HEAT AND GAS SUPPLY, VENTILATION, AIR CONDITIONING, GAS SUPPLY AND ILLUMINATION

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ANALYSIS OF EFFECTS OF HEAT-AND-POWER FEATURES ON THE ENERGY EFFICIENCY OF RESIDENTIAL BUILDINGS USING THE EXAMPLE OF 1-335 SERIES

Statement of the problem. One of the ways of reducing the volume of consumed fuel and energy resources is the reduction of energy consumption for heating reconstruction of residential buildings. A significant proportion of housing in need of reconstruction is made up by panel blocks of flats, particularly a series 1-335. For a more rational selection of measures, aimed at raising the level of thermal protection in the reconstruction of residential buildings, for minimizing heat loss and the formation of comfortable conditions of microclimate in the premises it is necessary to identify the most effective ones.

Results and conclusions. Based on the analysis of the developed regression dependence of the consumption of thermal energy, the degree of influence of the main heat-and-power features of the energy efficiency of residential buildings is identified. The most effective technical solutions for increasing the energy efficiency of large-panel buildings on the example of the facilities operated in climatic conditions in Bryansk were identified.

Keywords: energy sustainability, building envelope, engineering networks, thermal and energy characteristics, a housing residence, fuel and energy resources, reduction of energy consumption.

Introduction

The paper [1] examines the effect of the major heat and energy characteristics on the energy sustainability of residential buildings and such factors as the heat transfer resistance of enveloping structures and coefficients of the oncoming heat flow, reduction in the amount of heat coming in due to heat inertia of enveloping structures and efficiency of automatic regulation of heat coming in have been identified as most important.

The amount of domestic heat, temperature of the outside air and glassing coefficient of the façade become obvious if there is a change in the other parameters.

In the follow-up study the dependencies of the specific heat energy for heating of a large-panel building 1-335 in the weather conditions of Bryansk on the above characteristics will be examined. For that, let us design a universal regression dependence that accounts for changes in these characteristics caused by the suggested reconstruction of the building. The allowance will be made by leaving volume and planning characteristics unchanged.

1. Choosing of heat and energy characteristics (factors) to analyze

A building enclosure is formed by several isolated planes. Here, these are exterior walls, coating, closure over the technical facility and translucent structures as a particular component of the vertical planes. A change in the construction components and therefore a heat transfer resistance of these elements during the reconstruction has a large impact on the heat energy consumption per 1 m^3 of the heated space. Therefore there are four factors to consider such as heat transfer resistance of the exterior walls, windows and balcony doors, coating and enclosure over the technical facility.

The modernization of the engineering systems of the building as well as the introduction of the ventilation and utilization systems of the output air heat cause a reduction in infiltration losses and a more efficient control of the heat coming in. In order to account for these changes, another two factors need to be added which are the coefficient k_η that considers the total coefficient of efficiency of the heat recuperation being used and extra air infiltration and the coefficient ζ that considers a drop in the heat coming in as well as due to the efficiency of automatic regulation of the heat coming into the heating system.

The following principle was adopted in identifying the levels of change in the first factors: the lower level – the existing factor; the major level – minimum admissible standard value; the upper level – a value symmetrical to the major level. An allowance is made that the enveloping structures in determining the numerical values of the levels of the first, third and forth factors are medium inertial ($4 < D \leq 7$), while the value of the major level of the second factor is determined with the glass coefficient of the façade $f \leq 0.36$.

The factor x_1 is heat transfer resistance for the exterior walls R_w, $m^2 \cdot °C/Watt$, with the distribution over three change levels 0.842 (–1); 2.650 (0); 4.458 (+1).

The factor x_2 is heat transfer resistance for windows and balcony doors R_F, $m^2 \cdot °C$/Watt, with the distribution over three change levels 0.440 (-1); 0.600 (0); 0.760 (+1).

The factor x_3 is heat transfer resistance for the coating R_c, $m^2 \cdot °C$/Watt, with the distribution over three change levels 2.225 (-1); 4.140 (0); 6.055 (+1).

