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New Methodology for Designing External Fencing Structures Energy Efficient Civil Buildings

Said S. Shaumarov*
Tashkent Institute of Railway Engineers
Tashkent, Uzbekistan

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Abstract. Based on the performed theoretical studies and calculations, the developed methodological foundations of designing the external enclosing structures of energy-efficient buildings based on cellular concrete with a given set of properties are presented, which are of great economic importance for construction oriented in the modern period towards the creation of energy-efficient civil facilities.

Keywords: methodology, energy efficiency, exterior walls, design, cellular concrete, research, pore structure.

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О новой методологии проектирования наружных ограждающих конструкций энергоэффективных гражданских зданий

С. С. Шаумаров
Ташкентский институт инженеров
железнодорожного транспорта
Узбекистан, Ташкент

Аннотация. На основании выполненных теоретических исследований и расчетов представлены разработанные методологические основы проектирования наружных ограждающих конструкций энергоэффективных зданий на основе ячеистого бетона с заданным комплексом свойств, имеющие важное народнохозяйственное значение для строительства, ориентированного в современный период на создание энергоэффективных объектов гражданского назначения.

* Corresponding author E-mail address: shomarovss@gmail.com

Ключевые слова: методология, энергоэффективность, наружные стены, проектирование, ячеистый бетон, исследования, поровая структура.

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Introduction

Scientists all over the world are involved in the design of energy-efficient civil buildings and their structures: M. Mikheev [1], B. F. Vasiliev [2], Yu. A. Matrosov [3], V. M. Ilyinsky [4], Yu. A. Tabunshchikov [5, 6], V. N. Bogoslovsky [7], V. L. Kurbatov [8], A. S. Semchenkov [9], V. G. Gagarin [10], W. Feist [11] and others [12–14]. An analysis of the results of their research showed that the currently used methods of designing external building envelopes for buildings of this type do not have sufficient scientific justification, and the structural solutions of the walls themselves are rather complicated in technical design, do not take into account the specific climatic, economic and raw materials of the construction areas. In this regard, the development of a methodology for designing the exterior walls of energy-efficient civil buildings seemed quite relevant, which, in turn, required a series of special scientific studies.

Methodology development

From an analysis of literary sources and experience in the construction of civil buildings on the territory of the Republic of Uzbekistan, it was found that one of the most effective in their properties and manufacturing techniques for the construction of the exterior walls of buildings is a single-layer fencing made of cellular concrete. However, it is obvious that in order to solve the problem of creating wall fencing for energy-efficient buildings, a comprehensive approach is needed, which includes the formation of requirements for external walls that differ in static function and heat-shielding properties, determining the optimal structure of the material and developing appropriate technological methods that allow the construction to achieve the required qualities, design parts and assemblies that exclude heat transfer [15–16].

Having set out to obtain wall structures made of cellular concrete with the required strength and heat insulation properties in the least expensive way, it was decided to initially optimize the thickness of the outer wall of civil buildings based on existing experience in construction in the Republic of Uzbekistan. This saves money for manufacturers of building envelopes, as it significantly reduces the required number of sizes of formwork elements for the manufacture of panels or blocks.

An analysis of the structural solutions of the external walls in Uzbekistan made it possible to establish that the most appropriate size for the thickness of cellular concrete products may be 400 mm.

The required values of the coefficients of thermal conductivity of aerated concrete for external walls were established taking into account the climatic characteristics of the construction area, number of storeys and a given level of thermal protection of buildings, and the necessary strength properties were established based on the static functions of the designed walls (load-bearing or self-supporting). Calculations showed that the outer walls 400 mm thick of cellular concrete D700–D900, which can be used as material for load-bearing walls in seismic construction conditions, do not have the required heat-shielding properties (the thermal conductivity was found to be (52–69)% higher than required), which indicates the need for a directed effect on the structure of this material in order to reduce its heat conductivity coefficient, or a directed effect on the structure of cellular concrete D400 and D500 in order to increase their strength.

Providing both the required heat-shielding and strength properties of cellular concrete is a rather difficult task, since these properties represent an alternative with respect to average density, that is, a decrease in average density increases the thermotechnical and hygroscopic properties of cellular concrete, but reduces the strength properties and vice versa. To solve this problem, we used an approach based on mathematical modeling of the macrostructure of cellular concrete that meets the required thermal conductivity [17–18].

