Innovative Technologies in Development of Construction Industry

Edited by
Nikolai Ivanovich Vatin

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Preface

This Conference Proceedings volume contains the written versions of most of the contributions presented during the **scientific conference Week of Science in SPbSPU - Civil Engineering (SPbWOSCE 2014)**. Like in previous years, it took place in Saint-Petersburg, Russia.

December 3–4, 2014.

The Conference provided a setting for discussing recent developments in a wide variety of topics including Building constructions, buildings and structures; Foundations, underground structures; Heating, ventilation, air conditioning, gas supply and illumination; Water supply, sewerage, construction of water-resources conservation; Building materials and construction products; Strength of materials; Hydraulic engineering work; Building technology and organization; Roads, bridges and tunnels; Fluid mechanics and engineering hydrology; Structural mechanics; Environmental safety of civil engineering and municipal facilities; Architecture and urban planning; Green buildings, energy efficiency and sustainable development; Management in science and education in the field of Civil and Construction Engineering.

The Conference has been a good opportunity for participants coming from all over the world to present and discuss topics in their respective research areas.

We would like to thank all participants for their contributions to the Conference program and for their contributions to these Proceedings. Many thanks go as well to the Russian participants for their support and hospitality, which allowed all foreign participants to feel more at home.

We are looking forward to the **next scientific conference Week of Science in SPbSPU - Civil Engineering (SPbWOSCE 2015)** that will be held on December 2–3, 2015 at the same location. We hope that it will be an interesting and enjoying at least as all of its predecessors.

The Scientific committee.

Scientific conference
Week of Science in SPbSPU - Civil Engineering
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Jovanovski M.	PhD, professor, Dean of the Faculty of Civil Engineering	Skopje Ss. Cyril and Methodius University in Skopje jovanovski@gf.ukim.edu.mk	Macedonia
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Korsun A.V.	Prof. Ph.D.	Donbas National Academy of Civil Engineering and Architecture korsun_av@mail.ru	Ukraine
Lalin V.V.	D.Sc., professor, chief of department	Saint-Petersburg State Polytechnical University lalin@cef.spbstu.ru	Russia
Leonovich S.N.	Head of the Construction Technology Department, D.Sc., Professor	Belarusian National Technical University sleonovich@mail.ru	Belarus
Melnikov B.E.	D.Sc., professor, chief of department	Saint-Petersburg State Polytechnical University melnikovboris@mail.ru	Russia
Morozov V.I.	D.Sc., professor	St. Petersburg State University of Architecture and Civil Engineering morozov@spbgasu.ru	Russia
Mushchanov V.Ph.	Vice-Rector for Research, Head of the Theoretical and Applied Mechanics Department, D.Sc., professor	Donbas National Academy of Civil Engineering and Architecture volodymyr.mushchanov@mail.ru	Ukraine
Najdanovic D.	PhD, ass. professor, Dean of the Faculty of Civil Engineering	Belgrade University of Belgrade dusnaj@gmail.com	Serbia
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Petrichenko M.R.	D.Sc., professor, chief of department	Saint-Petersburg State Polytechnical University fonpetrich@mail.ru	Russia

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Žegarac Leskovar V.	Assit. Prof., Dr.	University of Maribor Faculty of Civil Engineering Department of Architecture vesna.zegarac@um.si	Slovenia

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Conference proceeding editor

Vatin N.I.	D.Sc., professor, director of Civil Engineering Institute	Saint-Petersburg State Polytechnical University director@ice.spbstu.ru	Russia

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CHAPTER 1:

Buildings and Structures

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The Brickwork Joints Effect On The Thermotechnical Uniformity Of The Exterior Walls From Gas-Concrete Blocks

Alexander Gorshkov[1, a] Nikolai Vatin[2,b], Darya Nemova[3,c], Darya Tarasova[4,d *]

[1,2,3,4]St. Petersburg State Polytechnical University, Polytechnicheskaya st. 29, 195251, St. Petersburg, Russia

[a]alsgor@yandex.ru, [b]vatin@mail.ru, [c]darya.nemova@gmail.com, [d]tarasovads@gmail.com

Keywords: Thermal conductivity, gas-concrete masonry, enclosure structures, mortar joints, thermotechnical uniformity, gas-concrete blocks.

Abstract. In the article the brickwork joints effect on the thermotechnical uniformity parameters of the walls of gas-concrete blocks are considered. The additional thermal energy losses through joint masonry are calculated.

The recommendations to reduce the brickwork joints effect on thermotechnical uniformity of external enclosure structures are offered.

Introduction

The blockwork of gas-concrete blocks is currently one of the most common building technologies on the Russian Federation territory. The gas-concrete masonry apply in construction of bearing, self-bearing and nonbearing enclosure structures of modern buildings such as high-rise building and low storey house as well as during installation of precast-monolithic slabs [1].

The autoclaved gas-concrete products have a relatively small thermal conductivity compared with other types of structural thermal insulation products [2-10]. It determines their high efficiency to meet the requirements for insulation of external walls. The estimate thermotechnical indicators of cell concrete of autoclave curing for some grade of product density are presented in table 1.

Table 1 - The estimate thermotechnical indicators of cell concrete of autoclave curing.