The factor x_4 is heat transfer resistance for the closure over the technical facility R_f, $m^2 \cdot °C$/Watt with the distribution over three change levels 1.646 (-1); 3.610 (0); 5.574 (+1).

The following principle was adopted in identifying the levels of change in the fifth factor: the lower level – no heat recuperation inside the building and low air tightness of the windows (less than 0.6 $m^2 \cdot h/kg$); the major level – arithmetic average between the upper and lower levels with following the requirement of the first edition of "Heat Protection of Buildings" [2] that says that the coefficient of efficiency of the ventilation system cannot be below 30 %; the upper level – maximum effective recuperation (coefficient of efficiency is 100 %).

The factor x_5 is the coefficient k_η that considers the total coefficient of efficiency of output heat recuperation being used and extra air infiltration:

$$k_\eta = k_v (100 - \eta_v) / 100,$$

where k_v is the coefficient that considers extra air infiltration through entrance lobbies and straight stair lift as well as infiltration which is over the standard air exchange in apartments with poorly airtight windows; η_v is the coefficient of efficiency of the ventilation system with heat recuperation.

$$k_\eta = 1,3(100-0)/100 = 1,3; \; k_\eta = 1,05(100-100)/100 = 0; \; 1,30(-1); 0,65(0); \; 0,00(+1).$$

The following principle was adopted in identifying the levels of change in the sixth factor: the lower level – no thermostats and automatic input regulation; the major level – the arithmetic average between the upper and lower levels which conforms to the introduction of one of the ways of controlling the amount of heat coming in; the upper level – thermostats and façade input control.

The factor x_6 is the coefficient of efficiency of automatic regulation of the amount of heat coming in ζ with the distribution over three change levels 0.50 (-1); 0.75 (0); 1.00 (+1).

Change ranges and levels of the factors are presented in the Table.

Table

Levels and change ranges of the factors

Name	Factors					
	x_1	x_2	x_3	x_4	x_5	x_6
Change range	1.808	0.160	1.915	1.964	0.65	0.25
Lower level (-1)	0.842	0.440	2.225	1.646	1.30	0.50
Major level (0)	2.650	0.600	4.140	3.610	0.65	0.75
Upper level (+1)	4.458	0.760	6.055	5.574	0.00	1.00

2. Developing a regression equation of heat consumption of the building

In order to describe a response surface $\hat{y} = f(x_1, x_2, x_3, x_4, x_5, x_6)$, a six-factor computing experiment was carried out using a second order plan. A 3^6 plan was used that includes 729 experiments.

The design of the equation involved choosing such a regression dependence that would provide for a high accuracy, i.e. yield a determination coefficient R^2 close to the unit and have as few coefficients as possible. The coefficients of the regression equation were calculated using the *method* of least *squares*. A response $\hat{y}$ (q_h^{des}, kJ/(m^3·^{o}C·day) was calculated using a developed software mathematical model implemented with *MS Excel* and *ExExMaker* package [3].

As a result, the following dependence was obtained:

$$\hat{y}=15,21-6,62\cdot x_1-2,66\cdot x_2-1,02\cdot x_3-0,62\cdot x_4-12,38\cdot x_5-4,77\cdot x_6-0,20\cdot 10^{-15}\cdot x_1\cdot x_2-$$
$$-0,69\cdot 10^{-15}\cdot x_1\cdot x_3-0,06\cdot 10^{-15}\cdot x_1\cdot x_4+1,30\cdot 10^{-15}\cdot x_1\cdot x_5+1,71\cdot 10^{-15}\cdot x_1\cdot x_6+1,37\cdot 10^{-15}\cdot x_2\cdot x_3+$$
$$+1,38\cdot 10^{-15}\cdot x_2\cdot x_4+0,41\cdot 10^{-15}\cdot x_2\cdot x_5-1,23\cdot 10^{-15}\cdot x_2\cdot x_6+0,52\cdot 10^{-15}\cdot x_3\cdot x_4-0,40\cdot 10^{-15}\cdot x_3\cdot x_5-$$
$$-0,90\cdot 10^{-15}\cdot x_3\cdot x_6+0,88\cdot 10^{-15}\cdot x_4\cdot x_5-0,89\cdot 10^{-15}\cdot x_4\cdot x_6+0,34\cdot 10^{-15}\cdot x_5\cdot x_6+4,52\cdot x_1\cdot x_1+$$
$$+0,71\cdot x_2\cdot x_2+0,47\cdot x_3\cdot x_3+0,34\cdot x_4\cdot x_4-0,51\cdot 10^{-15}\cdot x_5\cdot x_5-3,54\cdot 10^{-15}\cdot x_6\cdot x_6.$$

