Investigation of rational types of light concrete for external walls in conditions of hot climate

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ABSTRACT

Introduction. The paper presents theoretical and experimental studies of the improvement of the structure of lightweight concrete, which provides the maximum value of the attenuation of the amplitude of external air temperature fluctuations during the passage of heat flow through the walls and the reduction of thermal conductivity, the results of the 3-factor experiment on determining the rational structure of claydite concrete and the methods for their processing.

To determine the purposeful structure of the composition of lightweight concrete and its thermal conductivity, a complex of research works was carried out at the Central Research Institute for Housing, applied to lightweight concrete for exterior walls. The main optimization criterion was the maximum reduction in thermal conductivity while providing the necessary strength, durability and waterproofness.

The purpose of this work is theoretical research and experimental substantiation of methods for improving the structure of lightweight concrete used for a hot climate with improved functional performance.

Materials and methods. As material a claydite gravel with bulk density $p = 400 \text{ kg/m}^3$ of Lianozovsky plant (Moscow) was used, at a ratio of 40 % of the fraction 5–10 mm and 60 % of the fraction 10–20 mm and a Portland cement of the brand “400” of the Voskresensky plant, not plasticized. The water flow rate was varied for 10 seconds, to ensure the mixture to be vibropacked. As a foam generating agent and plasticizer, the “Saponified wood resin” (SDO) was used in a 5 % aqueous solution. The methods were adopted in accordance with the Recommendation on the technology of factory production and quality control of lightweight concrete and large-panel constructions of residential buildings. M. CNIIEP dwelling, 1980.

In the department of the lightweight concrete application at CNIIEP of dwelling, a method for the purposeful formation of the structure and composition of lightweight concrete, which provides a set of physic-technical, technological and technical-economic requirements, was developed.

Results. Calculations are reduced to obtaining mathematical models of dependence of strength R , density p , thermal conductivity λ and other indicators of concrete characteristics from initial factors in the form of regression equations. Based on the equations obtained, it was possible to determine the expedient composition of lightweight concrete, which, in combination with the operational characteristics, provides comparable results of the technical and economic characteristics of a single-layer structure from the projected type of lightweight concrete.

Conclusions. 1. An improved composition of the structural and heat insulating lightweight concrete for the load-bearing part of the structure, providing its high thermal stability by chemical additives and low consumption of porous sand, was developed. An algorithm for selecting its composition on computer is made.

2. The conducted researches in the field of design of external enclosing structures for hot climate conditions have shown that: single-layer exterior wall constructions with massiveness of $D \leq 4$ provide minimum allowable values of heat flux attenuation and temperature fluctuation amplitude on the inner wall surface.

KEYWORDS: strength, density, thermal conductivity, lightweight concrete, portland cement, durability, waterproofness, damping, heat resistance, thermal resistance, claydite concrete, heat transfer

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Исследование рациональных видов легких бетонов для наружных стен в условиях жаркого климата

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АННОТАЦИЯ

Введение. Представлен подход к усовершенствованию структуры легкого бетона, обеспечивающей максимальное значение затухания амплитуды колебаний температуры наружного воздуха при прохождении теплового потока через стены и снижение теплопроводности, результаты трехфакторного эксперимента по определению рациональной структуры керамзитобетона и методы их обработки.

Для определения целенаправленной структуры состава легкого бетона и его теплопроводности в ЦНИИЭП жилища был проведен комплекс научно-исследовательских работ, применительно к легкому бетону для наружных стен основным критерием оптимизации являлось максимальное снижение теплопроводности при обеспечении необходимой прочности, долговечности и водонепроницаемости.

Материалы и методы. Использован керамзитовый гравий с насыпной плотностью $\rho = 400 \text{ кг/м}^3$ Лианозовского завода (г. Москва), при соотношении 40 % фракции 5–10 мм и 60 % фракции 10–20 мм и портландцемент марки 400 Воскресенского завода не пластифицированный. Расход воды варьировали для обеспечения виброукладываемости смеси 10 с. В качестве пенообразователя и пластификатора применялась смола древесная омыленная в виде 5%-ного водного раствора. Методы приняты согласно Рекомендации по технологии заводского производства и контролю качества легкого бетона и крупнопанельных конструкций жилых зданий.

В отделе применения легких бетонов ЦНИИЭП жилища разработан метод целенаправленного формирования структуры и состава легкого бетона, обеспечивающего совокупность физико-технических, технологических и технико-экономических требований.

