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Heat and power characteristics analysis carried out for the residential building made of autoclaved aerated concrete blocks

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ABSTRACT

The object to be tested is a block of flats located in Volgograd (Russia, N 48°). Design insulation of double-layer wall structures made of AAC with exterior coating in the form of brick masonry can ensure minimum allowed element-by-element requirements for heat protection according to the Russian Construction Norms and Regulations (SP 50.13330.2012) provided the requirements for specific heat consumption for heating and ventilation in the building are met. In most cases double-layer exterior walls without extra insulation do not correspond to basic level of heat protection and almost do not have heat and energy reserved. An actual energy-saving class of the building in operation is significantly lower than the one stated in the design project. The deviation of actual heat protection for heating and ventilation in the building from the estimated value can reach more than 75%. With the aim to ensure actual energy-saving effect it is necessary to improve the model taken as a basis to determine estimated heat consumption for heating and ventilation in the building according to the Russian Construction Norms and Regulations (SP 50.13330.2012), and to ensue whether the actual design solution is performed correctly. Specific heat protection in the building shall be estimated with due account for edge zones of building envelopes based on 3-D temperature fields data. Only certified construction materials and structures can be used in construction. Extra insulation at points of HDD 20/8 >= 4200 K*day/year is recommended to minimize heat and power and energy risks and to improve heat protection of exterior walls made of AAC blocks. It is recommended to perform control over the quality of design and construction under state expertise of the projects and state construction supervision.

Contents

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1. Introduction

Nowadays, autoclaved aerated concrete is widely used in residential construction throughout the Russian Federation. High level consumer properties of the goods made of autoclaved aerated concrete [1—4] — such as raw materials availability, low fire hazard and high fire resistance, high accuracy, workability of masonry and high performance, low costs of production — contributed to its popularity to a great extent.

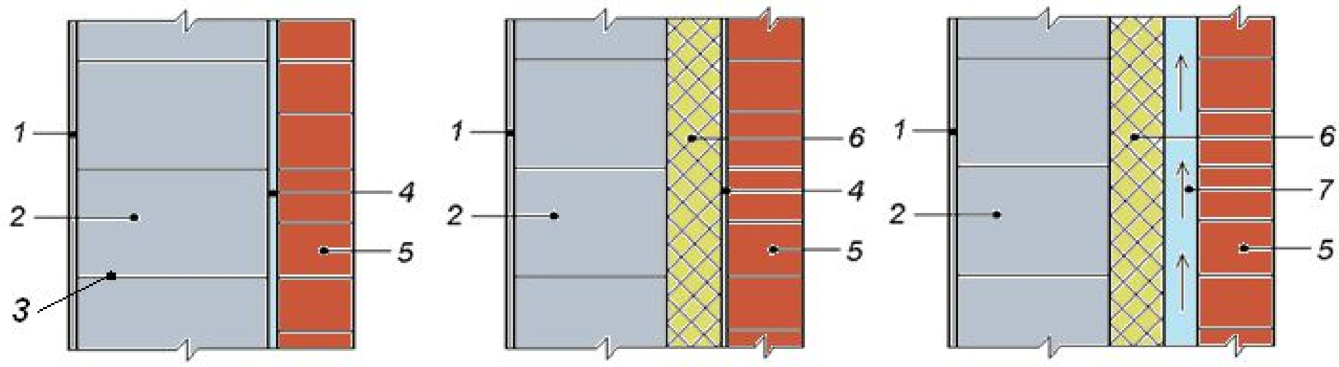
Structural and performance properties of the goods made of autoclaved aerated concrete are studied quite enough [5—22]. Authors N.I. Vatin, A.S. Gorshkov, G.P. Saharov, J.E. Tanner and others [5—8] considered the problem of improvement of mechanical properties of AAC blocks. The articles [8—11] give insights into how to improve heat and power materials and goods made of autoclaved aerated concrete. Humidity regime for exterior walls made of AAC blocks and its impact on heat-protective properties of envelopes have been researched by S. Rubene, M. Vilnitis, J. Noviks and S.V. Korniyenko [12, 13]. An analysis of defects and faults of goods and structures made of autoclaved aerated concrete have been carried out in the articles [14, 15]. Efficient mathematical models and methods to calculate heat and power characteristics of envelopes with heat and power non-uniform sections (edge zones) have been considered by A.S. Gorshkov, P.P. Rymkevich, N.I. Vatin and S.V. Korniyenko [16—18]. The works [19—25] of authors S.D. Kennedy, S. Lagüela, G. Verbeeck, G.P. Vasilyev, D.V. Nemova, M. Campanale and others deal with the issue of heat protection and energy performance of buildings.

Authors C. Feng, X. Yu and D. Wang [26] considered the problem of measurements on the hygric properties of autoclaved aerated concrete based on ISO and ASTM standards of static gravimetric tests, pressure plate tests, cup tests, capillary absorption tests and vacuum saturation tests. Authors C.–L. Wang, W. Ni, S.–Q. Zhang, S. Wang, G.–S. Gai and W.–K. Wang [27] considered the problem of preparation and properties of autoclaved aerated concrete using coal gangue (CGC) and iron ore tailings (ITOs). Authors X. Cao, X. Li and Y. Hu [28] give the life cycle assessment of EI of masonry materials: autoclaved flyash brick, sintered clay brick and aerated concrete block. Authors J. Zhang, Y. Gao and Z. Huang [29] considered the problem of comparative studies on the temperature stresses in external walls with different thermal insulation models. The results show that the thermal stress inside the wall is controlled by the initial temperature, temperature variation and elastic modulus of materials. Authors T. Guohong, D.M. Christopher, L. Tianlai and W. Tieliang [30] investigate the temperature variations inside Chinese solar greenhouses with external climatic conditions and enclosure materials. Authors S. Tian, J. Yu, and J. Nie [31] carry out the nonlinear FEM analysis of autoclaved aerated concrete block (AAC) composite masonry walls.

The author P. Sormunen considered a problem in energy efficiency of residential and public buildings in Finland [32].

We continue the analysis of efficiency of thermal insulation properties of walls made of autoclaved aerated concrete widely used for construction of buildings in Russia that we started in [1].

Modern constructive ways to improve heat protection of exterior walls made of AAC blocks are shown in the Picture 1.



Picture 1. Cross-section of the wall (schematic diagram): 1 — plaster; 2 — aerated concrete blocks; 3 — glue line; 4 — manufacturing clearance; 5 — front brick masonry; 6 — additional heat-insulation layer; 7 — ventilated cavity

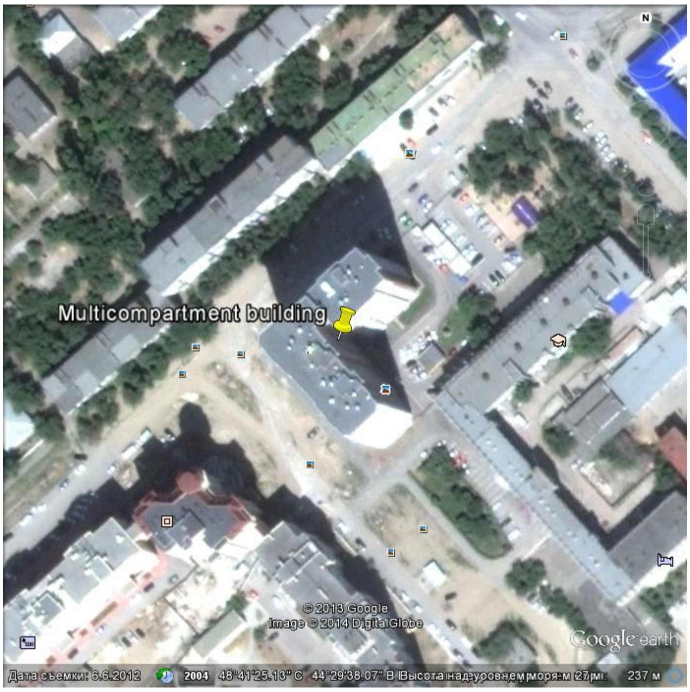
The energy saving problem in the Russian buildings is very important as the climate of the most part of Russia is colder than other states (see Table 1).

