МАТЕМАТИЧНІ МЕТОДИ, МОДЕЛІ Й ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ В ЕКОНОМІЦІ

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ECONOMIC-MATHEMATICAL MODELING OF THE ENERGY EFFICIENCY INDICATORS OF EXISTING HOUSING STOCK

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Introduction. The problem of increasing efficiency in the existing housing was caused by different reasons. In the current economic conditions, there is an issue of efficient use of fuel and energy resources. The results of the analysis of the structural cost of energy determined that the housing and utilities sector, in particular, residential buildings of old buildings, is one of the largest consumers of thermal energy (more than 30% of the total consumption of fuel in the country). Previous investigations provided an opportunity to identify the energy saving potential in this sector which is estimated at 50 to 70% from the current level of energy consumption.

An overview of recent research sources and publications. R. Z. Podolets considered in his writings the problems of using mathematical models to determine the optimal directions and volumes of investments in the energy industry [1]. In the works by V. A. Kapustyan, M. G. Chepel was proposed an approach to study adequacy of economic and mathematical tools which used for the assessment of impacts of subsidies in the energy sector [2]. The issues of formation of economic-mathematical models of the dynamics of the changing state of the housing market were studied by L. Y. Galchinskiy [3]. The technical condition of the housing stock of Ukraine was investigated by M. Sukhonos, T. G. Molodchenko [4]. The problem of energy saving in the housing Fund was considered by V. P. Volkov [5]. However, there is an open question of optimization of the energy efficiency indicators of the existing housing stock, including with use of economic-mathematical methods.

Statement of the problem. The study of statistical data allows assert that for the scientific development of theoretical bases of increasing the efficiency of the housing stock, further improvement of the applied basis is advisable to create optimization economic-mathematical model of energy consumption.

The main material and results. A variety of indicators is used to assess the energy efficiency. As a rule, the energy efficiency indicators are the specific values presented as a ratio of energy consumption (measured in energy units) to activity data (expressed in natural units) (f. 1). Energy consumption can be expressed in different units (kilowatt-hours, joules, tons of oil equivalent, etc.). Data on activities can cover a wide range of types (cement, floor space, passenger-kilometers, population etc.) and be expressed in the same number of units (tons, square meters, kilometers, number of staff, etc.)

$$The\ level\ of\ energy\ efficiency = \frac{Energy\ consumption}{Operations} \quad (1)$$

The energy efficiency indicators are calculated at the level of end-use or subsector, or even at the level of equipment energy consumption. For example, within the residential sector energy consumption for heating per unit area is a measure of efficiency at the level of final consumption. The consumption of household technical devices is an indicator of energy efficiency at the level of equipment energy consumption [6].

Applied part of the research done on the statistics of Ukraine for 2009-2014 [7]. The basic indicators of energy efficiency of the existing housing stock (table 1).

Preparation of a more detailed assessment of energy efficiency requires the application of this scientific approach, like a decomposition, that allows us to consider any of the investigated system as a complex consisting of separate interconnected subsystems, which in turn can be divided into parts.

Table 1

The basic indicators of energy efficiency of the existing housing stock

Indicator	**Energy consumption**	**Operations**
Consumption of energy resources for 1sq.m. of residential square toe/sq. m.	Final consumption household sector total, thousand toe **(Y_1)**	Residential area of housing apartments (municipal settlements and rural locality), thousand m^2 **(Y_2)**
Energy resources consumption per capita, toe/person	Final consumption household sector total, thousand toe **(Y_1)**	The existing population, thousand **(Y_3)**

So, there are factors that affect to the final consumption in the household sector, to volume of living space of residential areas (urban settlements and rural areas) and to number of the existing population. Relationship strength is established through the correlation coefficient (R), the results shown in table 2.

Table 2

Factors of influence on energy efficiency components (Y_1, Y_2, Y_3)