Результаты. Одним из преимуществ теоретического исследования и экспериментального обоснования методов совершенствования структуры легкого бетона, применяемых для условия жаркого климата, обладающих улучшенными эксплуатационными качествами являются расчеты, которые сводятся к получению математических моделей зависимости прочности R , плотности ρ , теплопроводности λ и других указателей характеристик бетона от исходных факторов в виде уравнений регрессий. На основании полученных уравнений представилось возможным определить целесообразный состав легкого бетона, который по совокупности эксплуатационных характеристик обеспечивает получение сопоставимых результатов технико-экономических показателей однослойной конструкции из запроектированного вида легкого бетона.

Выводы. 1. Разработан усовершенствованный состав конструкционно-теплоизоляционного легкого бетона для несущей части конструкции, обеспечивающий ее высокую теплоустойчивость за счет применения химических добавок и низкого расхода пористого песка. Составлен алгоритм подбора его состава на компьютер.

2. Проведенные исследования в области проектирования наружных ограждающих конструкций для условий жаркого климата показали, что однослойные конструкции наружных стен при массивности $D \leq 4$ обеспечивают минимально допустимые величины затухания теплового потока и амплитуды колебания температуры на внутренней поверхности стены.

КЛЮЧЕВЫЕ СЛОВА: прочность, плотность, теплопроводность, легкий бетон, портландцемент, долговечность, водонепроницаемость, затухание, теплоустойчивость, термическое сопротивление, керамзитобетон, теплопередача

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INTRODUCTION

Modern large-panel structures and technology of their manufacture should reliably provide the normative level of operational requirements with the minimum material consumption and labor input of factory and construction production per unit of useful area of the dwelling.

Improvement of such structures is achieved, mainly due to more rational use of efficient building materials and form making technology, which allows to obtain more economical sections.

The external wall is an important constructive element, which the operational condition of living quarters largely depends on. Single-layer lightweight panels have advantages over multilayer ones: they are easier in manufacturing, congeneric in cross-section; they do not have bridges of cold. Their heat-protective properties are determined by the structure and physical characteristics of lightweight concrete (expanded by haydite concrete), which greatly depend on humidity. By obtaining a high initial humidity, claydite-concrete walls can dry out on both sides, that is another advantage of single-layer structures. The rate of evaporation depends on the structure and thickness of the wall: the thicker it is, the more water is introduced into it and the more it will be removed. Scientists, who made a great contribution into the development of theoretical and experimental stud-

ies of the structures of external walls and their materials on the resistance to climatic influences, are V.N. Bogoslovsky, B.F. Vasiliev, A.V. Ershov, Z. Lomtadze, T.G. Maklakova, E.A. Soldatov, N.Y. Spivak, N.S. Stroganov, A.J. Tabunshchikov, F.V. Ushkov, E.I. Ugryumov, K.F. Fokin, A.M. Shklover and others.

There are the works of foreign scientists, known in this field: N. Borel, N. Wagner, C. Gertis, S.I. Camerer, C. Cadet, Roger, C. Lirch, McAdams, H. Heben, F. Heck and others.

According to B.F. Vasiliev [1], the thermal resistance of a single-layer fence can be increased not due to passive increase in its thickness, but because of an active improvement in the structure of the material. This will reduce thermal conductivity coefficient, in some cases without reducing the density of the material.

Experimental studies carried out by A.V. Ershov, E.A. Soldatov [2] in the microclimate laboratory in the building physics of TashZNIIEP from 1960 to 1969, SamGAS [3] in 1970–1978, served as a scientific basis for issuing recommendations about the thickness, material choice and type of external fences taking into account the thermal action of solar radiation in the territory of Central Asia.

Investigations of heat resistance of wall fences under conditions of hot climate received little attention, which explains insufficient illumination in the normative technical literature of the characteristics of the heat

resistance of fences from the action of solar radiation. Only SNiP II-3-79¹ briefly outlines the question of determining the attenuation of external air temperature fluctuations in fences, and compares the obtained values with the normed.

At present, the production of single-layer wall panels made of lightweight concrete prevails over the release of multi-layered panels with an effective insulant. The share of lightweight structures accounts for 70 % of the volume of panels produced [3]. Moreover, in most cases (up to 80 %); they do not meet the requirements of the current standards, because of the increased (by 10–15 %) density of the haydite concrete. The increase in the density of the haydite concrete worsens the microclimate in the premises during the winter period significantly.