Table 1. The actual values of external air temperature according to long-term measurements for geographical points of the world

Geographical point	Geographic latitude (N)	Monthly average outside air temperature, °C	
		January	July
Moscow	55°45′	–6.70	20.6
St. Petersburg	59°57′	–5.38	19.9
Paris	48°45′	5.68	20.0
Stockholm	59°20′	–1.34	18.5
Helsinki	60°10′	–4.71	18.5
Tokyo	35°41′	6.52	26.3
London	51°30′	6.85	19.5
Berlin	52°31′	1.83	20.6
San Francisco	37°46′	11.8	18.8
Quebec	46°49′	–11.2	20.4

However, the survey deals with quite a few articles about heat and power characteristics of residential buildings made of autoclaved aerated concrete in the conditions of moderate continental climate of Russia. Estimation of heat protective level and energy-efficiency performance of such buildings are limited by the need to carry out complicated estimations of two or three dimensional temperature fields. Energy performance survey of buildings under field conditions requires costly equipment, high manpower input and their relevant top-level competence to be applied. Lack of measured data on actual expenses for heating and ventilation of buildings makes it difficult to test energy performance of residential buildings made of autoclaved aerated concrete under field conditions and to match them with data relevant for moderate continental climate.

An object to be tested is a block of flats located in Volgograd (Russia, N 48°). According to the construction regulation of RF (SP 131.13330.2012) the climate region for construction should be — IIIB. Monthly outside air temperature in January is equal to –6.9 °C, in July — 23.9 °C. Humid area is 3 (dry). The building has 21–23 over-ground floors, 3 sections, basement and an insulated attic (Picture 2). There are rooms for social purpose in the first floor of the building.



Picture 2. General view of the building

Geometric features are given in the Table 2.

Table 2. Geometric features of the building

Indicator	Subscript, measurement unit	Value
Total area of envelopes including:	A_{sum}, m^2	19345
exterior walls	A_w, m^2	14274
windows, balcony doors	A_F, m^2	2979
entrance doors	A_{ed}, m^2	27
floors	A_c, m^2	1093
slabs over basement	A_b, m^2	940
slabs under bay-windows	A_{bw}, m^2	32
Heated volume	V_h, m^3	87000
Building compactness	k_e, 1/m	0.222
Coefficient of glazing for facades	k_F	0.172

Distinction between load-bearing and enclosing structures is a major feature of this project. Load-bearing base of the building is a reinforced frame with precast framework with flat plates of slabs. There are perforated holes in slabs, filled with thermal inserts made of polyester foam, to decrease heat losses in the cold season along the outside contour of the slab. Heat protective cover of the building consists of different types of envelopes. Exterior walls are made of AAC 400 mm thick blocks in a form of masonry with exterior 120 mm thick brick facing. Interior surface of walls are plastered using complex mortar. Walls are supported floor-by-floor by plates of slabs. Brick masonry is connected to autoclaved aerated concrete blocks using flexible bonds. Double-glazed windows and balcony doors are made of PVC profiles. Attic slabs and slabs over the basement are thermally insulated. Insulated bay-widows are assumed to increase level of natural lightning and to improve duration of insulation in rooms.

Thermal inserts made of efficient insulators are assumed to improve heat-conductive properties of the covers and the increase of heat protective properties.

According to the Russian Construction Norms and Regulations the level of heat protection for envelopes is set in relation to purpose of use of a building, type of a structure and heating degree days during the heating season of the year. The value of heating degree days during the heating season for residential buildings is to be determined under estimated inside air temperature of the building equal to 20 °C in relation to the season with daily average outside air temperature less than 8 °C. The building being considered is operated under conditions of moderately continental climate of Russia. Estimated value of heating degree days during the heating season HDD = 3925 K·days/year.

There is a centralized heat supply, which source is an individual heat supply unit connected to outdoor heating networks. The individual heat supply unit is arranged in the basement. There is a double pipe heating system with bottom-pipe distribution and flat-by-flat perimeter distribution. Convectors with temperature regulators are used as heaters. Estimated parameters of a heat carrier for heating are 85—65 °C. The building is naturally ventilated. Air intake is secured through regulated window casement in living rooms and kitchens; air recovery is carried out through exhaust ventilation in kitchens and sanitary facilities. Engineering systems of buildings are equipped with metering devices for heat energy, cold and hot water, electric power and gas.

The building was built in 2007. At the moment of energy survey the life service of the building was about 5 years.

The detailed description of the energy-saving activities applied in the project is given in the work [19].

Basic terms and definitions in accordance with the Russian Construction Norms and Regulations SP 50.13330.2012 used in this article are given below.

Heat protective encasement of the building — an aggregate group of building envelopes, which form a closed contour, to limit building volume to be heated.

Reduced resistance to heat transfer in the building envelope — the magnitude, which describes an averaged area-based density of heat flow through the fragment of heat protective encasement under stationary conditions of heat transfer, which is equal to the ratio of the difference between temperatures at opposite sides of the fragment to the averaged area-based density of heat flow through the fragment.

Specific heat protection of the building — the magnitude, which is equal to heat loss per unit of building volume to be heated per time unit while temperature drop of 1 K trough the heat protective encasement of the building.

Specific heat consumption for heating and ventilation — the magnitude, which is equal to heat consumption per unit of building volume to be heated per time unit in relation to temperature drop with due account for air interchange and extra heat release.

A heat protective encasement shall meet the following requirements:

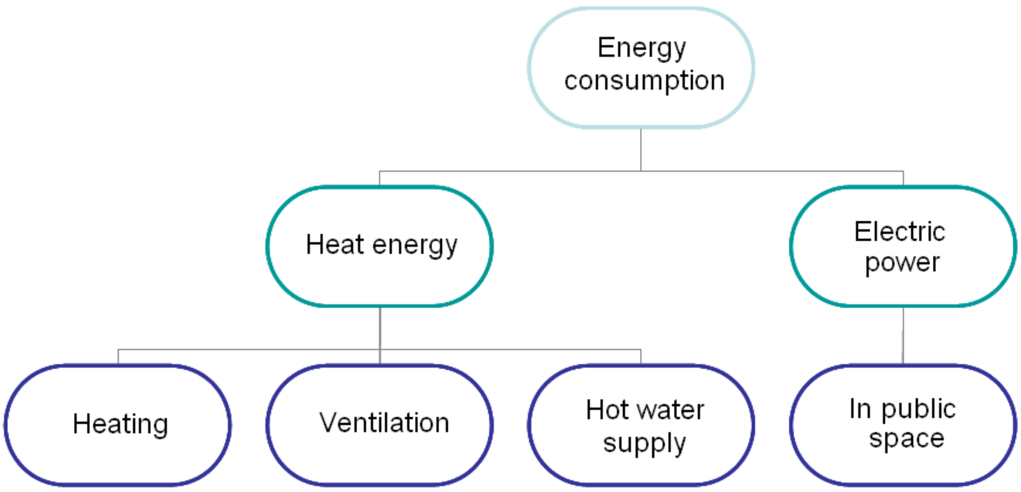
a) reduced resistance to heat transfer in building envelopes shall be not less than rated values (element-by-element requirements);

b) specific heat protection of a building shall not be less than a rated value (complex requirements);

c) temperature at surfaces of building envelopes shall be not less than the minimum allowed value (sanitary and hygienic requirement).