Materials	The characteristics of the material in the dry state			The estimated coefficients (with conditions) of			
	Density ρ_0, [kg/m^3]	Heat capacity c_0, [kJ/kg·°C]	Coefficient of heat conductivity λ_0, [W/m·°C]	the mass relation of moisture in a material ω, [%]		heat conductivity λ, [W/m·°C]	
				A	B	A	B
Cell concrete of autoclave curing	600	0.84	0.14	4	5	0.160	0.183
	500	0.84	0.12	4	5	0.141	0.147
	400	0.84	0.096	4	5	0.113	0.117
	300	0.84	0.072	4	5	0.084	0.088

It is known that the joints of masonry of buildings external enclosure structures are heat-conducting inclusions. In most cases the effect of seams on the above heat transmission resistance of the walls is not taken into account. In the actual values of the resistances to heat transfer may not coincide with the calculated. It affects the parameters of the energy efficiency of buildings [21-29].

However the wall construction of small piece gas-concrete products (blocks) requires the use of cement mortars to fasten blocks in the masonry with each other. As such solutions are used cement-sand mortar or thin cement glue. Because of the presence of cement joints in the masonry the so-called "cold bridges" are formed [11-20]. This is due to the fact that the thermal conductivity of cement mortar used for bonding the blocks in the masonry significantly higher than the thermal conductivity of cell concrete with grade of density D300 and D600.

The calculation of thermotechnical uniformity coefficients of the masonry with open joints

We will consider the mortar joints influence of masonry on the thermotechnical uniformity parameters of the walls of gas-concrete blocks.

To calculate we will accept the regular repetitive fragment of masonry walls made from concrete blocks (Fig. 1). Thickness of the considered fragment is 375 mm. The sizes of blocks of a masonry: length is 625 mm, width is 375 mm, height is 250 mm. The grade of blocks density is D400, heat conductivity coefficient for service conditions is B, λ_B=0.117 W/m · ºC according to GOST 31359.

Consider the following options of blockwork:

1. blockwork on glue with an average thickness of horizontal and vertical joints of masonry 2 mm (Fig. 1);
2. blockwork on mortar with an average thickness of horizontal and vertical joints of masonry 10 mm (Fig. 2).

The calculation of the thermal resistance of the regular fragment of wall structure will make by the method of conductivity addition.

The blockwork on glue. We will allocate a blockwork fragment and will divide it into segments with various conductivity by planes that parallel to a thermal stream. We receive two uniform and identical segments with the following parameters (Eq. 1, Eq. 2):

$$R_{g.c.} = \frac{\delta_{g.c.}}{\lambda_{g.c.}} = \frac{0.375}{0.117} = 3.21\,(m^2 \cdot {}^{\circ}C / W) \tag{1}$$

$A_{g.c.} = 1.25 \cdot 0.5 = 0.625\,(m^2)$

$$R_{p-p} = \frac{\delta_{p-p}}{\lambda_{p-p}} = \frac{0.375}{0.93} = 0.40\,(m^2 \cdot {}^{\circ}C / W) \tag{2}$$

$A_{p-p} = 1.254 \cdot 0.002 \cdot 2 + 0.504 \cdot 0.002 \cdot 2 = 0.007\,(m^2)$.

We determine the thermal resistance of all regular fragments (Eq. 3):

$$R^r = \frac{\sum_{i=1}^{m} A_i}{\sum_{i=1}^{m} \frac{A_i}{R_i}} = \frac{0.625 + 0.007}{\frac{0.625}{3.21} + \frac{0.007}{0.4}} = 2.98\,(m^2 \cdot {}^{\circ}C / W) \tag{3}$$

The coefficient thermotechnical uniformity of masonry with regard to joint:

$$r = \frac{R^r}{R_{г.б.}} = \frac{2.98}{3.21} = 0.93$$

It means that additional thermal energy losses through joint masonry are equal 7%.

The blockwork on mortar. We will make similar calculation for a regular fragment B (Eq. 4, Eq. 5):

$$R_{g.c.} = \frac{\delta_{g.c.}}{\lambda_{g.c.}} = \frac{0.375}{0.117} = 3.21\,(m^2 \cdot {}^{\circ}C / W) \tag{4}$$

$A_{g.c.} = 1.25 \cdot 0.5 = 0.625\,(m^2)$

$$R_{p-p} = \frac{\delta_{p-p}}{\lambda_{p-p}} = \frac{0.375}{0.93} = 0.40\,(m^2 \cdot {}^{\circ}C / W) \tag{5}$$

$A_{p-p} = 1.27 \cdot 0.01 \cdot 2 + 0.52 \cdot 0.01 \cdot 2 = 0.036\,(m^2)$

Thermal resistance of all regular fragments:

$$R^r = \frac{\sum_{i=1}^{m} A_i}{\sum_{i=1}^{m} \frac{A_i}{R_i}} = \frac{0.625 + 0.036}{\frac{0.625}{3.21} + \frac{0.036}{0.4}} = 2.34\ (m^2 \cdot {}^\circ C / W)$$

The coefficient thermotechnical uniformity of masonry with regard to joint:

$$r = \frac{R^r}{R_{г.б.}} = \frac{2.34}{3.21} = 0.73.$$

It means that additional thermal energy losses through joint masonry are equal 27%.

Because of additional energy losses it is necessary to increase the rated capacity of the heating system and to increase of thermal energy consumption in the building for heating.

Table 2 shows the estimated coefficients of thermal homogeneity r for some types of masonry walls made of concrete blocks with different thickness of the mortar joints in the masonry.