MATERIALS AND METHODS

When choosing a constructive and technological solution for lightweight concrete of exterior wall panels, the thermal engineering characteristics of concrete, which depend on its composition and structure, are of utmost importance. Assignment of the calculated coefficient of thermal conductivity is always a rather complex and important task.

To determine the expedient structure of the composition of lightweight concrete and its thermal conductivity, a complex of research works was carried out in the CNIIEP² [4, 5, 6].

With regard to lightweight concrete for exterior walls, the main optimization criterion is the maximum reduction of thermal conductivity while providing the necessary strength, durability and water resistance.

To find a rational structure of lightweight concrete, which provides the maximum value of attenuation of the amplitude of fluctuations in the temperature of the outside air during the passage of the heat flow, it was necessary to determine theoretically the conditions under which optimal parameters like ρ density, D massiveness, thermal conductivity λ and heat build-up S [7] are achieved.

As noted above, in order to create a comfortable microclimate in residential areas in conditions of summer overheating, it is necessary to ensure high heat resistance of external enclosure structures. One of the main indicators that determine this feature is the density and thermal conductivity of the material. At the same time, the best results when using lightweight concrete (haydite concrete) are achieved, provided that for a given concrete the coefficient of thermal conductivity

is minimal. Concrete of this composition provides the greatest heat flow attenuation and a decrease in temperature fluctuation amplitude of the internal surface.

To improve the thermal regime of residential premises in a hot climate, it is necessary to achieve greater damping of the heat flow in the wall. This is achievable largely by improving the structure of the material and the production technology of a single-layer external wall made of lightweight concrete.

In the department of the use of light concrete in CNIIEP of dwelling, a complex of research works was carried out in order to find the optimal solution of the prescription and technological regulations ensuring the greatest value of the heat flux attenuation in the lightweight external panel wall [8].

A number of methods for designing and selecting lightweight concrete compounds on porous aggregates are known. In most accepted methods, the practice of selecting the composition of heavy concrete is used.

In spite of all the diversity, the provision of a given strength of concrete with a minimum consumption of cement dominates as a requirement. Proceeding from the required convenient stacked concrete mixture, its water demand, and therefore, the possible or necessary V/C , ensuring the given strength, is determined. The transfer of methods for selecting the composition of heavy concrete when working with lightweight concrete leads, as a rule, to loss of the main advantages of lightweight concrete.

For this type of porous filler of lightweight concrete, there is a relative correlation of thermal conductivity and density of the prefixed structure of concrete. A change in the structure with a fixed strength and density inevitably entails a change in thermal conductivity.

In the department of application of lightweight concrete of CNIIEP of dwelling, a method for the purposeful formation of the structure and composition of lightweight concrete has been developed, which provides a set of physico-technical, technological and technical-economic requirements [9].

The defining parameters of porous aggregates have been adopted, the main of which are:

- the shape of the grain (crushed stone, gravel, size ratio);
- maximum limiting size (LS) — 5, 10, 20, 40 mm;
- compressive strength in a cylinder R_c ;
- bulk density in a dried condition ρ_b ;
- constructive quality ratio $\frac{R_c}{\rho_b}$;
- granulometry index according to the standard set of sieves n ;
- exponent of the equation of the sieving curve

$$Y = \left(\frac{x}{pk} \right)^n,$$

where: Y — filler flow through a standard set sieve; x — hole size, mm.

¹ SNiP II-3-79. Building heat engineering Standards of designing. Moscow, 1986; 32.

² Methodical instructions for reducing the density and increasing the heat-shielding ability of easy-concrete panels of external walls. Moscow, Central research and development design Institute of standard and experimental design of housing (TSNIIEP housing). 1989; 28.

For the lightweight mixture, the following basic parameters were adopted:

- aggregate-structural factor $M / M + K$ the ratio of bulk fractions;
- shallow (M/S) to the sum of the fractional volumes of fine and coarse fractions.

Depending on the type of aggregate, the aggregate structure of concrete, the condition of forming the structure and the technology of its production, the properties of the concrete of the structure change. The structure defined by the aggregate-structural factor, differs in the indicator $M / M + K$ varying from 0 to I.