Estimated value of specific heat consumption for heating and ventilation of the building shall be less or equal to rated (nominal) value.

The real structure of annual power consumption of the building more complete considering thermal energy for heating and ventilation and electric power for public space (Picture 3).



Picture 3. Structure of annual power consumption of the building

It is the stimulating factor of development of modern energy-saving innovative construction technologies. However the detailed analysis of the specified components of annual power balance of the building is beyond this research.

2. Methods

Estimation of heat protection level and energy performance in the building

The authors of the article carried out estimation of heat and power indicators with the aim to determine a design heat protection level and energy performance of the building.

Estimation of heat protection level and energy performance is conducted on the basis of mathematic modeling of the heat regime process in building envelopes and heat and power indicators for the building in the cold season.

Mathematic modeling of the heat regime process in building envelopes was conducted with due account for edge zones of building envelopes using programming and computing software «Energy efficiency and heat protection of buildings (ENTEZA)». Programming and computing software «ENTEZA» developed by S.V. Kornienko [17]. The programming and computing software «ENTEZA» makes it possible to estimate impact of edge zones on heat protection properties of envelopes and outline ways to improve elements of building encasement according to computing of 3-D temperature fields.

Extra heat loss through edge zones is determined, and reduced resistance to heat transfer in building envelopes is computed, on the basis of estimation of temperature fields in the area of coupling joints in building envelopes. The values of reduced resistance to heat transfer in different types of building envelopes are used for element-by-element heat protection of the building. Complex estimation of building heat protection is carried out on the basis of specific heat protection in the building. Monitoring by temperature fields is conducted to identify whether design heat protection level in building envelopes meets sanitary and hygienic requirements.

An estimated specific heat consumption for heating and ventilation in the building q_h^{des}, W/(m^3·K), according to the Russian Construction Norms and Regulations SP 50.13330.2012 is determined to estimate energy performance under the formula:

$$q_h^{des} = \beta_h(1-\xi)[k_{tr} + k_{ven} - \nu\zeta(k_{int} + k_s)], \tag{1}$$

where β_h — the coefficient which takes into account extra heat consumption of the heating system; ξ — the coefficient which takes into account heat consumption decrease provided flat-by-flat record of heat consumption for heating is available; k_{tr} — specific heat protection of the building, W/(m^3·K); k_{ven} — specific ventilation of the building, W/(m^3·K); ν — the coefficient which takes into account decrease in heat gains due to thermal inertia in building envelopes; ζ — the coefficient which takes into account efficiency of automated heat supply in heating systems; k_{int} — specific household heat release in the building, W/(m^3·K); k_s — specific solar radiation heat gains in the building, W/(m^3·K).

Rated specific heat consumption for heating and ventilation can be identified according to the Russian Construction Norms and Regulations SP 50.13330.2012.

An energy-saving class for the project is determined by the relative deviation of estimated specific heat consumption for heating and ventilation from the rated value.

Actual estimation of energy performance in the building under field conditions

Actual estimation of energy performance in the building under field conditions in the cold season was conducted using express method [19]. The method states that heat consumption for heating and average inside and outside air temperature is measured in the building under examination during the heating season for certain time intervals. These measurements are taken to compute specific heat consumption for heating and ventilation in the building and to determine energy-saving class.

Measuring and recording of the energy consumption parameters were conducted in accordance with the bespoke method during two weeks starting from 22.12.2011 up to 04.01.2012. Monitoring of heat loss for heating in relation to communal heating meter is automatically carried out once a day. Daily average inside air temperature corresponds to top-boundary comfortable conditions according to the Russian State Standard GOST 30494–2011. Daily average outside air temperature is determined according to the data of the nearest weather station. A heat flow in the heating system Q_h^i, W, which is equal to the difference between inside t_{int}^i and outside t_{ext}^i air temperatures (herein i — measurement number), is determined on the basis of data related to heat consumption.

The mathematical model $Q_h(\Delta t)$ in the form of the equation of linear regression is constructed based on statistically processed data with minor sample (N =14):

$$Q_h = a(t_{int} - t_{ext}), \tag{2}$$

where a — an empirical coefficient, W/K.

In the formula (2) the empirical coefficient a states for specific heat consumption for heating and ventilation in the building, which is to be determined by total heat consumption per time unit while temperature drop between inside and outside air equal to 1 K.

Actual specific heat consumption for heating and ventilation in the building is to be determined:

$$q_h^{act} = \frac{a}{V_h}, \tag{3}$$

where V_h — building volume to be heated.

This method makes it possible to determine specific heat consumption for heating with the relative error exceeding ±10%, and ensures accuracy of results comparatively to the Russian State Standard GOST 31168— 2003.

Actual expenses of heat energy on hot water supply and electric power in public space were determined by collective metering devices of energy resources.

3. Results and discussion

The estimation results of heat protection level and energy performance in the building and actual energy performance under field conditions are given below.

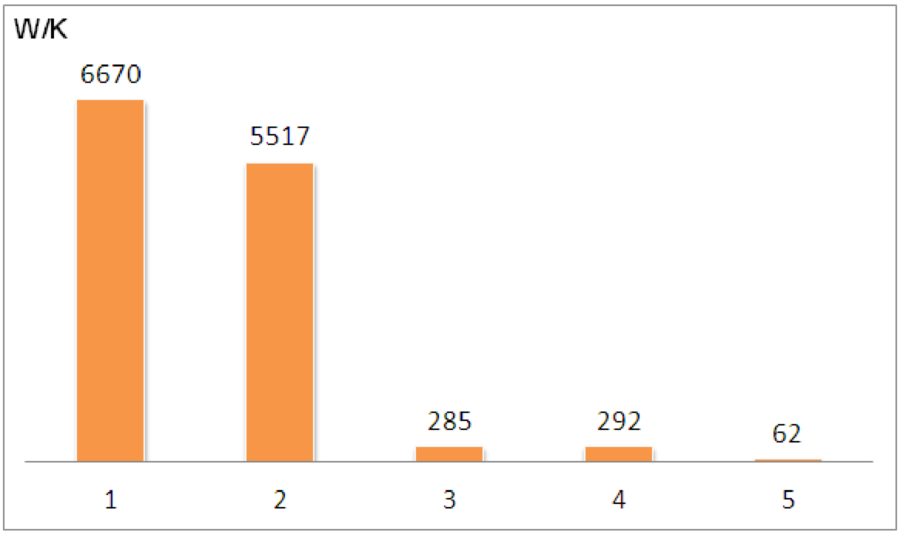
Element-by-element estimation of heat protection in the building showed that insulation level of building envelopes under design meet the requirements of the Russian Construction Norms and Regulations SP 50.13330.2012 (Table 3).

Table 3. Element-by-element heat protection in the building based on design data

Building envelope	Rated resistance to heat transfer R_o^{req}, m²·K/W		Estimated resistance to heat transfer R_o^{des}, m²·K/W
	Minimum allowed level of heat protection	Basic level of heat protection	
Exterior walls	1.75	2.77	2.14
Windows, balcony doors	0.42	0.44	0.54
Entrance doors	0.42	0.44	0.54
Floor	3.33	4.16	3.84
Slab over basement	2.94	3.67	3.22
Slab under bay-windows	3.33	4.16	3.56

According to the Standard it is allowed to decrease basic level of heat protection in building envelopes, but it shall not be less than minimum allowed level of heat protection (see Table 3), provided requirements for specific heat consumption for heating and ventilation in the building are met.