Factor	Characteristic	Units of measurement	R
1	2	3	4
X_1	Equipment of apartments (single household) heating (towns and countryside)	thousand units.	0,85
X_2	Consumer total expenditure on housing, water, electricity, gas and other fuels (average per month per household)	UAH	-0,54
X_3	Consumer price indices for housing, water, electricity and other fuels	% to the front. year	-0,51
z_1	Aggregate consumer expenditures (average per month per household), total cash costs	UAH	0,99
z_2	Benefits and non-cash subsidies for housing and communal services, electricity and fuel (average per month per household)	UAH	0,54
z_3	Cash income (average per month per household)	UAH	0,98
S_1	The total area of renovated residential premises	thousand sq. m	0,60
S_2	Disposal of total area of residential premises	thousand sq. m	0,81
S_3	Receipt of total area of residential premises	thousand sq. m	0,86
v_1	The total cost of capital repairs of houses	thousand UAH	0,80
v_2	Expenditures for housing from state budget	million UAH	0,60
v_3	Expenditures for housing from local budgets	million UAH	0,71
u_1	Old housing stock (urban settlements and rural area), total area	thousand sq. m	0,71
u_2	The emergency housing Fund (urban settlements and rural area), total area	thousand sq. m	0,58
u_3	The area of residential new construction	thousand sq. m	0,90
Q_1	Wages (average per month per household)	UAH	0,58
Q_2	Income from entrepreneurship and self-employment (average per month per household)	UAH	0,78
Q_3	Pensions (average per month per household)	UAH	-0,59
Q_4	The number of households	thousands	0,99

An important indicator is the energy consumption in the household sector: use of energy resources, heat and electricity for domestic use (heating, cooking, etc.). The share of this indicator in the total final energy consumption in 2014 amounted to 33%.

For the construction and implementation of econometric models was used the package of applied program STATISTICA 8.0 – a versatile integrated system for statistical analysis and data processing [8].

The dependence Y_1 (final consumption, household sector total, thousand toe) from factors is in formula 2.

$$Y_1 = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 \qquad (2)$$

Solution (2) is the following multiple linear regression equation:

$$Y_1 = -4777.24 + 2.95 \cdot X_1 - 13.44 \cdot X_2 - 26.76 \cdot X_3 \qquad (3)$$

The results of estimating the parameters of equation (3) shown in Fig. 1

One of the main indicators of the density correlation of the Y indicator to the factors X_i *(i =1, m)* and the indicator of the degree of proximity to mathematical forms of communication to the sample data is the coefficient of multiple correlation. The correlation coefficient ranges from -1 to 1, and if R > 0, then between the random variables X and Y there is a direct correlation, if R < 0, then between these random variables there is an inverse relationship. For the developed model *Multiple R (coefficient of multiple correlation)*= 0.946, which indicates a close connection Y_1 with X_1, X_2, X_3 factors, and proximity to the selected mathematical model of the sample data.

	Regression Summary for Dependent Variable: Y1 (Y1) R= ,94574340 R?= ,89443058 Adjusted R?= ,73607645 F(3,2)=5,6483 p<,15410 Std.Error of estimate: 687,27					
N=6	**Beta**	Std.Err. of Beta	B	Std.Err. of B	t(2)	p-level
Intercept			-4777,24	22751,96	-0,20997	0,853138
X1	0,797881	0,361868	2,95	1,34	2,20489	0,158263
X2	-0,483294	0,294689	-13,44	8,19	-1,64001	0,242684
X3	-0,191367	0,423185	-26,76	59,17	-0,45221	0,695433

Fig. 1. Summary statistics for stepwise regression

The ratio of the sum of squares centered theoretical values for the centered sum of squares of sample values is called the sample coefficient of multiple determination. The closer the sample (experimental) values are closer to the regression line, the closer the sample coefficient of multiple determination is close to 1. In our case, *R-square =* R^2 *(determination coefficient) = 0.89 and Adjusted* R^2*(adjusted coefficient of determination) = 0.74*, reflecting the quality of the description of the existing dependence.

One of the problems of choice is the issue of determining the materiality of influence on an indicator of individual factors in the construction of an econometric model of development economic processes. The significance of influence of factors on indicator can be determined using F-statistics. According to the Fisher criterion F (3.2) = 5.65, which is higher than the critical table value and demonstrates the value of communication. Obtained by t-test of the coefficient estimates are statistically significant. A measure of the dispersion of the values that are observed relative to the direct regression, that is, the standard error of estimate = 687.27. This value can then be used to construct the borders of the forecast final consumption of the household sector only. This value increases the predictive value of an optimistic forecast and, accordingly, reduced with the pessimistic forecast. Consequently, the resulting mathematical model is adequate to experimental data and on the basis of this model it is possible to carry out economic analysis and to find the value of the forecast.