For this index η the optimal value is the parameter of an aggregate-structural factor

$$\frac{M}{M+K} = \left(\frac{d}{pk} \right)^n, \quad (1)$$

where: d — is the size of a sieve hole from 0 to 5 mm of fine aggregate (5, 3 or 1.25 mm).

For the condition $0 < \frac{M}{M+K}$ the structure is coarse-pored,

$0.15 < \frac{M}{M+K} < 0.7$ a normal structure, $0.7 < \frac{M}{M+K} < 1$ structure is small grained (sand off).

Thus, it seems possible to find rational ranges of values of granulometry and aggregate-structural $\frac{M}{M+K}$.

Factor $M / M + K$ varies from 0 to I. In the range of values 0...0.15, large-porous. Optimal value

$$\frac{M}{M+K} = \left(\frac{5}{pk} \right)^n.$$

In its turn

$$n = A + \frac{R_c}{\rho_b} + 10, \quad (2)$$

where: A — is the coefficient, depending on the shape of the aggregate grain.

The possibilities of modifying the structure by the introduction of plasticizing substances as well as porous structures are also used.

The author faced with the task of finding the parameters of the structure of a light concrete mixture, ensuring the effective damping in the course of heat flow through the concrete of the external wall in the conditions of hot climate of Central Asia.

For this purpose, an experiment plan has been developed in which variables are directly related to the heat flow damping parameters V^3 .

$$V = 0,9 \sqrt[3]{\frac{D}{S+Y}} \left(\frac{S+\alpha_v}{S+Y} \right) \cdot \left(\frac{\alpha_b+Y}{\alpha_b} \right). \quad (3)$$

To determine the effect of the individual I quantities on the damping index, an algorithm was developed (3), in which variable values were adopted:

$$D, \lambda, \rho, \delta, R, S.$$

The values changed in accordance with the accepted intervals (Table 1).

To determine minimum value of λ a 3-factor experiment was performed based on the possibilities of regulating the properties of lightweight concrete due to a purposeful change in its structure (Table 2).

Theoretically, it was necessary to find structures for which the thermal conductivity coefficient is minimal for maximum density.

In order to reduce a cement consumption and to reduce the coefficient of thermal conductivity due to a large inclusion in the conglomerate of the glass phase, a limited amount of crushed expanded clay sand is in-

³ KMK 2.01.04-97 Construction heat engineering. Tashkent, Goskomarkhitektstroy Publ., 1997; 74.

Table 1. Intervals of the values of output thermophysical parameters of haydite concrete

Parameters' names	Parameters value		Interval
	min	max	
Coefficient of thermal conductivity, W(m°C)	0.24	0.56	0.09
Density in a dry condition, kg/m ³	800	1400	100
Fence thickness, m	0.24	0.36	0.03
Total heat transfer resistance, m ² °C/W	1.19	0.83	0.125
Coefficient of the material heat absorption, W/m ² , °C	3.83	7.75	0.6

Table 2. Experiment plan

Factors	Units measurements	Levels		
		lower -1	initial 0	upper +1
Gravel "G"	l/m ³	950	1000	1050
Cement "C"	kg/m ³	200	250	300
Foam "P"	l/m ³	240	170	100

troduced into the composition when it is sprayed with technical foam.

This corresponds to the structure of claydite concrete with a low consumption of crushed expanded clay sand with a constant value of an aggregate-structural factor $\frac{M}{M+K} = 0,15$ (M, K — a volume of small and large aggregates).

According to the plan of the 3-factor experiment, in the preparation of compositions 1–8, claydite gravel with a bulk density $\rho = 400 \text{ kg/m}^3$ from Lianozovsky plant (Moscow), at a ratio of 40 % of the fraction 5–10 mm and 60 % of the fraction 10–20 mm was used. Haydite sand $\rho = 700 \text{ kg/m}^3$ for compositions 1–8 was obtained by crushing haydite gravel of Lianozovsky plant. At the same time, the fractional composition of the sand was 20 % of the fraction of 0...0.15 mm 60 % of the fraction of 0...1.25 mm.

The determination of the basic initial composition of the concrete mixture, the plan for the experimental conditions were adopted according to.

In the department of lightweight concrete application, a three-factor experiment was conducted, to determine of the optimum of the structure of lightweight concrete. For the accepted three-factor system, the factors C , G , and P , experimental batches were performed according to the plan given at Table 3.