Considering Tables 2 and 3 specific heat loss through the building encasement were computed (see Picture 4). Total specific heat loss through the encasement of the building is equal to 12826 W/K.



Picture 4. Structure of specific heat loss through the encasement of the building: 1 — exterior walls; 2 — windows, balcony doors; 3 — floors; 4 — slabs over basement; 5 — others

As it is shown in the Picture 4, the major part of heat loss (95%) comes through the building facades including: exterior walls — 52%, windows and balcony doors — 43%. This can be explained by a significant impact of edge zones in exterior walls and not very efficient heat protective properties of translucent building envelopes. Minor shares of heat losses through floor and slabs over basement are due to minor area and higher level of insulation of these structures in comparison with the facades of the building.

The estimated specific heat protection of the building obtained on the basis of the design data is equal to 0.147 W/(m³·K), which is less than the rated value of 0.173 W/(m³·K), consequently, the design solution of the building meets the complex requirements for heat protection.

The temperature at the inner surface of enclosing structures in the area of heat conducting inclusions in the corners of exterior walls and window jambs is higher than inside air dew point if there is estimated outside air temperature, consequently, the design solution of the building meets the sanitary and hygienic requirements.

Thus, the heat protective encasement meets standard requirements SP 50.13330.2012.

When estimating specific heat consumption for heating and ventilation in the building there were considered all the adjustment coefficients in accordance with the Russian Construction Norms and Regulations SP 50.13330.2012:

- the coefficient which takes into account decrease in heat gains due to thermal inertia in building envelopes $\nu = 0.773$;
- the coefficient which takes into account efficiency of automated heat supply in heating systems $\zeta = 1.0$;
- the coefficient which takes into account extra heat consumption in the heating system, $\beta_h = 1.13$.

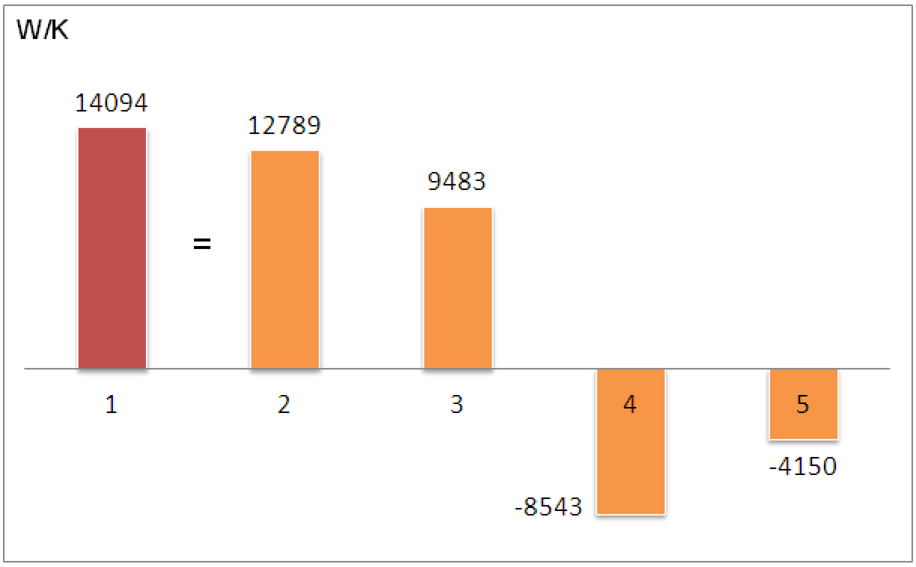
Due to the fact that there was no heat consumption record for heating in the flats the coefficient ξ is taken with the value 0.

The estimated results of heat and power indicators in the building are given in the Table 4.

Table 4. Estimation of energy performance in the building on the basis of design data

Indicator	Subscript, measurement unit	Value
Specific heat protection in the building	k_{tr}, W/(m³·K)	0.147
Specific ventilation in the building	k_{ven}, W/(m³·K)	0.109
Specific household heat release in the building	k_{int}, W/(m³·K)	0.0982
Specific heat solar radiation heat in the building	k_s, W/(m³·K)	0.0477
Estimated specific heat consumption for heating and ventilation in the building	q_h^{des}, W/(m³·K)	0.162
Nominal basic) specific heat consumption for heating and ventilation in the building	q_h^{req}, W/(m³·K)	0.290
Relative deviation q_h^{des} from q_h^{req}	%	–44.1
Energy-saving class of the building	A (very high)	

The heat balance for the building was computed on the basis of data obtained (Picture 5).



Picture 5. Heat balance for the building: 1 — heat consumption for heating and ventilation; 2 — heat protection; 3 — ventilation; 4 — household heat release; 5 — solar radiation heat gains

The data shown in the Picture 5 differ from the other Table ones (Table 4) due to adjustment coefficients.

The analysis of the heat balance shows that heat loss in the building during the heating season is much higher than heat gains. The major part of heat loss is monitored through heat protection encasement of the building, which can be specifically explained by the design solution of exterior walls to use autoclaved aerated blocks without extra insulation having estimated level of heat protection lower than basic level. Heat loss for ventilation in the building is less than transmission heat loss by 25.8%. The major part of total heat gains in the building account for household heat release related to the use of electric cookers in flats. An estimated heat demand for heating and ventilation in the building during heating season amounts to 4.78 TJ/year.

Design level of energy performance of the building meets the requirements of the Russian Construction Norms and Regulations SP 50.13330.2012.

Possibility to conduct the element-by-element estimation of heat protection in the building by the minimum allowed reduced resistance to heat transfer in the envelopes (Table 3 made it possible to meet the requirement to the specific heat consumption for heating and ventilation in the building ($q_h^{des} < q_h^{req}$).

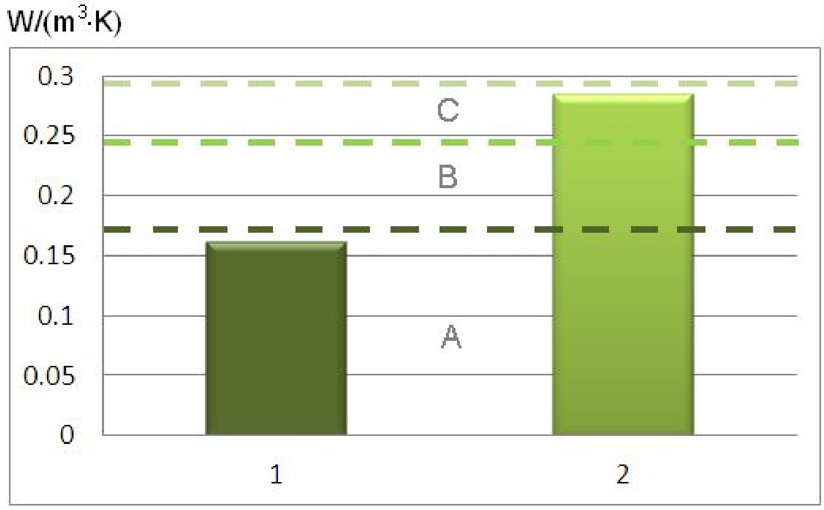
Visual monitoring with the use of tools meant to inspect heat protection encasement while energy survey of the building showed that subcontractors used less efficient used double-glazed units instead of triple-glazed units assigned by the design project. Numerous defects of translucent building envelopes and coupling joints in the area of wall openings — such as low quality of windows, mismatch between the dimensions of windows and wall openings, incorrect fixing of windows to exterior walls, low quality of construction welds, discrepancy of window jambs to the requirements of project design documentation — were found. The defects, caused by a subcontractor while construction, inevitably result in decrease in energy performance of the object.