The regression coefficients were estimated using Student's criterion [4]. The coefficient was assumed to be significant if its absolute value is over the confidence coefficient, i.e. at $|b_j| > t \cdot s_{\{bj\}}$ where b_j is the j-th coefficient; t is Student's criterion from the table; $s_{\{bj\}}$ is a quadratic error of the regression coefficient.

$$s_{\{bj\}} = \sqrt{s^2_{\{bj\}}} = \sqrt{s^2_{\{y\}} / N} = s_{\{y\}} / \sqrt{N},$$

where $s^2_{\{bj\}}$ is a dispersion of the regression coefficient; N is a number of experiments; $s^2_{\{y\}}$ is a dispersion of the reproduction of the experiment:

$$s^2_{\{y\}} = \frac{\sum_1^N \sum_1^n (y_{iq} - y_i)^2}{N(n-1)} = \frac{2\sum_1^N (y_{iq} - y_i)^2}{N},$$

where $i = 1, 2, \ldots, N$; $q = 1, 2, \ldots, n$; $s^2_{\{y\}} = 85.036 \cdot 10^{-30}$.

Dispersion and thus confidence intervals for all the coefficients (as well as the interaction effects) are equal as they are only dependent on the experiment error and a number of experiments.

Having dropped all the insignificant coefficients, we have the final dependence:

$$\hat{y} = 15,21 - 6,62 \cdot x_1 - 2,66 \cdot x_2 - 1,02 \cdot x_3 - 0,62 \cdot x_4 - 12,38 \cdot x_5 -$$
$$- 4,77 \cdot x_6 + 4,52 \cdot x_1 \cdot x_1 + 0,71 \cdot x_2 \cdot x_2 + 0,47 \cdot x_3 \cdot x_3 + 0,34 \cdot x_4 \cdot x_4.$$

This equation of regression provides the determination coefficient $R^2 = 1$ and adequacy dispersion $S^2_{АД} = 172,631 \cdot 10^{-30}$.

In order to test the adequacy hypothesis, Fisher's criterion is used:

$$F = s^2_{АД} / s^2_{\{y\}}.$$

The design criterion $F = 2.030$ is over $F_{0.05;728;718} = 1.043$ from the table and therefore with a confidence probability of 0.95 the obtained regression equation can be considered adequate and suitable for use in further analysis of the effect of the parameters. The interpretation of the results of the study into the effect of the chosen factors on the specific heat consumption on the heating of the building was performed using the analysis of the resulting dependence.

The response $\hat{y}$ in the examined factor space was most largely affected by the factor x_5 (k_η). It was found to have a negative linear effect, which suggests a dramatic drop in the specific heat consumption on the heating of the building using recuperation and preventing the windows from being poorly airtight.

The second most significant one is the factor x_1 (R_w). It was found to have a negative linear and positive quadratic effects, which suggests a drop in the specific heat consumption if there is a change in the amount of heat coming in from the exterior walls from 0.842 to 4.458 $m^2 \cdot$ °C/Watt.

The third most significant one is the factor x_6 (ζ). It was found to have a negative linear effect, which suggests a drop in the specific heat energy consumption if the effective heating system is introduced with a possibility of automatic control of individual heat carrier for opposite facades of the building depending on the temperature of the outside air of the premises of each façade being heated.

The forth significant one is the factor x_2 (R_F). It was found to have a negative linear and positive quadratic effect, which suggests a drop in the specific heat energy consumption if there is a change in the amount of heat coming in from the windows and balcony doors from 0.440to 0.760 $m^2 \cdot$ °C/Watt.