It is worth noticing that if the independent variable is the « + » sign, this means that it has a positive effect on the dependent variable value, otherwise it has a negative impact. Characteristics of each identified dependency are caused by socio-economic development of the country or region in particular. For example, if a feature quantity of apartments (houses) heating (urban settlements and rural areas) is the « + » sign, it means that there is an increase in comfortable living conditions for the population in the country, and this will lead to an increase in final consumption of energy in the domestic sector. If is in front of the total consumer spending on housing, water, electricity, gas and other fuels, UAH. (average per month per household) and consumer price indices for housing, water, electricity and other fuels, % (to previous year) the sign « – », it means that an increase of household expenditure on utilities is a reduction of the final energy consumption in the domestic sector.

The regression equation can be used to predict the values of the effective feature. Supposed that X_1 = 11350 thousand units, X_2 = 400 UAH, X_3 = 120%, then Y_1 = 20098 thousand toe. The table of the forecast results is presented in Fig. 2.

The table shows specified (predicted) final consumption household sector total – 20098 thousand toe with 95% confidence interval (16602; 23594).

Variable	Predicting Values for (Y1) variable: Y_1 B-Weight	Value	B-Weight * Value
X_1	2,9481	11350,00	33460,76
X_2	-13,4366	400,00	-5374,63
X_3	-26,7557	120,00	-3210,69
Intercept			-4777,24
Predicted			20098,20
-95,0%CL			16602,20
+95,0%CL			23594,21

Fig. 2. The results of the forecast

To determine the main indicators of the efficiency of the existing housing stock from the effect of factors was built 6 economic-mathematical models. Base models and performance test of adequacy: the correlation coefficient and the F-statistics are given in table 3.

As *Multiple R (multiple correlation coefficient) and* R^2 *(coefficient of determination)* of the constructed models close to unity, between productive characteristics and factor variables there is a tight multiple-link and high quality describe the existing dependencies.

The obtained multiple linear regression are significant according to the Fisher criterion, since $F_r > F_t$, indicating the adequacy of the obtained mathematical models.

Also, was determined the predicted values of the effective characteristics and 95% confidence interval of forecast, table 4.

Table 3

The main characteristics of economic-mathematical models

Effective sign	The mathematical form of the model (General)	R	R^2	F_r	F_t
1	2	3	4	5	6
Y_1 – final consumption household sector total, thousand toe	$Y_1 = a_0 + a_1X_1 + a_2X_2 + a_3X_3$	0,95	0,89	5,65	3,2
X_2 – consumer total expenditure on housing, water, electricity, gas and other fuels, UAH.	$X_2 = c_0 + c_1z_1 + c_2z_2 + c_3z_3$	0,99	0,99	143,4	3,2
Y_2 – residential area of housing apartments (municipal settlements and rural locality), thousand sq. m.	$Y_2 = b_0 + b_1S_1 + b_2S_2 + b_3S_3$	0,97	0,94	11,67	3,2
S_1 – the total area of the renovated dwellings, thousand sq. m.	$S_1 = \delta_0 + \delta_1v_1 + \delta_2v_2 + \delta_3v_3$	0,95	0,91	6,7	3,2
S_3 – income total housing area, thousand sq. m.	$S_3 = \beta_0 + \beta_1u_1 + \beta_2u_2 + \beta_3u_3$	0,94	0,89	5,4	3,2
Y_3 – the existing population, thousand	$Y_3 = \varphi_0 + \varphi_1Q_1 + \varphi_2Q_2 + \varphi_3Q_3 + \varphi_4Q_4$	0,99	0,99	2675	4,1

Table 4

The predicted values of the effective signs

The mathematical form of the model (the solution)	Forecast values	Confidence interval
$Y_1 = -4777.24 + 2.95 \cdot X_1 - 13.44 \cdot X_2 - 26.76 \cdot X_3$	20098,20	(16602; 23594)
$X_2 = -40.865 + 0.92 \cdot z_1 + 3.72 \cdot z_2 + 0.002 \cdot z_3$	382,53	(365,93; 399,12)

Продовження таблиці 4

$Y_2 = 504412.1 + 40.1 \cdot S_1 - 10.0 \cdot S_2 + 11.8 \cdot S_3$	604783,5	(547640,2; 661926,9)
$S_1 = -535,655 + 0,005 \cdot v_1 + 0,878 \cdot v_2 + 0,001 \cdot v_3$	1238,7	(857,9; 1619,5)
$S_3 = -34093.6 + 12.7 \cdot u_1 - 24.3 \cdot u_2 + 5.7 \cdot u_3$	25884,3	(18245,3; 33523,4)
$Y_3 = 31277.53 - 1.33 \cdot Q_1 - 3.09 \cdot Q_2 + 1.69 \cdot Q_3 + 0.94 \cdot Q_4$	42849,9	(41846,8; 43853,0)

As a result of this research, it is advisable to build a hierarchical tree logical inference for presentation of the results in general form (Fig. 3, 4).