Table 2 - Values of the thermal homogeneity coefficient for some types of masonry walls with solid wall unreinforced of products from cellular concrete autoclaved with the size of the product in the masonry 625×250 mm

Mark blocks on the density	The thickness of masonry joints	The coefficient of thermal homogeneity of the masonry r with an estimated coefficient of thermal conductivity of a solution λp-p, [W/m · ºC]								
		0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
D300	2 mm	0.99	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.90
	10 mm	0.94	0.88	0.84	0.80	0.76	0.73	0.70	0.67	0.64
D400	2 mm	099	0.98	0.97	0.96	0.96	0.95	0.94	0.93	0.92
	10 mm	0.96	0.92	0.88	0.85	0.82	0.79	0.76	0.73	0.71
D500	2 mm	0.99	0.99	0.98	0.97	0.97	0.96	0.95	0.94	0.94
	10 mm	0.98	0.95	0.91	0.88	0.86	0.83	0.80	0.78	0.76
D600	2 mm	1.00	0.99	0.99	0.98	0.98	0.97	0.96	0.95	0.95
	10 mm	0.99	0.97	0.94	0.91	0.89	0.87	0.84	0.82	0.80
D700	2 mm	1.00	1.00	0.99	0.98	0.98	0.97	0.97	0.96	0.96
	10 mm	1.00	0.98	0.95	0.93	0.91	0.89	0.87	0.85	0.83
Note - the values of the coefficient of thermal homogeneity at intermediate values of the weld thickness and the thermal conductivity of masonry mortar is allowed to take on interpolation or calculated using the above methodology.										

Because of laying joint the thermotechnical uniformity of walls from gas-concrete blocks is broken, the coefficient of thermotechnical uniformity of a laying becomes other than unit. Besides than joints are thicker and the heat conductivity of masonry structure is higher than a coefficient r is less and the specified heat transmission resistance of a wall fragment is smaller.

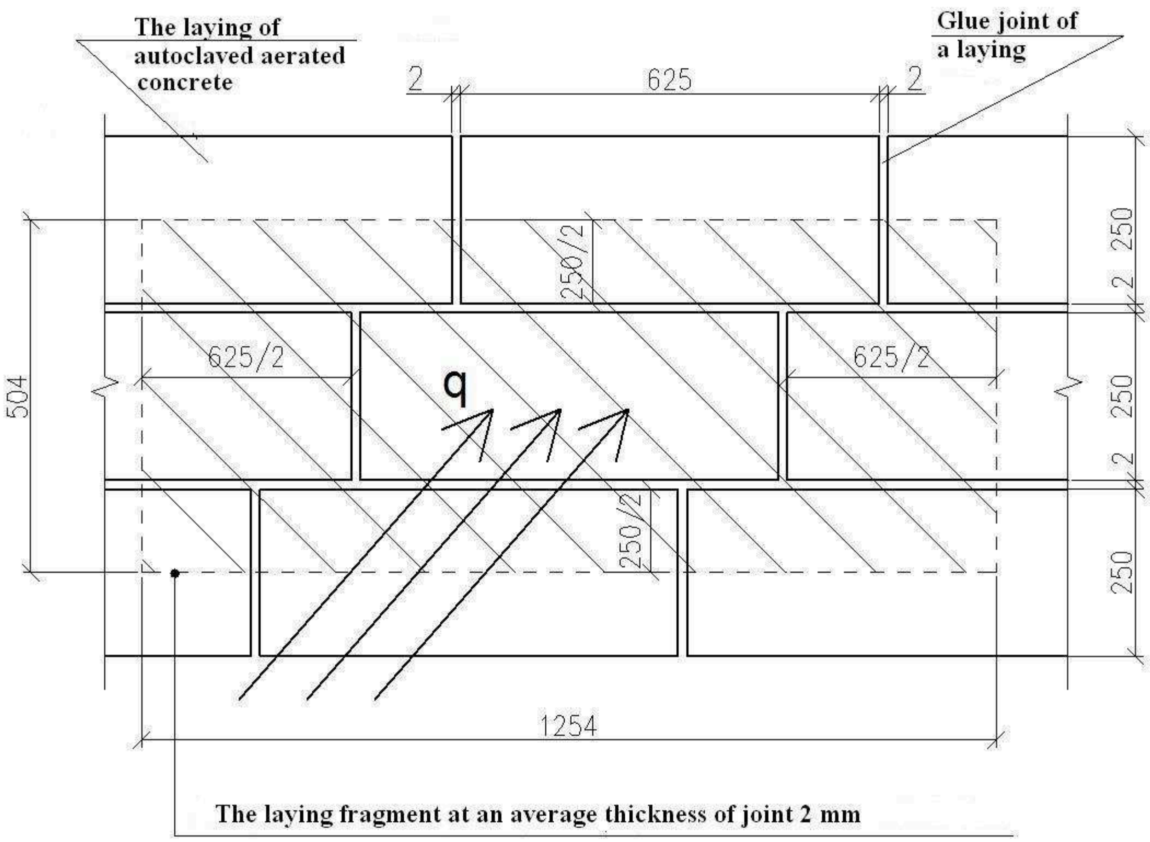

Figure 1. The blockwork on glue with an average thickness of horizontal and vertical joints of masonry 2 mm