Estimation results of energy efficiency of the building based on field measurements are given in Table 5.

Table 5. Estimation of energy performance in the building based on field measurements

Indicator	Subscript, measurement unit	Value
Actual specific heat consumption for heating and ventilation in the building	q_h^{act}, W/(m³·K)	0.285
Rated (basic) specific heat consumption for heating and ventilation in the building	q_h^{req}, W/(m³·K)	0.290
Relative deviation q_h^{act} from q_h^{req}	%	–1.72
Energy-saving class	C (normal)	

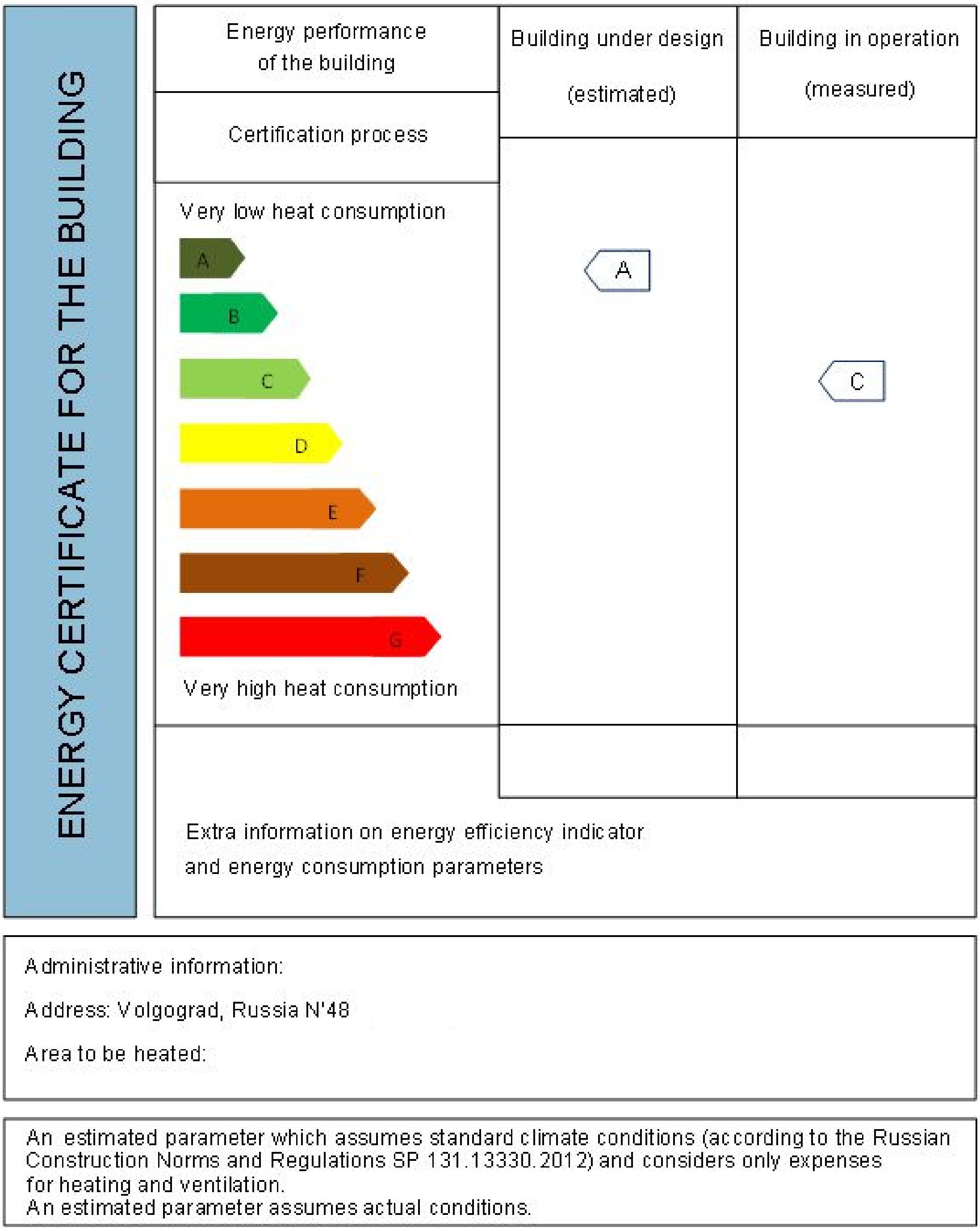
As it seen from the Table 5, an actual level of energy efficiency in the building meets the requirements of the Russian Construction Norms and Regulations SP 50.13330.2012. However, it should be noted that actual specific heat consumption for heating and ventilation in the building is much higher than an estimated value obtained on the basis of design data (by 75.9%). If to compare with the design solution energy performance of the building in operation is significantly less (Picture 6).



Picture 6. Specific heat consumption for heating and ventilation in the building: 1 — estimated; 2 — actual

In Picture 6 the boundaries of energy-saving classes are marked with dashed lines and state energy-saving classes according to the requirements of the Russian Construction Norms and Regulations SP 50.13330.2012 (A — very high, B — high, C — normal).

The results of estimated and experimental monitoring of the building under inspection can be nominally reflected in the energy certificate of the building according to the standard EN 15217:2007 (Picture 7).



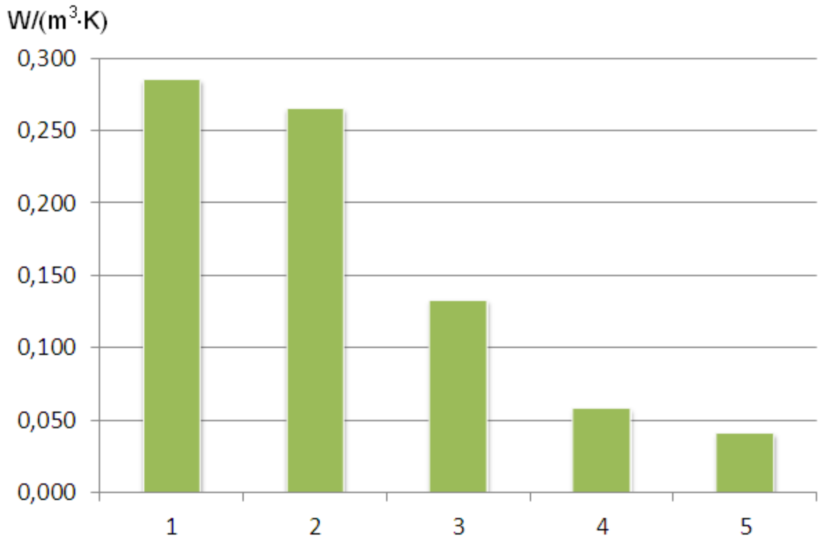
Picture 7. Energy performance report form for the building in operation (EN 15217:2007)

Certainly, is of the international scientific interest to compare the received results to modern foreign construction norms. Comparison of results is executed on the example of Helsinki (Finland). Estimated value of heating degree days during the heating season HDD = 5028 K·days/year. As shown in the table 1 climate of Finland during the heating season is similar to climate of the European part of Russia. We used new Finnish construction regulations on heating and ventilation in residential buildings [32]. Based on the available data on a special method the specific heat consumption for heating and ventilation has been calculated (see Table 6).