For experiments, haydite gravel of fractions of 10–20 and 5–10 mm was used, which was applied with a change in flow according to the plan of the 3-factor experiment (Table 2) and Portland cement of the brand “400” from Voskresensky plant, not plasticized. The water flow rate varied to ensure a vibro stacking time of mixture for 10 seconds. As a foaming agent and a plasticizer, a “wood saponified resin” (SDO) was used in the form of a 5 % aqueous solution.

The technical foam was manufactured in a centrifugal foam generator. Concrete mixture was manufactured in a laboratory trough-shaped mixer with a horizontal shaft paddle at 32 rev/min. The working solution [the plasticizer was introduced into the mixture in 1 minute after the mixture had been stirred with water, followed by stirring for the next 2 minutes.

The sample cube with an edge of 15 cm was produced on a laboratory vibro site.

TBO was conducted according to the regime 2h + 6h + 2h (temperature increase + isothermal warming + temperature decrease) in a steam chamber at a maximum temperature of 85 °C. In total, according to the plan of the experiment, 8 lots were produced, (compositions No. 1–8) (Table 4).

In addition, for comparison, two lots were additionally produced (with larger and lower cement consumption) of haydite concrete with optimal $\frac{M}{M+K} = 0.33$ on haydite and quartz sand with addition of SDO 1:20, respectively, compositions No. 9 and 10 (Table 5).

It is should be noted that the strength index is strongly influenced by the amount of technical foam. Thus, at cement consumption of 300 kg with foam consumption of 100 and 200 l/m³, concrete strength decreased from 12.6 MPa (composition No. 1) to 7.1 MPa (composition No. 6), respectively. It is typical that at cement consumption of 176 kg and foam of 200 l/m³ concrete strength was obtained respectively 1.7 and 1 MPa (compositions No. 4 and 8) and, thus, these lots were excluded from consideration because, the concrete grade should be B 7, 5.

The compressive strength of concrete, the volumetric mass of dry concrete, thermophysical characteristics, and other observations obtained as a result of experiments, are listed in Table 4 for the subsequent calculations.

Calculations are reduced to obtaining mathematical models of dependence of strength R , density ρ , thermal conductivity λ and other indicators of concrete characteristics from the initial factors in the form of regression equations of the following types:

$$R = \alpha_0 + \alpha_1 \cdot G + \alpha_2 \cdot C + \alpha_3 \cdot P + \alpha_{1,2} \cdot G \cdot C + \alpha_{1,3} \cdot G \cdot C + \alpha_{2,3} \cdot C \cdot P; \quad (4)$$

$$\rho = v_0 + v_1 \cdot G + B_3 \cdot C + B_3 \cdot P + B_{1,2} \cdot G \cdot C + B_{1,3} \cdot G \cdot C + B_{2,3} \cdot C \cdot P; \quad (5)$$

$$\lambda = C_0 + C_1 \cdot G + C_2 \cdot C + C_3 \cdot P + C_{1,2} \cdot G \cdot C + C_{1,3} \cdot G \cdot C + C_{2,3} \cdot C \cdot G, \quad (6)$$

where: G, C, P — are factor scores in a code scale (accepted according to the plan of experiments).

Output characteristics of strength and operating abilities of concrete were: Y_1 — definition/limit of com-

Table 3. Experiment plan

No of experiment	G	C	P
1	+1	+1	+1
2	+1	+1	-1
3	+1	-1	+1
4	+1	-1	-1
5	-1	+1	+1
6	-1	+1	-1
7	-1	-1	+1
8	-1	-1	-1

Table 4. Structures and compositions of haydite foam concrete and haydite concrete

Com- position No.	Actual consumption of materials per 1 m ³						Density ρ, kg/m ³	Strength R, MPa	Thermal conductiv- ity λ _o , W/m ^o C
	Aggregate by fractions, mm			cement, kg	water, l	foam, l/kg			
	10–20	5–10	0–5						
1	610/200	406/160	183/109	290	155	97/17	962.4	12.67	0.313
2	525/183	350/133	158/109	250	139	200/43	855.6	4.61	0.260
3	643/210	429/169	194/118	204	136	102/18	878.4	6.86	0.275
4	556/182	371/146	168/103	176	112	212/34	759.6	1.74	0.232
5	586/192	390/151	154/100	308	147	103/15	956.4	12.00	0.310
6	545/181	363/145	143/95	287	127	229/35	901.2	7.13	0.285
7	590/190	393/156	155/101	207	138	103/16	822.0	5.00	0.250
8	503/164	335/131	132/86	176	112	212/32	699.6	1.00	0.220
9	565/189	317/126	436/716	248	153	1.8	1316.0	10.10	0.584
10	592/196	332/137	457/405	260	208	1.8	1037.0	9.8	0.350

Note: in compositions 9 and 10 $\frac{M}{M+K} = 0.33$, in other cases — 0.15.

pressive strength, MPa; Y_2 — density, kg/m³; Y_3 — thermal conductivity, W/m²°C.