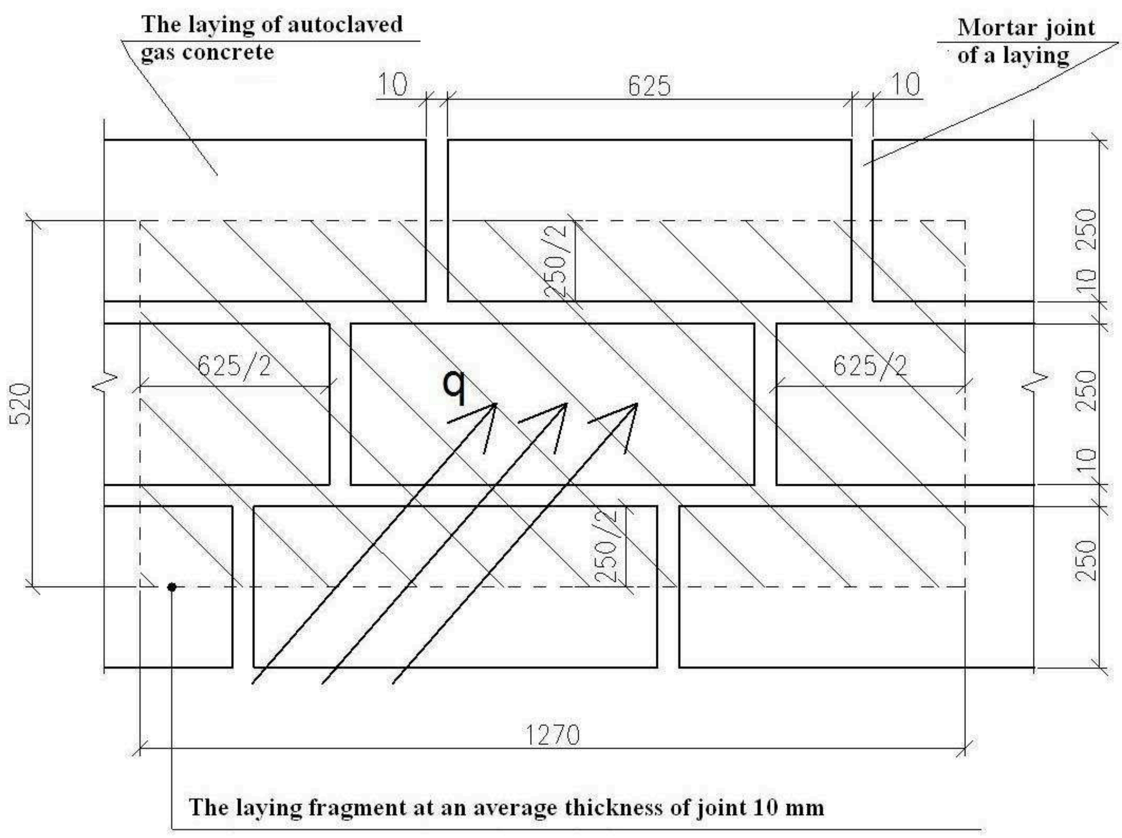

Figure 2. The blockwork on mortar with an average thickness of horizontal and vertical joints of masonry 10 mm

Resume

Because of laying joint the thermotechnical uniformity of walls from gas-concrete blocks is broken, the coefficient of thermotechnical uniformity of a laying becomes other than unit. Besides than joints are thicker and the heat conductivity of masonry structure is higher than a coefficient r is less and the specified heat transmission resistance of a wall fragment is smaller.

The polyurethane glues can be recommended to reduce the brickwork joints effect on thermotechnical uniformity of external nonbearing enclosure structures.

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Calculation method of justification of technical actions for prevention of ice dams formation on buildings with a pitched roof

Nikolay Vatin[1, a]; Aleksandr Gorshkov[2, b]; Darya Nemova[3,c] ; Aydos Urustimov[4,d] ; Anastasiia Staritcyna[5,e *] and Pavel Ryimkevich[6,f]

[1,2,3,4,5]Saint-Petersburg State Polytechnical University, St.Petersburg, 195251,Russian Federation
[6]Mozhaisky Military Space Academy, St.Petersburg, 197082, Russian Federation

[a]vatin@mail.ru, [b]alsgor@yandex.ru, [c]darya.nemova@gmail.com, [d]aidos_urustimov@mail.ru, [e*]a.staritsyna@mail.ru, [f]rymkewitch@yandex.ru

Keywords: energy efficiency, heat balance equation, cold attic, roof covering, icicle.

Abstract. The article presents the methodology of thermal balance equation generation for cold attics. This methodology is aimed to provide the scientific basis for engineer activities to prevent the ice hillock building-up on roofs during the periods of the lowest temperature of outside air. The complex of actions that leads to reduction of damages from buildings of thermal energy is listed, heating up to improvement of parameters of a microclimate in the operated rooms of the top floors of buildings. For realization of these actions any materials and technologies providing the necessary level of thermal isolation for the concrete building and satisfying to the fire-prevention and sanitary and hygienic requirements existing in the territory of the Russian Federation are used.

Introduction

When snow collects on a roof, there is a thawing and refreezing cycle. In an ideal, snow would thaw from a roof, water would go to ditches, and to the earth. However, interaction of two key factors generates a problem - it is the external temperature and temperature of internal part of an attic.

Than more warmly on an attic, especially more intensively snow melts on a roof surface. This thawed snow usually flows down from the roof edge. Nevertheless, under certain conditions, when air temperature is very low, this water freezes on the edge of a roof where the internal surface of a roof doesn't heat up an attic. This refreezing over and over again, gradually forms an ice dam.