Table 6. Estimated values of specific heat consumption for heating and ventilation in residential buildings based on VTT-Standard [32]

Building type	Value, W/(m^3·K)
Standard building (modern)	0.265
Low-energy-consumption building	0.133
Passive house	0.058
Energy consumption close to zero	0.041

The results of estimated and experimental monitoring of the building under inspection can be nominally reflected on the energy chart according to the VTT-Standard (Picture 8).



Picture 8. Specific heat consumption for heating and ventilation in residential buildings in Russia and Finland: 1 — actual (Russia); 2 — standard building (modern); 3 — low-energy-consumption building; 4 — passive house; 5 — energy consumption close to zero

As it seen from the Picture 8, an actual specific heat consumption for heating and ventilation in the building is higher than corresponding value for standard modern building, operated in similar climatic conditions of Finland (according to the VTT-Standard). The relative deviation of the actual value from estimated is equal to +7.5%. However the actual value is much higher than for other energy efficient buildings than confirms, generally speaking, insufficiently outstanding energy performance of the building.

Major reasons for deviation of actual specific heat consumption for heating and ventilation in the building from an estimated one:

1) tolerance of the model (1), taken as a basis to determine estimated heat consumption;
2) available heat-performance risks caused by double-layer exterior walls made of AAC-blocks with exterior coating in the form of brick masonry without extra insulation;
3) mismatch of actual heat parameters of materials related to building envelopes and design data;
4) unauthorized deviations from the design project admitted by a subcontractor while construction;
5) low quality of construction and assembly works.

With the aim to increase energy performance of the building in operation it is required to monitor heat and energy features and determine whether it is rational to develop compensatory activities under thermal modernization of the building under inspection. At application of the energy efficient translucent enclosing structures in buildings is recommended to minimize energy risks and to improve heat protection of exterior walls made of AAC blocks (see Picture 1).

At the same time increase in a heat-shielding of envelope using the modern highly effective heat-insulating porous materials often leads to increase in risks of deterioration in temperature and moisture conditions, especially in edge zones of the enclosing structures, that demands development within the project of actions for protection against moisture.

4. Conclusions

According to the results of estimation and experimental analysis of heat properties of the block of flats made of aerated autoclaves concrete blocks the following was set:

1. Design insulation of double-layer wall structures made of AAC with exterior coating in the form of brick masonry can ensure minimum allowed element-by-element requirements for heat protection according to the Russian Construction Norms and Regulations SP 50.13330.2012 provided the requirements for specific heat consumption for heating and ventilation in the building are met. In most cases double-layer exterior walls without extra insulation do not correspond to basic level of heat protection and almost do not have heat and energy reserved.

2. An actual energy-saving class of the building in operation is significantly lower than the one stated in the design project. The deviation of actual heat protection for heating and ventilation in the building from the estimated value can reach more than 75%.

3. With the aim to ensure actual energy-saving effect it is necessary to improve the model taken as a basis to determine estimated heat consumption for heating and ventilation in the building and to ensue whether the actual design solution is performed correctly. Specific heat protection in the building shall be estimated with due account for edge zones of building envelopes based on 3-D temperature fields data. Only certified construction materials and structures can be used in construction. Extra insulation at points of HDD 20/8 $\geq$ 4200 K·day/year is recommended to minimize heat and power and energy risks and to improve heat protection of exterior walls made of AAC blocks. It is recommended to perform control over the quality of design and construction under state expertise of the projects and state construction supervision.

4. The solution of the problem of increase in energy-efficiency class of buildings is complex and has is balanced to affect both increase in level of a heat-shielding and improvement of engineering systems for achievement of thermal comfort in rooms.

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References

[1]. Korniyenko S.V., Vatin N.I., Gorshkov A.S. Thermophysical field testing of residential buildings made of autoclaved aerated concrete blocks. Magazine of Civil Engineering. 2016. No. 4. Pp. 10–25. (eng)

[2]. Suhasini R. Autoclaving cement concrete: A review. International Journal of Applied Engineering Research. 2014. No. 9 (11). Pp. 1603–1617.

[3]. Van Boggelen W., Völker K. New opportunities for autoclaved aerated concrete [Neue Chancen für Porenbeton]. Betonwerk und Fertigteil-Technik/Concrete Precasting Plant and Technology. 2004. No. 70 (3). Pp. 60–64.

[4]. Nemova D.V., Spiridonova T.I., Kurazhova V.G. Neizvestnye svojstva izvestnogo materiala [Unknown properties of the known material]. Construction of Unique Buildings and Structures. 2012. No. 1. Pp. 36–46. (rus)

[5]. Saharov G.P. Razvitie proizvodstva i povyshenie konstruktivnyh svojstv avtoklavnogo jacheistogo betona i izdelij na ego osnove [Development of production and increase of constructive properties of autoclave cellular concrete and products on its basis]. Tehnologii betonov. 2012. No. 11–12 (76–77). Pp. 56–58. (rus)

[6]. Tanner J.E., Varela J.L., Klingner R.E., Brightman M.J., Cancino U. Seismic testing of autoclaved aerated concrete shearwalls: A comprehensive review. ACI Structural Journal. 2005. No. 102 (3). Pp. 374–382.

[7]. Gorshkov A.S. Uslovija obespechenija ustojchivosti dlja pojetazhno-opertyh sten iz gazobetonnyh blokov [Conditions of ensuring stability for the walls transferring loading as floor-by-floor from AAC]. Tehnologii betonov. 2014. No. 4(93). Pp. 49–55. (rus)

[8]. Gorshkov A.S., Vatin N.I. Svojstva stenovyh konstrukcij iz jacheistobetonnyh izdelij avtoklavnogo tverdenija na poliuretanovom kleju [Properties of the wall structures made of autoclaved cellular concrete products on the polyurethane foam adhesive]. Magazine of Civil Engineering. 2013. No. 5 (40). Pp. 5–19. (rus)

[9]. Gorshkov A.S., Grinfel'd G.I., Mishin V.E., Nikiforov E.S., Vatin N.I. Povyshenie teplotehnicheskoj odnorodnosti sten iz jacheisto-betonnyh izdelij za schet ispol'zovanija v kladke poliuretanovogo kleja [Improvement of Thermotechnical Uniformity of Walls Made of Cellular Concrete Products Through the Use of Polyuretane Glue in Masonry]. Stroitel'nye materialy. 2014. No. 5. Pp. 57–64. (rus)

[10]. Kočí V., Maděra J., Černý R. Exterior thermal insulation systems for AAC building envelopes: Computational analysis aimed at increasing service life. Energy and Buildings. 2012. No. 47. Pp. 84–90.

[11]. Jin H.-Q., Yao X.-L., Fan L.-W., Xu X., Yu Z.-T. Experimental determination and fractal modeling of the effective thermal conductivity of autoclaved aerated concrete: Effects of moisture content. International Journal of Heat and Mass Transfer. 2016. No. 92. Pp. 589–602.

[12]. Korniyenko S. Advanced hygrothermal performance of building component at reconstruction of S. Radonezhskiy temple in Volgograd. MATEC Web of Conferences. 2016. No. 53, 01003.

[13]. Rubene S., Vilnitis M., Noviks J. Frequency Analysis and Measurements of Moisture Content of AAC Masonry Constructions by EIS. Procedia Engineering. 2015. No. 123. Pp. 471–478.