Mathematical modeling of the structure of cellular concrete with given values of thermal conductivity

The correctness of the task, in addition to experimental studies, follows from the thermodynamic analysis of heat and moisture transfer in porous materials. For a theoretical description of the process of heat and moisture transfer in porous media, one can use the system of differential equations obtained by A. V. Lykov:

$$C_\Sigma \frac{\partial T}{\partial t} - \varepsilon r \frac{\partial W_l}{\partial t} = \nabla(\lambda \nabla T) + (C_l D_l \nabla W_l + C_l D_{Ti} \nabla T)\nabla T, \tag{1}$$

$$(1-\varepsilon)\frac{\partial W_l}{\partial t} = \nabla(D_l \nabla W_l) + (D_{Ti} \nabla T). \tag{2}$$

In (1), (2): $C_\Sigma = C_s + W_1 C_1$; T, λ – respectively the temperature and thermal conductivity of a wet body; C_s – is the specific heat of a unit volume of the dry porous material W_l, C_l, r, D_l, D_{Tl} – is the concentration, specific heat, specific heat of evaporation, heat transfer coefficient of liquid moisture, coefficient of thermal diffusion of the liquid, respectively; ε – phase transformation criterion, which is defined as the ratio of the change in moisture content through evaporation and condensation to the change in moisture content due to liquid transfer; $\nabla = \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \frac{\partial}{\partial z}$ – operator Nabla.

The system of differential equations of heat and moisture transfer in porous materials presented in form (1), (2) is undoubtedly simpler than its classical representation [19–21], but this simplicity, firstly, creates certain difficulties in their practical application, since the criterion phase transition is a «fictitious» physical parameter for which there is no fundamental possibility of measuring it. Secondly, from the point of view of the problem posed by us, it is extremely important that in equations (1), (2) in the explicit form there is no predominance for porous materials, in particular, for cellular concrete, the porosity parameter. Therefore, we transform equations (1), (2) to the form, eliminating the parameter ε, from them, introducing the porosity parameter P:

$$C_\Sigma \frac{\partial T}{\partial t} - r \frac{\partial W_l}{\partial t} = \lambda \nabla T + (k \nabla W_l + m \nabla T)\nabla T - r \nabla(D_l \nabla W_l + D_{Ti} \nabla T), \tag{3}$$

$$R \frac{\partial T}{\partial t} + Q \frac{\partial W_l}{\partial t} = \nabla[(D_{Tv} + D_{Ti})\nabla T] + \nabla[(D_v + D_l)\nabla W_l], \tag{4}$$

$$C_\Sigma = C_s + W_l C_l + W_v C_v; \; m = \frac{\partial\lambda}{\partial T} + C_v D_{Tv} + C_l D_{Tl}; \; k = \frac{\partial\lambda}{\partial W_l} + C_l D_l + C_v D_l;$$

$$W_v = \rho_v \left(P - \frac{W_l}{\rho_l} \right); \; \rho_v = \rho_v(T, W_l);$$

$$R = \frac{\partial\rho_v}{\partial T}\left(P - \frac{W_l}{\rho_l} \right); \; Q = 1 - \frac{\rho_v}{\rho_l} + \frac{\partial\rho_v}{\partial W_l}\left(P - \frac{W_l}{\rho_l} \right).$$

This system of differential equations (3) and (4) describes the heat transfer process for a given coefficient of thermal conductivity, depending on the macrostructure of aerated concrete, characterized by the porosity parameter *P*.

In accordance with the conceptual approach to the problem of mathematical modeling of the macrostructure of porous materials, the software package «Modeling the macrostructure of cellular concrete with predetermined thermotechnical properties» was developed [22–23].

Based on the developed physical and mathematical model, which has been algorithmized and implemented in the form of the specified software product, by numerical calculations, it was possible to determine the optimal parameters of the pore structure of cellular concrete (pore size at their adopted three-modal laying, the thickness of the inter-pore walls), which allow achieving both the required strength and thermal conductivity coefficient (Table 1).