Existence ice built-up on roofs of buildings after their mechanical removal in the course of cleaning and snow dumping from roofs often leads subsequently to leakages of a roofing covering. It is damaged as a result of shock influences by sharp metal subjects. Thus, absence ice built-up on roofs provides the best safety of a roofing covering after cleaning and snow dumping, increases operational service life of a covering, reduces probability of formation of leakages.

Problem review

In this work the problem of icicles formation on roofs of buildings and ways of fight against this negative phenomenon is considered. Especially considerably this problem is shown on garret roofs of buildings with a pitched roof. A number of the Russian [1-15] and foreign publications [16-22] are devoted to this problem and ways of its decision.

It should be noted that icicles are only visible part of this problem, which consists in formation on a roof of an ice dam. The ice dam (fig. 1) in the form of a crest of ice is usually formed on a roof parallel to the line of its eaves, prevents a descent of the thawing snow from a roof [23-28].

Insufficient thermal insulation and lack of appropriate ventilation of a garret, and also solar radiation at the end of winter, cause heating of a roofing covering to above-zero temperature and snow fusion above a dam while temperature on eaves remains lower than zero. In this case water flows down on a roof and collects behind a dam crest. Further ways of this saved-up water within intra daily fluctuation of external temperature: extension of a body of an ice dam, modulation or infiltration through a dam with formation of icicles, infiltration through a roofing covering in the form of leakages [29, 30].

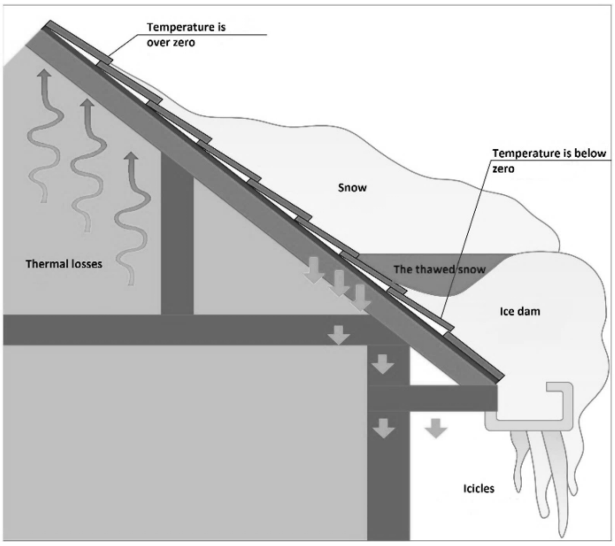

Fig. 1. Formation of an ice dam

The purpose of work is development of scientific and technical justification of specifications and the engineering actions providing prevention of ice build-up formation on buildings roofs with not heated attic during the periods of time with the lowest temperatures of external air.

Equation of thermal balance

The technique offered in work is based on drawing up the equation of thermal balance of garrets of the building. The scheme of balance of heat losses and heatreceipts of garrets of the building with a cold attic and a pitched roof is submitted in figure 2.

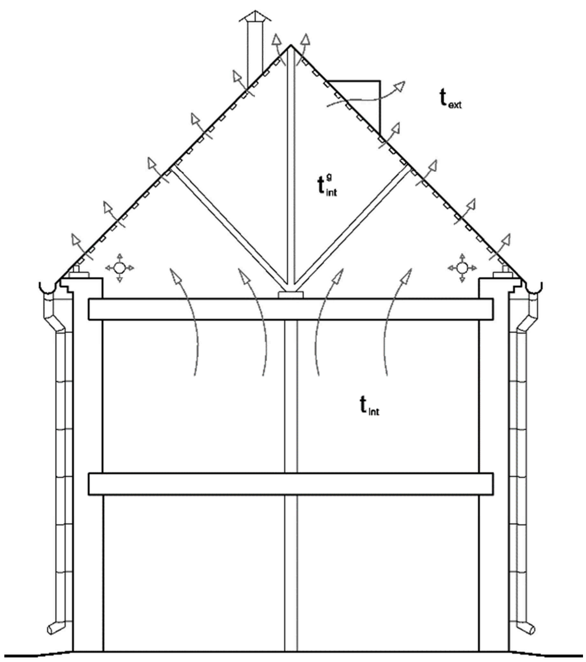

Fig. 2. Scheme of balance of heat losses and heatreceipts

From the presented scheme of thermal balance of rooms of a cold attic it is visible that heatreceipts in them are formed due to inflow of heat through garret overlapping of the top floor rooms of the operated building, and also at the expense of a thermolysis of the heating system pipelines laid on an attic [31]. Heat losses consist of heat losses through external protecting designs of an attic (walls and a covering) and heat losses due to ventilation of garrets by external air.