[14]. Koudelka T., Kruis J., Maděra J. Coupled shrinkage and damage analysis of autoclaved aerated concrete. Applied Mathematics and Computation. 2015. No. 267. Pp. 427–435.

[15]. Korniyenko S.V. Evaluation of thermal performance of residential building envelope. Procedia Engineering. 2015. No. 117. Pp. 191–196.

[16]. Gorshkov A.S., Rymkevich P.P., Vatin N.I. Modelirovanie processov nestacionarnogo perenosa tepla v stenovyh konstrukcijah iz gazobetonnyh blokov [Simulation of non-stationary heat transfer processes in autoclaved aerated concrete-walls]. Magazine of Civil Engineering. 2014. No. 8 (52). Pp. 38–48. (rus)

[17]. Korniyenko S.V. Mnogofaktornaja ocenka teplovogo rezhima v jelementah obolochki zdanija [Multifactorial forecast of thermal behavior in building envelope elements]. Magazine of Civil Engineering. 2014. No. 8 (52). Pp. 25–37. (rus)

[18]. Korniyenko S.V. The experimental analysis and calculative assessment of building energy efficiency. Applied Mechanics and Materials. 2014. No. 618. Pp. 509–513.

[19]. Kennedy S.D., Vangeem M.G., Lawrence T., Lord R. Energy Efficiency: Building on Standard 90.1. ASHRAE Journal. 2010. Vol. 52. No. 6. Pp. 22–28.

[20]. Lagüela S., Martínez J., Armesto J., Arias P. Energy Efficiency Studies Through 3D Laser Scanning and Thermographic Technologies. Energy and Buildings. 2011. Vol. 43. No. 6. Pp. 1216–1221.

[21]. Verbeeck G., Hens H. Life Cycle Inventory of Buildings: A Contribution Analysis. Building and Environment. 2010. Vol. 45. No. 4. Pp. 964–967.

[22]. Vatin N.I., Velichkin V.Z., Gorshkov A.S., Pestryakov I.I., Peshkov A.A., Nemova D.V., Kiski S.S. Al'bom tekhnicheskikh resheniy po primeneniyu teploizolyatsionnykh izdeliy iz penopoliuretana torgovoy marki «SPU-INSULATION» v stroitel'stve zhilykh, obshchestvennykh i promyshlennykh zdaniy [Album of technical solutions on application of heat-insulating products from polyurethane foam of the SPU-INSULATION trademark in construction of residential, public and industrial buildings]. Construction of Unique Buildings and Structures. 2013. No. 3 (8). Pp. 1–264. (rus)

[23]. Vasilyev G.P., Lichman V.A., Kolesova M.V., Peskov N.V., Brodach M.M., Tabunshchikov Y.A. Simulation of Heat and Moisture Transfer in a Multiplex Structure. Energy and Buildings. 2015. Vol. 86. Pp. 803–807.

[24]. Campanale M., Moro L. Autoclaved aerated concrete: Experimental evaluation of its thermal properties at high temperatures. High Temperatures–High Pressures. 2015. No. 44 (5). Pp. 369–382.

[25]. Vasil'ev G.P., Lichman V.A., Peskov N.V. Metodika instrumental'nogo opredelenija jenergopotreblenija vvodimyh v jekspluataciju zdanij [Technique of Instrumental Determination of Energy Consumption in Buildings Taken into Use]. Zhilishhnoe stroitel'stvo. 2014. No. 12. Pp. 32–36. (rus)

[26]. Feng C., Yu X., Wang D. Measurements on the hygric properties of autoclaved aerated concrete. Tumu Jianzhu yu Huanjing Gongcheng/Journal of Civil, Architectural and Environmental Engineering. 2016. No. 38 (2). Pp. 125–131.

[27]. Wang C.–L., Ni W., Zhang S.–Q., Wang S., Gai G.–S., Wang W.–K. Preparation and properties of autoclaved aerated concrete using coal gangue and iron ore tailings. Construction and Building Materials. 2016. No. 104. Pp. 109–115.

[28]. Cao X., Li X., Hu Y. Life cycle assessment of EI of masonry materials. Advanced Materials Research. 2012. No. 347–353. Pp. 4055–4061.

[29]. Zhang J., Gao Y., Huang Z. Comparative studies on the temperature stresses in external walls with different thermal insulation models. Harbin Gongcheng Daxue Xuebao/Journal of Harbin Engineering University. 2011. No. 32 (7). Pp. 895–905.

[30]. Guohong T., Christopher D.M., Tianlai L., Tieliang W. Temperature variations inside Chinese solar greenhouses with external climatic conditions and enclosure materials. International Journal of Agricultural and Biological Engineering. 2008. No. 1(2). Pp. 21–26.

[31]. Tian S., Yu J., Nie J. Nonlinear FEM analysis of autoclaved aerated concrete block composite masonry walls. Jianzhu Jiegou Xuebao/Journal of Building Structures. 2006. No. 27(SUPPL.). Pp. 336–340.

[32]. Sormunen P. Energoeffektivnost zdaniy. Situatsiya v Finlyandii [Energy efficiency of buildings. A situation in Finland]. Magazine of Civil Engineering. 2010. No. 1. Pp. 7–8. (rus)

Анализ теплоэнергетических характеристик жилого здания из газобетонных блоков

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ИНФОРМАЦИЯ О СТАТЬЕ	История	Ключевые слова
научная статья **doi: 10.18720/CUBS.51.4**	Подана в редакцию: 30.06.2016	здания; строительство; гражданское строительство; эффективность использования энергии; автоклавный газобетон; тепловая защита; класс энергоэффективности;

АННОТАЦИЯ

Объектом исследования является многоквартирный жилой дом, расположенный в Волгограде. Проектный уровень теплоизоляции двухслойных стеновых конструкций из газобетонных блоков с наружной облицовкой кирпичной кладкой может обеспечить минимально допустимые поэлементные требования по теплозащите согласно СП 50.13330.2012 только при выполнении требований к удельной характеристике расхода тепловой энергии на отопление и вентиляцию здания. Без дополнительной теплоизоляции двухслойные наружные стены в большинстве случае не соответствует базовому уровню теплозащиты и практически не имеют резерва по тепловой защите и энергосбережению. Фактический класс энергосбережения эксплуатируемого здания значительно ниже, чем установленный в проекте. Отклонение фактического расхода тепловой энергии на отопление и вентиляцию здания от расчетного значения может достигать более 75%. С целью обеспечения реального энергосберегающего эффекта необходимо как совершенствовать модель, положенную в основу определения расчетной характеристики расхода тепловой энергии на отопление и вентиляцию здания согласно СП 50.13330.2012, так и обеспечивать соответствие фактического исполнения проекту. Определение удельной теплозащитной характеристики здания следует производить с учетом краевых зон ограждающих конструкций на основе расчета трехмерных температурных полей. В строительстве следует использовать только сертифицированные строительные материалы и конструкции. Для минимизации теплотехнических и теплоэнергетических рисков и повышения уровня теплозащиты наружных стен из автоклавных газобетонных блоков рекомендуется дополнительная теплоизоляция в пунктах строительства с ГСОП больше либо равно 4200 К*сут/год. Следует осуществлять контроль за качеством проектирования и строительства в рамках проведения государственной экспертизы проектов и государственного строительного надзора.

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Литература

[1]. Корниенко С.В., Ватин Н.И., Горшков А.С. Натурные теплофизические испытания жилых зданий из газобетонных блоков // Инженерно-строительный журнал. 2016. № 4. С. 10–25. (Eng)

[2]. Suhasini R. Autoclaving cement concrete: A review. International Journal of Applied Engineering Research. 2014. No. 9 (11). Pp. 1603–1617.