The elements of the tree are interpreted as follows: arcs, leaving the vertices are the effective characteristics; arc incoming in the vertices are the factors of influence; the vertices are the economic-mathematical model.

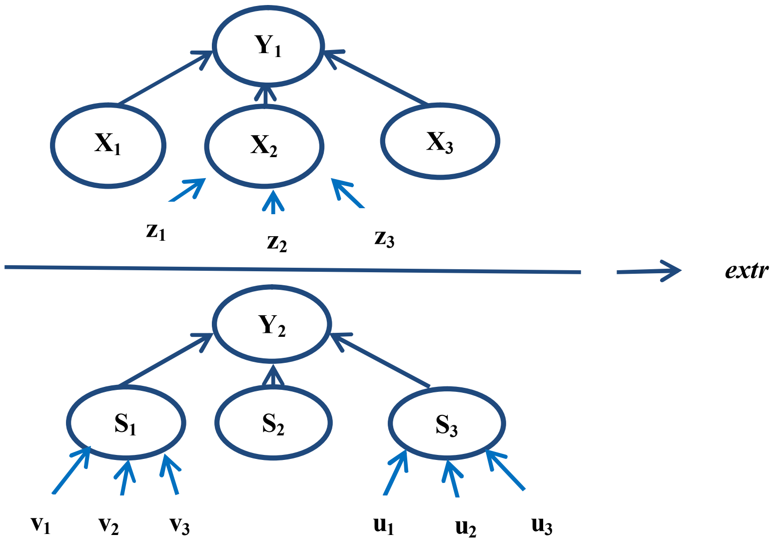

Fig. 3. Hierarchical tree logical inference to optimize energy consumption indicator per 1 sq. m. of living space

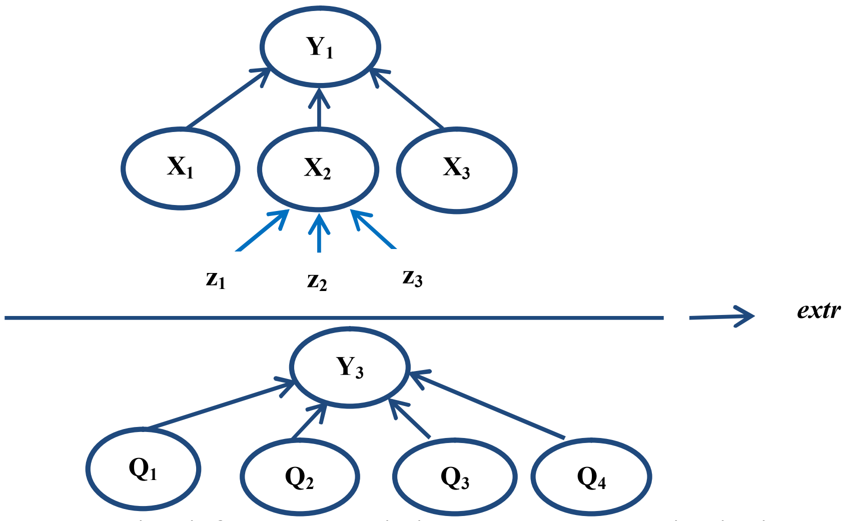

Fig. 4. Hierarchical tree logical inference to optimize energy consumption indicator per capita

Hierarchical tree (Fig. 3) corresponds to the objective function (4) and system constraints (5):

$$\frac{Y_1}{Y_2} = \frac{a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3}{b_0 + b_1 S_1 + b_2 S_2 + b_3 S_3} \to \min \tag{4}$$

$$\begin{cases} X_2 = c_0 + c_1 z_1 + c_2 z_2 + c_3 z_3 \\ S_1 = \delta_0 + \delta_1 v_1 + \delta_2 v_2 + \delta_3 v_3 \\ S_3 = \beta_0 + \beta_1 u_1 + \beta_2 u_2 + \beta_3 u_3 \end{cases} \quad (5)$$

Hierarchical tree (Fig. 4) corresponds to the objective function (6):

$$\frac{Y_1}{Y_3} = \frac{a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3}{\varphi_0 + \varphi_1 Q_1 + \varphi_2 Q_2 + \varphi_3 Q_3 + \varphi_4 Q_4} \to \min \quad (6)$$

