Адекватність цієї моделі перевірена шляхом порівняння з діаграмою «енергія-температура».*

Ключові слова: методи системної динаміки, мультиплікативна залежність, теплове споживання будівлі, діаграма «енергія-температура»

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