Analytically the scheme of thermal balance of garrets of the building can be expressed the following equation:

$$\left(t_{int} - t_{int}^{\bar{g}}\right) \cdot \sum_{i=1}^{n} \left(\frac{A_i^+}{R_i^+} \right) + \sum_{j=1}^{n} \left(q_{pj} \cdot l_{pj} \right) = \left(t_{int}^{\bar{g}} - t_{ext} \right) \cdot \sum_{k=1}^{n} \left(\frac{A_k^-}{R_k^-} \right) + 0,28 \cdot V_g \cdot n_{\alpha} \cdot t_{ext}, \quad (1)$$

t_{int} – temperature of internal air in the top floor rooms of the building, accepted according to requirements of GOST 30494 for residential and public buildings, GOST 12.1.005 for production buildings, °C, or defined in the course of natural measurements of parameters of a microclimate in rooms of the building;

t_{ext} – temperature of external air, °C, accepted for the respective settlement on the average temperature of the coldest five-day week with security 0,92 according to Construction Norms and Regulations 23-01;

$t_{int}^{\bar{g}}$ – air temperature in rooms of a cold attic of the building, ºC;

A_i^+, R_i^+ – the area, sq.m and the specified resistance to a heat transfer, sq.m • °C/W, protections between rooms heated in the building and rooms of a cold attic (garret overlapping, partitions between garrets and rooms of ladder marches, etc.);

q_{pj} – the linear density of a thermal stream through the thermal insulation surface, falling on 1 linear meter of length of the pipeline of a certain diameter taking into account heat losses through the isolated support, flange connections and fittings, W/m (for attics and cellars of q_{pj} value depending on the nominal diameter of the pipeline and the average temperature of the heat carrier are provided in the tab. of 12 construction regulations 23–101);

l_{pj} – length of the pipeline of a certain diameter, m (for the operated buildings is accepted according to actual data);

A_k^-, R_k^- – the area, sq.m, and the specified resistance to a heat transfer, sq.m • °C/W, a site of external enclosing structures of garrets (a covering, external walls, fillings of window apertures in the presence);

V_g – the volume of the air filling space of a cold attic, m^3;

n_α – frequency rate of air exchange in rooms of a cold attic, h^{-1}.

The left member of equation (1) shows total quantity of the thermal energy coming to rooms of a cold attic, the right part - losses of thermal energy through the external enclosing structures, and due to ventilation of garret space external air.

Condition of prevention of formation ice built-up on roofs of buildings with a cold attic in the period of the lowest temperatures of external air is the requirement according to which air temperature in garrets shouldn't more, than on 4 ºC to exceed temperature of external air.

In 2–4 ºC generally it appears differences of temperatures insufficiently for a warming up of the bottom layer of the snow cover lying on a roofing covering. Analytically this condition can be expressed in the following look:

$$t_{int}^{\bar{g}} - t_{ext} \le 4\,^{o}C, \quad (2)$$

$t_{int}^{\overline{g}}$, t_{ext} – the same, as in the equation (1).

The climate of St. Petersburg during the heating period of operation is characterized by considerable dispersion of temperatures of external air. For climatic conditions of St. Petersburg the air temperature of the coldest five-day week with security 0,92 makes 26 °C lower than zero.

Performance of a condition (2) at a temperature of external air of 26 °C lower than zero automatically means performance of a condition (2) at more high temperatures of external air (that is at $t_{ext}\geq$ 26 °C lower than zero).

From the equation (1) it is possible to calculate air temperature in a cold attic of the building:

$$t_{int}^{g} = \frac{t_{int}\cdot\sum_{i=1}^{n}\left(\frac{A_i^{+}}{R_i^{+}}\right)+t_{ext}\cdot\sum_{k=1}^{n}\left(\frac{A_k^{-}}{R_k^{-}}\right)+\sum_{j=1}^{n}\left(q_{pj}\cdot l_{pj}\right)-0,28\cdot V_g\cdot n_{\alpha}\cdot t_{ext}}{\sum_{i=1}^{n}\left(\frac{A_i^{+}}{R_i^{+}}\right)+\sum_{k=1}^{n}\left(\frac{A_k^{-}}{R_k^{-}}\right)}, \quad (3)$$

All designations in the equation (3) same, as in the equation (1).

The analysis of expressions (1) and (3) allows to make the following conclusions. To reduce a thermal stream through the external enclosing structures of a cold attic rooms it is necessary to reduce air temperature on an attic. At preset values of temperatures external (t_{ext}) and internal (t_{int}) air, the invariable geometrical sizes of the enclosing structures of a cold attic (A_i^{+}, A_k^{-}, V_g) and the constant length of pipelines of systems of heating and hot water supply (l_{pj}), decrease in air temperature in rooms of a cold attic is provided with reduction of heatreceipts.

It is possible to achieve reduction of heatreceipts to rooms of a cold attic the following engineering actions:

- warming of garret overlapping (increase sizes R_i^{+});
- thermal insulation of pipelines of systems of heating and hot water supply (reduction of size q_{pj});
- increase in air exchange in garrets (increase n_{α} in value).

Resume

The listed above actions for prevention of formation of ice dams and ice built-up (icicles) on the eaves of a roof are rather well-known. The listed above actions for prevention of formation of ice dams and ice built up (icicles) on the eaves of a roof are rather well-known. Advantage of the offered calculation method consists in exact determination of the demanded heater thickness for isolation of pipelines and warming of garret overlappings. Heating of garret overlapping reduces inflow of heat from rooms of the top operated building floor, isolation of pipelines reduces their thermolysis. Thus the amount of heat arriving on an attic decreases. Respectively, on an attic air temperature decreases. At a certain thickness of a layer of a heater which can be calculated on the equation of thermal balance, such decrease in air temperature in garret space (t_{int}^{g}) is reached at which energy of a thermal stream becomes insufficiently for a warming up of a cover of the snow lying on a roofing covering of the building. If snow on a roof doesn't thaw over rooms of an attic, won't be formed ice built-up on the eaves of a roofing covering. It should be noted that only at simultaneous performance of the listed above actions the positive result from their introduction can be reached. Heating only of garret overlapping without the corresponding isolation of pipelines can lead to defrosting of the heating system laid on an attic.