Table 1. The results of modeling the macrostructure of aerated concrete corresponding to a given coefficient of thermal conductivity for a «random» type of packaging with a uniform probability density of a three-modal distribution and a matrix density of 2000 kg/m^3

Coefficient thermal conductivity, W/m °C	The size Since, mm	Thickness Partitions, mm	Average density, kg/m^3	Strength, MPa	Porosity, %
1	2	3	4	5	6
0,085	r_1=2,426 r_2=1,618 r_3=3,466	2,208	300	1	85
0,095	r_1=2,473 r_2=1,649 r_3=3,534	2,251	400	2	81
0,123	r_1=2,403 r_2=1,602 r_3=3,434	2,187	500	3	74
0,143	r_1=2,220 r_2=1,480 r_3=3,171	2,020	600	4	71
0,174	r_1=1,808 r_2=1,205 r_3=2,582	2,020	700	5	66
0,199	r_1=1,429 r_2=0,952 r_3=2,041	1,300	800	6	60

Continuation of Table 1

1	2	3	4	5	6
0,233	r_1=0,931 r_2=0,621 r_3=1,330	0,847	900	8	55
0,262	r_1=0,575 r_2=0,384 r_3=0,822	0,524	1000	10	52
0,314	r_1=0,161 r_2=0,107 r_3=0,230	0,147	1100	12	45
0,334	r_1=0,073 r_2=0,049 r_3=0,105	0,067	1200	16	40

The above simulation results determine the direction of development of appropriate technological methods based on existing standard techniques to achieve the required structure parameters of aerated concrete, providing the desired heat engineering and/or strength properties.

Another important point is the ability to diagnose structural parameters and physical properties of cellular concrete. For these purposes, using the theory of fractal dimension, a «Program for determining the properties of cellular concrete based on image analysis» was developed.

Based on the results of the research, a methodology for the design of external walling was developed, which is presented in the form of a diagram in Fig.

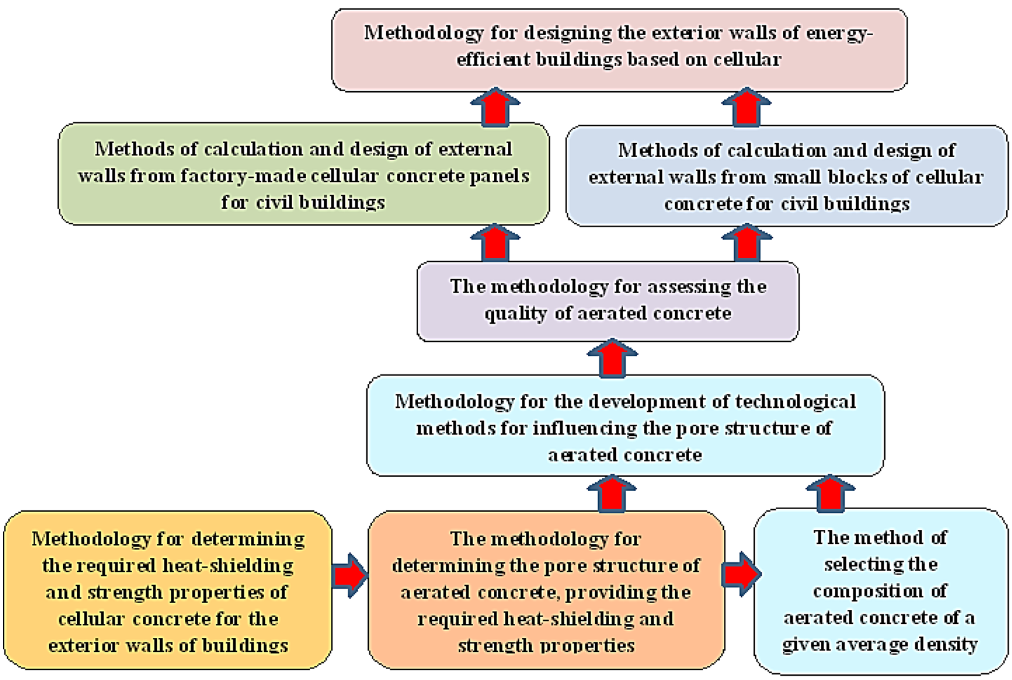

Fig. Design methodology for exterior walls of energy-efficient buildings based on aerated concrete

Conclusion

The developed methodological foundations for designing exterior walls for energy-efficient civil buildings, including a number of standard and newly proposed methods based on the results of theoretical and experimental studies, allow us to design exterior walling with improved heat-shielding properties and at the same time technological, economically feasible and environmentally friendly, in addition, indicate a further prospect of research in this direction.

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