The fifth most significant one is the factor x_3 (R_c). It was found to have a negative liner and positive quadratic effect, which suggests an insignificant drop in the specific heat energy consumption if there is a change in the heat transfer resistance for the coating from 2.225 to 6.055 $m^2 \cdot$ °C/Watt.

The last most significant one is the factor x_4 (R_f). It was found to have a negative linear and positive quadratic effect, which suggests an insignificant drop in the specific heat energy consumption if there is a change in heat transfer resistance for the closure over the technical facility from 1.646 to 5.574 $m^2 \cdot$ °C/Watt.

Fig. 1 identifies 12 graphs that show the response surface depending on the mutual effect of the factors provided that the four remaining factors are in the major level (0).

Fig. 2 shows a graphic presentation of the effect of the examined factors on a drop in heat energy consumption for the heating.

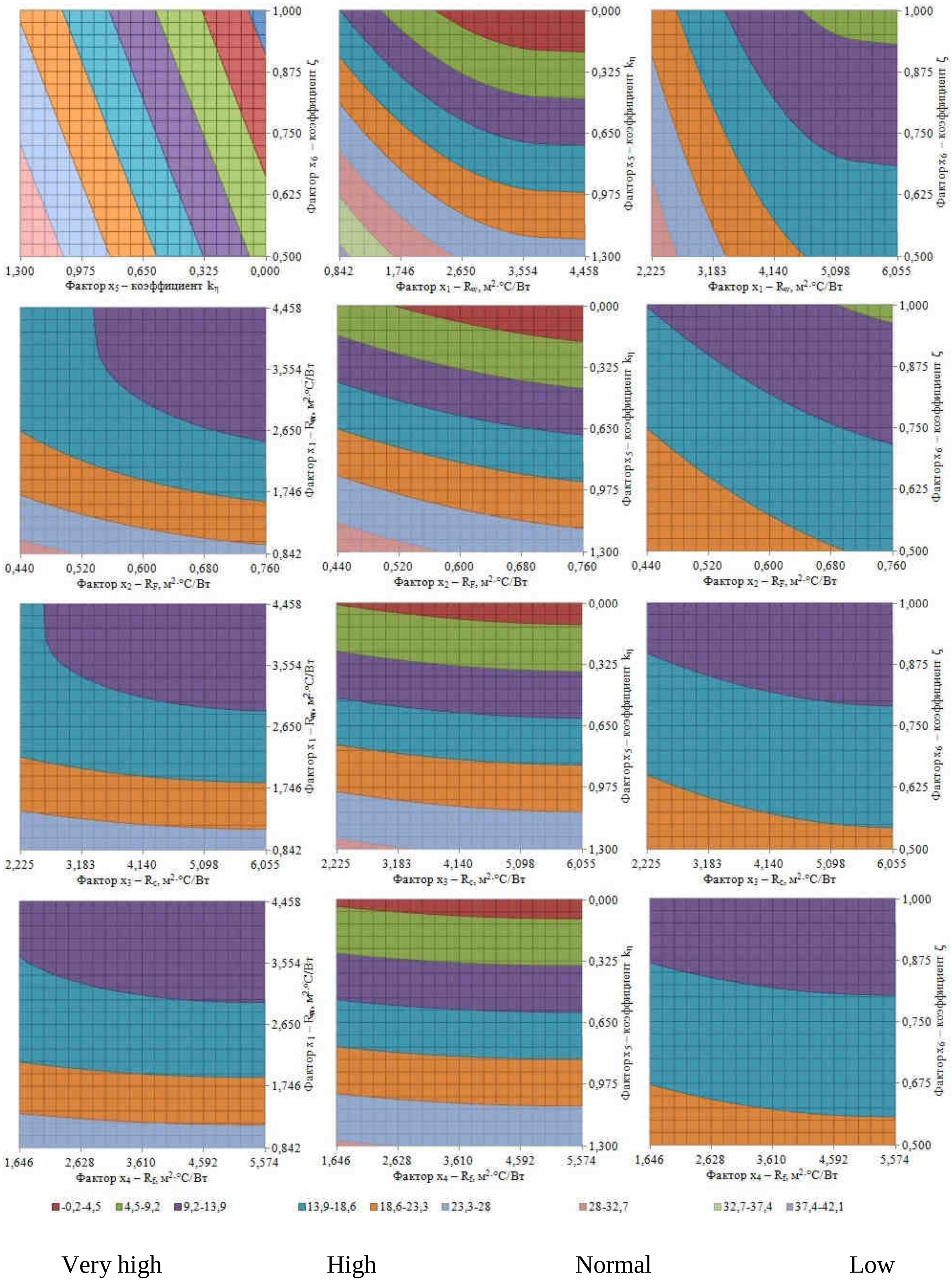

Fig. 1. Specific heat energy consumption for the heating of the existing building q_h^{des}, kJ/(m^3·°C·day) depending on the combination of different factors
(where фактор means factor, коэффициент means coefficient)

A similar range of effects was obtained in the dissertation [5] for residential buildings of other massive types (four- and five-storey brick buildings of the type 1-447; five-storey large-panel buildings of the type 1-464; nine- and ten-storey large panel buildings of the type 111-90).