Besides a solution of the problem of formation ice built-up on buildings roofs with a cold attic, the listed complex of actions leads to reduction of losses by buildings of thermal energy by heating, to improvement of microclimate parameters in the operated rooms of the top floors of buildings. For realization of these actions any materials and technologies providing the necessary level of thermal insulation for the concrete building, and satisfying to the fire-prevention and sanitary and hygienic requirements existing in the territory of the Russian Federation can be used.

The analysis of a formula (3) leads also to other important conclusion. Air temperature (t_{int}^{g}) increases in garrets at increase in resistance to a heat transfer of the external enclosing structures of a cold attic (R_k^-), for example a roofing covering. It automatically leads to violation of a condition (2). Thereby conditions for formation of ice built-up on a roofing covering are created. The snow layer of a certain thickness on a roofing covering increases its resistance to a heat transfer R_k^- that is a counterbalance for actions for prevention of formation ice built-up on roofs of buildings. It means that one of conditions of prevention of formation ice built-up on roofs is periodic cleaning of snow from roofing coverings of buildings with a cold attic. It is necessary to clean snow from roofing coverings of buildings anyway, even at cumulative realization of the actions offered above.

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Fire Resistance of Non-Crack Resistant Flexural Reinforced Concrete Elements

Vyacheslav Belov[1,a], Valery Morozov[2,b*]

[1]Research and Design Institute "GI VNIPIET", ROSATOM State Nuclear Energy Corporation, Vtoraja Sovetskaja ul. 9/2a, St. Petersburg, 191036, Russia

[2]Saint Petersburg State University of Architecture and Civil Engineering, Vtoraja Krasnoarmejskaja ul. 4, St. Petersburg, 190005, Russia,

[a]v_belov@to.spbaep.ru, [b]morozov@spbgasu.ru

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Abstract. In developed countries only loss of property because of fire makes annually up to 2 % of their national income. The bearing capacity of reinforced concrete structures at high temperature impact is lost within several dozens of minutes. Disappointing statistics of increase of both the number of fires and the scope of damage due to them aggravates the actual problem of determination of reinforced concrete structures fire-endurance. The main problems and methods of evaluation of reinforced concrete structure fire resistance are stated. Within the framework of block approach to evaluation of strain of flexural reinforced concrete elements with cracks, design model of reinforced concrete thermo-force resistance is made. Extended nomenclature of influences of high temperature at fire on decrease of performance of bearing reinforced concrete structures is considered. Empirical dependencies of strength and strain characteristics of concrete and reinforcement on high temperatures are used. Proposals on specification of evaluation of fire resistance of statically indeterminate reinforced concrete structures are formulated.

Introduction

The norms of designing concrete and reinforced concrete structures in evaluation of reinforced concrete fire resistance go behind the needs of construction practice (see, for example, [1–15]). That said using the notion of operational integrity of building structures, the acting normatives directly define only the conditions of design section strength. Thus, the functional failure of structural system is identified with life-limiting failure of its individual components (parts) [16, 17]. Such situation simplification does not guarantee provision of structural safety. From the points of view of reliability theory, the probability of occurrence of structural system limit state C in simplified form is evaluated as

$$P(C) = P(C \mid L) \bullet P(L \mid E) \bullet P(E), \tag{1}$$

where P(E) is probability of implementation of initiating event E,
$P(L \mid E)$ is probability of local failure L at implementation of E,
$P(C \mid L)$ is probability C at implementation of L.
But $P(C \mid L)$ factor is not considered in verification procedures of acting norms.

Substantial specificity here is brought by non-stationary temperature strains. Besides, design models of section rated limit states are taken apriori and without consideration of the background of their straining, not always "for reserve".

Main Part

Fire resistance of building structures is determined by experimental and design methods. That's why, their harmonious combination is necessary. In general, design methods contain thermotechnical part [18–20] and statical part whose aim is to determine the structure bearing capacity [2, 5, 21, 22].

Results of complex analysis of experimental and theoretical studies of change of characteristics of concrete, reinforcement and their contact collaboration, strength and rigidity of flexural reinforced concrete elements under the influence of fire are presented in the article.

Divergent model of resistance and method of evaluation of operation and limit states at fire for reinforced concrete elements of various profiles with cracks is proposed. Within the framework of the approach proposed, the following stages of element strain are marked:

- stage I ($0 \le M \le M_{crc}$) is initial stage progressing with keeping concrete macrosoundness;
- stage Ia (Mcrc<M≤M0) corresponds to the phase of formation of stabilized system of normal macrocracks;
- stage II (M0<M≤M00) is the operational one and is featured with balanced development of earlier formed quasiregular system of normal cracks;
- stage III (M= Mres, Mres→0) of postbuckling behaviour with formation of quasiperfectlink

Stage completion criteria (element divergence):

– $\varepsilon_s = \varepsilon_{suT}$ (break of stretched reinforcement),
where ε_{suT} is limit resistance to stretching of reinforcement at high temperatures;
and/or
– $N_{sc} = N_{sc,cr}$ (loss of stability of compressed reinforcing belt),
where $N_{sc,cr}$ is critical force for compressed reinforcement;
and/or
– $N_b = N_{b,cr}$ (loss of stability of element compressed zone),
where $N_{b,cr}$ is critical force for element compressed zone;
N_b is resultant of concrete compressing stresses.