[3]. Van Boggelen W., Völker K. New opportunities for autoclaved aerated concrete [Neue Chancen für Porenbeton]. Betonwerk und Fertigteil-Technik/Concrete Precasting Plant and Technology. 2004. No. 70 (3). Pp. 60–64.

[4]. Немова Д.В., Спиридонова Т.И., Куражова В.Г. Неизвестные свойства известного материала // Строительство уникальных зданий и сооружений. 2012. № 1. С. 36–46.

[5]. Сахаров Г.П. Развитие производства и повышение конструктивных свойств автоклавного ячеистого бетона и изделий на его основе // Технологии бетонов. 2012. № 11–12 (76–77). С. 56–58.

[6]. Tanner J.E., Varela J.L., Klingner R.E., Brightman M.J., Cancino U. Seismic testing of autoclaved aerated concrete shearwalls: A comprehensive review. ACI Structural Journal. 2005. No. 102 (3). Pp. 374–382.

[7]. Горшков А.С. Условия обеспечения устойчивости для поэтажно-опертых стен из газобетонных блоков Технологии бетонов. 2014. № 4(93). С. 49–55.

[8]. Горшков А.С., Ватин Н.И. Свойства стеновых конструкций из ячеистобетонных изделий автоклавного твердения на полиуретановом клее // Инженерно-строительный журнал. 2013. № 5 (40). С. 5–19.

[9]. Горшков А.С., Гринфельд Г.И., Мишин В.Е., Никифоров Е.С., Ватин Н.И. Повышение теплотехнической однородности стен из ячеисто-бетонных изделий за счет использования в кладке полиуретанового клея // Строительные материалы. 2014. № 5. С. 57–64.

[10]. Kočí V., Maděra J., Černý R. Exterior thermal insulation systems for AAC building envelopes: Computational analysis aimed at increasing service life. Energy and Buildings. 2012. No. 47. Pp. 84–90.

[11]. Jin H.-Q., Yao X.-L., Fan L.-W., Xu X., Yu Z.-T. Experimental determination and fractal modeling of the effective thermal conductivity of autoclaved aerated concrete: Effects of moisture content. International Journal of Heat and Mass Transfer. 2016. No. 92. Pp. 589–602.

[12]. Korniyenko S. Advanced hygrothermal performance of building component at reconstruction of S. Radonezhskiy temple in Volgograd. MATEC Web of Conferences. 2016. No. 53, 01003.

[13]. Rubene S., Vilnitis M., Noviks J. Frequency Analysis and Measurements of Moisture Content of AAC Masonry Constructions by EIS. Procedia Engineering. 2015. No. 123. Pp. 471–478.

[14]. Koudelka T., Kruis J., Maděra J. Coupled shrinkage and damage analysis of autoclaved aerated concrete. Applied Mathematics and Computation. 2015. No. 267. Pp. 427–435.

[15]. Korniyenko S.V. Evaluation of thermal performance of residential building envelope. Procedia Engineering. 2015. No. 117. Pp. 191–196.

[16]. Горшков А.С., Рымкевич П.П., Ватин Н.И. Моделирование процессов нестационарного переноса тепла в стеновых конструкциях из газобетонных блоков // Инженерно-строительный журнал. 2014. № 8(52). С. 38-48.

[17]. Корниенко С.В. Многофакторная оценка теплового режима в элементах оболочки здания // Инженерно-строительный журнал. 2014. № 8(52). С. 25–37.

[18]. Korniyenko S.V. The experimental analysis and calculative assessment of building energy efficiency. Applied Mechanics and Materials. 2014. No. 618. Pp. 509–513.

[19]. Kennedy S.D., Vangeem M.G., Lawrence T., Lord R. Energy Efficiency: Building on Standard 90.1. ASHRAE Journal. 2010. Vol. 52. No. 6. Pp. 22–28.

[20]. Lagüela S., Martínez J., Armesto J., Arias P. Energy Efficiency Studies Through 3D Laser Scanning and Thermographic Technologies. Energy and Buildings. 2011. Vol. 43. No. 6. Pp. 1216–1221.

[21]. Verbeeck G., Hens H. Life Cycle Inventory of Buildings: A Contribution Analysis. Building and Environment. 2010. Vol. 45. No. 4. Pp. 964–967.

[22]. Ватин Н.И., Величкин В.З., Горшков А.С., Пестряков И.И., Пешков А.А., Немова Д.В., Киски С.С. Альбом технических решений по применению теплоизоляционных изделий из пенополиуретана торговой марки «SPU-INSULATION» в строительстве жилых, общественных и промышленных зданий // Строительство уникальных зданий и сооружений. 2013. № 3 (8). С. 1–264.

[23]. Vasilyev G.P., Lichman V.A., Kolesova M.V., Peskov N.V., Brodach M.M., Tabunshchikov Y.A. Simulation of Heat and Moisture Transfer in a Multiplex Structure. Energy and Buildings. 2015. Vol. 86. Pp. 803–807.

[24].Campanale M., Moro L. Autoclaved aerated concrete: Experimental evaluation of its thermal properties at high temperatures. High Temperatures–High Pressures. 2015. No. 44 (5). Pp. 369–382.

[25].Васильев Г.П., Личман В.А., Песков Н.В. Методика инструментального определения энергопотребления вводимых в эксплуатацию зданий // Жилищное строительство. 2014. № 12. С. 32–36.

[26].Feng C., Yu X., Wang D. Measurements on the hygric properties of autoclaved aerated concrete. Tumu Jianzhu yu Huanjing Gongcheng/Journal of Civil, Architectural and Environmental Engineering. 2016. No. 38 (2). Pp. 125-131.

[27].Wang C.–L., Ni W., Zhang S.–Q., Wang S., Gai G.–S., Wang W.–K. Preparation and properties of autoclaved aerated concrete using coal gangue and iron ore tailings. Construction and Building Materials. 2016. No. 104. Pp. 109–115.

[28].Cao X., Li X., Hu Y. Life cycle assessment of EI of masonry materials. Advanced Materials Research. 2012. No. 347–353. Pp. 4055–4061.

[29].Zhang J., Gao Y., Huang Z. Comparative studies on the temperature stresses in external walls with different thermal insulation models. Harbin Gongcheng Daxue Xuebao/Journal of Harbin Engineering University. 2011. No. 32 (7). Pp. 895–905.

[30].Guohong T., Christopher D.M., Tianlai L., Tieliang W. Temperature variations inside Chinese solar greenhouses with external climatic conditions and enclosure materials. International Journal of Agricultural and Biological Engineering. 2008. No. 1(2). Pp. 21–26.

[31].Tian S., Yu J., Nie J. Nonlinear FEM analysis of autoclaved aerated concrete block composite masonry walls. Jianzhu Jiegou Xuebao/Journal of Building Structures. 2006. No. 27(SUPPL.). Pp. 336–340.

[32].Сормунен П. Энергоэффективность зданий. Ситуация в Финляндии // Инженерно-строительный журнал. 2010. № 1. С. 7–8.

Корниенко С.В. , Ватин Н.И., Горшков А.С. Анализ теплоэнергетических характеристик жилого здания из газобетонных блоков // Строительство уникальных зданий и сооружений. 2016. №12 (51). С. 45-60.

Korniyenko S., Vatin N., Gorshkov A. Heat and power characteristics analysis carried out for the residential building made of autoclaved aerated concrete blocks. Construction of Unique Buildings and Structures, 2016, 12 (51), Pp. 45-60.