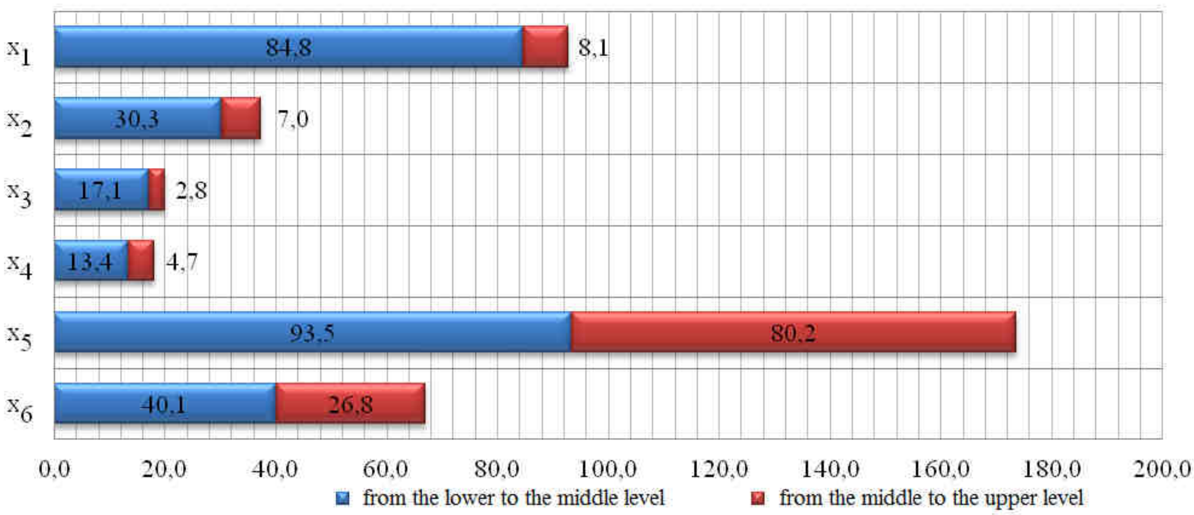

Fig. 2. Effect of the examined factors, %, on the specific heat energy consumption on the heating of the existing building q_h^{des}, kJ/(m^3·°C·day)

The graphs show that if all the enveloping structures are heated up to the major level (a minimum admissible standard value) without changing the engineering systems the building would be classified as standard energy efficient (class «C»). If besides thermal modernization, engineering systems undergo reconstruction up to the major level (the total coefficient of efficiency of the recuperator of no less than 30 %, thermostats and automatic control of each façade), the building would be classified as highly energy efficient (class «B»).

Conclusions

1. Classifying a building as highly energy efficient (class «B») in heating all the enveloping structures up to the major level can be achieved by eliminating excessive infiltration over the standard air exchange in flats when the windows are poorly airtight. The introduction of the central control of the heating system would suffice as well.

2. Classifying a building as extremely energy efficient (class «A») would be achieved by recuperation with the coefficient of efficiency of no less than 70 % and introduction of the central automatic control of the heating system with mandatory thermal controls. This cannot be achieved by improving the heating system without changing the system of ventilation.

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