Regression equations for strength (4) and operational (5, 6) properties/abilities of concrete are obtained.

RESULTS

On the basis of equations obtained, it was possible to determine the expedient composition of lightweight concrete, which, according to the combination of operational properties, provides comparable results of technical and economic indicators of a single-layer structure from the projected type of lightweight concrete.

After processing the results (Table 4), it turned out that the regression equations do not reveal extremes. Therefore, graph analytical analysis of the results was carried out.

The graphs obtained in the planned experiment with painted haydite concrete for haydite concrete at haydite sand, are intersected at one point close to B7.5 strength, which confirms the adequacy of the solution.

For single-layer panels of external walls in accordance with GOST 11309-65⁴, it is necessary to use

⁴ GOST 11309-65. Houses large-panel residential. Basic technical requirements.

lightweight concretes of the integrated structure, which is achieved either by porosity of the solution part or by using concrete with a sufficient content of porous sand or by cement. These requirements for lightweight concrete are dictated by the condition that the external walls do not get wet through the plain of the panels. At the same place, studies show that the thermal conductivity of combined haydite concrete is higher than that of concrete with a small inter-grain porosity.

Haydite concrete with quartz sand is preferable for strength and cement consumption, however, a sharp increase in density and especially in thermal conductivity required additional study of the influence of these factors on the final value of the heat flow attenuation.

With this end, a comparison and calculation of the exponent V of the heat flow attenuation was made (Table 5).

Table 5 is made up of the condition that the thickness of the wall is equal $\delta = 0.30$ m from the four types and haydite concrete structures under consideration. It follows from the table that the maximum value of the heat flow attenuation was noted in the composition of haydite concrete No. 5 (see Table 4), characterized by cup strength of 12 MPa at a density of 956 kg/m³ and a thermal conductivity coefficient of 0.31 W/m °C.

These indications were obtained with a cement consumption of 308 kg/m³. Approximately similar in-

Table 5. Variant calculations of heat flux damping values and material cost conditions per 1 m² of the wall

No.	Cement II, kg	Density ρ , kg/m ³	Thermal conductivity λ_0 , W/m ² °C	Thermal resistance, m ² °C /W	Estimated coef- ficient of heat ab- sorption, W/m ² °C	Thermal inertion D	Heat flow attenuation V	Cost of materials per 1 m ² , rub
I	290	962.4	0.313	0.96	4.80	4.63	38.40	9.35
5	308	956.4	0.310	0.97	4.77	4.63	39.30	9.00
9	248	1316.0	0.584	0.51	7.51	3.83	18.49	7.03
10	260	1037.0	0.350	0.86	5.28	4.52	34.34	10.93

dicators were obtained for composition № 1. It should be noted that the composition No. 10 of haydite concrete at haydite sand at $\frac{M}{M+K} = 0.33$ showed a value of $V = 34.34$, i.e. 14 % less than composition No. I (with a strength of 9.8 MPa and a cement consumption of 260 kg/m³). Low heat resistance was noted for the structure of haydite concrete, porous with quartz sand. At a strength of 10 MPa, density of 1316 kg/m³ and a cement consumption of 248 kg/m³, the attenuation $V = 18.49$ was found, which is 2.12 times less than composition No. I. At the same time, for a thickness $\delta = 0.30$ m, the minimum allowable attenuation of the heat flow is provided, which should be at least 15.

Economic evaluation showed that at a thickness of $\delta = 30$ m the least conditional cost of materials per 1 m² of the wall, takes place at the panels of external walls of a porous haydite concrete at a quartz sand. At the same time, as mentioned earlier, a minimal attenuation of the heat flow is achieved. To assess the economic efficiency of a single-layer structure external wall panel defined a conditional cost of materials per 1 m² of the wall, at the same wall the heat flow attenuation was equal $V = 39.3$, which corresponds the best experimental value (Table 6).