Received optimization function of the minimum energy consumption per 1 sq. m. of residential space on the basis of economic-mathematical models (4 – 5) (7):

$$\frac{Y_1}{Y_2} = \frac{a_0 + a_1 X_1 + a_2 \left(c_0 + c_1 z_1 + c_2 z_2 + c_3 z_3\right) + a_3 X_3}{b_0 + b_1 \left(\delta_0 + \delta_1 v_1 + \delta_2 v_2 + \delta_3 v_3\right) + b_2 S_2 + b_3 \left(\beta_0 + \beta_1 u_1 + \beta_2 u_2 + \beta_3 u_3\right)} \to \min \quad (7)$$

On the basis of economic-mathematical models (6) received optimization function of the minimum energy consumption per person (8):

$$\frac{Y_1}{Y_3} = \frac{a_0 + a_1 X_1 + a_2 \left(c_0 + c_1 z_1 + c_2 z_2 + c_3 z_3\right) + a_3 X_3}{\varphi_0 + \varphi_1 Q_1 + \varphi_2 Q_2 + \varphi_3 Q_3 + \varphi_4 Q_4} \to \min \quad (8)$$

Conclusions. Therefore was used the structural-analytical analysis of the measurement of energy efficiency as a category of energy consumption reduction per 1 m2 per capita, based on the developed criterion of minimizing the energy consumption per 1 sq. m per capita under the given constraints in the context of energy efficiency.

Comparison of the obtained optimal values of consumption of key energy efficiency indicators will give the opportunity to propose policies for improving energy efficiency in the existing housing stock of Ukraine, which should begin with the definition of energy saving potential, setting of targets, regular monitoring of implementation of tasks and measures in case of failure.

The expected benefits of energy efficiency for Ukraine is the reduction of energy consumption and dependence on their import, the growth of welfare of population, reducing investment in energy infrastructure and improvement of the ecological situation after reduction of greenhouse gases.

The proposed method can be applied to determine the energy efficiency indicators at the regional level.

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студентка. Полтавський національний технічний університет імені Юрія Кондратюка. **Економіко-математичне моделювання показників енергоефективності існуючого житлового фонду**. Досліджено питання підвищення ефективного енергоспоживання в існуючому житловому фонді України. Для оцінювання ефективності енергоспоживання обрано показники енергоефективності, які подано у вигляді відношення енергоспоживання (виміряного в одиницях енергії) до даних про діяльність (виражених у натуральних одиницях). Визначено основні показники енергоефективності існуючого житлового фонду України на підставі статистичних даних. Розроблено дворівневу систему економіко-математичних моделей для побудови оптимізаційної функції мінімального споживання енергоресурсів на 1м^2 житлової площі та оптимізаційної функції мінімального споживання енергоресурсів на одну особу. Проаналізовано моделі на адекватність і знайдено прогнозні значення результативних показників для України. Здійснено експериментальну апробацію розробленої системи моделей у пакеті прикладних програм Statistica Statsoft.

Ключові слова: показники енергоефективності, економіко-математичне моделювання, кореляційний аналіз, множинна лінійна регресія, адекватність, оптимізаційна функція.

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Разработана двухуровневая система экономико-математических моделей для построения оптимизационной функции минимального потребления энергоресурсов на 1 м^2 жилой площади и оптимизационной функции минимального потребления энергоресурсов на одного человека. Проанализированы модели на адекватность, и найдены прогнозные значения результативных показателей для Украины. Осуществлена экспериментальная апробация разработанной системы моделей в пакете прикладных программ Statistica Statsoft.

Ключевые слова: показатели энергоэффективности, экономико-математическое моделирование, корреляционный анализ, множественная линейная регрессия, адекватность, оптимизационная функция.

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Komelina Olha Vladimirovna, Doctor of Economics, Professor. **Shcherbinina Svetlana Adamovna**, Senior Lecturer. **Serdyuk Kateryna Igorevna**, student. Poltava National Technical Yuri Kondratyuk University. **Economic-mathematical modeling of the energy efficiency indicators of existing housing stock**. It was developed two-level system of economic and mathematical models to build the optimization function of the minimum energy consumption per 1 sq. m. of residential space on the basis of economic-mathematical models and optimization function of the minimum energy consumption per person. In article was analyzed the model for adequacy and found the predicted values of the effective feature for Ukraine. Also was implemented a pilot approbation of the developed system models in the application package Statistica Statsoft.

Keywords: energy efficiency, economic-mathematical modeling, correlation analysis, multiple linear regression, the adequacy of the optimization function.