The data of Table 6 show that for haydite concrete on quartz sand the required wall thickness was $\delta = 0.383$ m, for haydite foam concrete $\delta = 0.30$ m and for haydite concrete on haydite sand $\delta = 0.315$ m. At the same time, due to a change in the thermal conductivity and the heat build-up index, $S = 5.28$ W/m °C, despite the increase in the thickness of the wall, the massiveness values differ insignificantly.

Thus, to ensure a high value of the heat flow attenuation in the wall with a wall thickness of $\delta = 0.3$ m, haydite concrete of the merged structure, porous or plasticized (composition No. 5 with a reduced consumption of haydite sand with a plasticizer). Porous while mixing, haydite concrete on quartz sand also provides $V = 39.9$ at wall thickness $\delta = 0.383$ m.

Comparing the cost of materials per 1 m² of the wall surface, it can be seen that the maximum cost is achieved with haydite concrete, porous at haydite sand. However, the different value of the cost of haydite concrete, porous by foam, is insignificant. Therefore, the choice of structure is determined by other factors of local importance.

The gained attenuation of the heat flow along the wall thickness $\delta = 0.30$ m at the investigated haydite concrete structures allows to reduce temperatures of the inner surface of the wall in more than 1.5 times as compared to the level currently achieved in practice for the production of external wall panels in conditions of a hot climate.

However, it can be argued that it is more rational to increase the resistance to heat transfer of the wall not by its thickening, but by improving the technological process for the production of haydite concrete. It will make it possible to obtain the minimum coefficient of thermal conductivity of the material and, possibly, a rapid evaporation of moisture from it.

In modern conditions, an increase in the heat resistance of walls made of lightweight concrete is possible due to the use of a lower density of a haydite concrete, the use of highly effective thermal liners and air layers, as well as fine porous aggregates instead of quartz sand and the porosity of haydite concrete. The introduction

Table 6. Comparison of the criteria of a lightweight single-layer panel wall construction of equal heat flow attenuation

No. of composition	Thermal resistance R , m ² °C/W	Estimated coefficient of heat absorption S , W/m ² °C	Thermal inertia D	Thickness δ , m	Cost of materials per 1 m ² of the wall, rub
I	0.968	4.80	4.65	0.303	9.50
5	0.970	4.77	4.63	0.300	9.00
9	0.656	7.51	4.92	0.383	8.98
10	0.900	5.28	4.75	0.315	11.47

Table 7. Estimated coefficients of thermal conductivity of haydite concrete

Density in a dry condition ρ , kg/m ³	Thermal conductivity, W/m°			
	Wet λ_w	Dry λ_0	SNiP II-3-79**	
			λ_0	λ_A
700	0.230	0.157	0.19	0.22
750	0.255	0.165	0.195	0.275
800	0.283	0.194	0.21	0.24
850	0.312	0.209	0.231	0.26
900	0.339	0.224	0.24	0.285
950	0.349	0.243	0.255	0.305
1000	0.360	0.262	0.27	0.33

of new materials in construction is impossible without knowledge of their thermophysical characteristics. In addition, the coefficient of thermal conductivity of building materials — a variable value, which depends on humidity, temperature, bulk weight and components of the material (Table 7).

The results of the experiment confirmed the correctness of the proposed technique for developing a prescription and technological regulation for the production of lightweight concrete for walls that provide the greatest attenuation of the heat flow and a decrease in the amplitude of the variation in the temperature of the internal surface, which makes it possible to improve the thermal regime of residential premises under summer overheating. The amplitude of the internal-temperature fluctuation not exceeding 1.5 °C is considered satisfactory, with an amplitude of the outside temperature fluctuation of about 25 °C.

Further increase of heat-resistance and heat-shielding qualities of panels can be achieved due to the rational use of wall screening [10].

CONCLUSIONS

1. The conducted researches in the field of design of external enclosing structures for hot climate conditions have shown that: single-layer external wall constructions with the massiveness of $D \leq 4$ provide minimum allowable values of heat flow attenuation and temperature fluctuation amplitude on the inner wall surface.

2. An improved composition of the structural and thermal insulation lightweight concrete for the load-bearing part of the structure, which ensures its high thermal stability due to the use of chemical additives and low consumption of porous sand, was developed.

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