Problem-oriented option of strain block model [23, 24] is used. Flat shape of bend is kept at one-, two-, three- and four-sided fire effect. [20]. The problem of determination of element stress and strain state amounts to task solution for symmetrical half of individual block with length *L*.

$$\Sigma N=0;\ \int_{-B/2}^{B/2}\int_{0}^{x}\sigma_b(\varepsilon)dydz + E_s\cdot A_{sc}\cdot\varepsilon_b\cdot\frac{x-a`}{x} = E_s\cdot A_s\cdot\varepsilon_s; \tag{2}$$

$$\Sigma M=M;\ M=\int_{-B/2}^{B/2}\int_{0}^{x}\sigma_b(\varepsilon)zdydz + E_s\cdot A_{sc}\cdot\varepsilon_b\cdot a`\cdot\frac{x-a`}{x} + E_s\cdot A_s\cdot\varepsilon_s\cdot(H-a); \tag{3}$$

strain compatibility condition:

$$\frac{U_b}{U_s}=\frac{x}{H-a-x};\ \frac{(1+\alpha_E\cdot\mu)\cdot[\varepsilon_{bm}+(\varepsilon_b-\varepsilon_{bm})\cdot\omega_b]\cdot L}{\frac{a_{crc,a}}{2}+\alpha_E\cdot\mu\cdot\varepsilon_b\cdot L}=\frac{x}{H-a-x}, \tag{4}$$

where $\alpha_E=\frac{E_s}{E_b}$ is modular ratio; $\omega_b=\frac{\varepsilon_b}{\varepsilon_{bR}}$ is stress diagram fullness ratio ε_b by block length; $\mu=\frac{A_S}{B\cdot H}\cdot\left(1+\frac{z_s^2}{r_y^2}\right)$ is reinforcement ratio considering eccentric position of bars; $r_y=\sqrt{\frac{I_y}{A_B}}$ is inertia radius; A_b=BxH.

$$\Sigma N=0;\ \int_{-B/2}^{B/2}\int_{0}^{H-2a}\sigma_{bm}(\varepsilon_{bm})dydz + E_s\cdot A_{sc}\cdot\varepsilon_{bm}\cdot\frac{x_m-a`}{x_m} = E_s\cdot A_s\cdot\varepsilon_{sm}; \tag{5}$$

$$\Sigma M=M_0; \tag{6}$$

$$M_0=\int_{-B/2}^{B/2}\int_{0}^{H-2a}\sigma_{bm}(\varepsilon_{bm})zdydz + E_s\cdot A_{sc}\cdot\varepsilon_{bm}\cdot a`\cdot\frac{x_m-a`}{x_m} + E_s\cdot A_s\cdot\varepsilon_{sm}\cdot(H-a); \tag{7}$$

strain compatibility condition $\frac{\varepsilon_{bm}}{\varepsilon_{sm}} = \frac{x_m}{H-a-x_m}$; (8)

"reinforcement-concrete" contact $y = -0.5$ h+a;

strain compatibility condition:

$$\left(1+\alpha_E \cdot \mu\right)\varepsilon_{sm} = \alpha_E \cdot \mu \cdot \varepsilon_s + \sqrt{\varepsilon_s^2 - \frac{2\left(1+\alpha_E \cdot \mu\right)}{1+\alpha} \cdot \frac{\pi_s}{A_s} \cdot \frac{\tau_{\max}}{E_s} \cdot g \cdot \left(\frac{g}{g_R}\right)^{\alpha}}, \quad (9)$$

where π_s is perimeter of reinforcement section; $g = \frac{1}{2} \cdot a_{crc}$ is shift of reinforcement with respect to concrete hooping; $g_R = 0{,}15\ C_0$ is shift at reaching the limit of bond strength; C_0 [mm] is pitch of corrugation of reinforcement bar with diameter d_s ; $\alpha = 0.3$.

$$N_s - N_{sm} = \int_0^{L_0} \tau_{bond}\,dx = \tau_{\max} \cdot \left(\frac{g}{g_R}\right)^{\alpha} \cdot L \cdot \omega_\tau; \quad (10)$$

$$\frac{d_s}{4} \cdot E_s \cdot \left(1+\alpha_E \cdot \mu\right) \cdot \left(\varepsilon_s - \varepsilon_{sm}\right)^2 = \tau_{\max} \cdot \left(\frac{g}{g_R}\right)^{\alpha} \cdot \left[\frac{g}{L} + \alpha_E \cdot \mu \cdot \varepsilon_s - \left(1+\alpha_E \cdot \mu\right) \cdot \varepsilon_{sm}\right] \cdot L \quad (11)$$

Well-approved local bond law is used (see, for [25]). The main variables in equation resolving system are: height x of compressive zone of concrete, relative strains of the mostly compressed fabric of concrete ε_b and stretched reinforcement ε_s in section with crack $l=L$, and three similar parameters in middle section $l=0$ (x^m, $\varepsilon^m{}_b$, $\varepsilon^m{}_s$). Pitch of stabilization of normal cracks $l_{crc} = 2L_0$ is determined in assumption that stress diagram fullness ratio of bond tangential stresses ω_τ is equal to stress diagram fullness ratio of relative strains of reinforcement $\omega_s = \frac{\frac{g}{L_0} + \alpha_E \cdot \mu \cdot \varepsilon_s - \varepsilon_{sm} \cdot \left(1+\alpha_E \cdot \mu\right)}{\left(1+\alpha_E \cdot \mu\right) \cdot \left(\varepsilon_s - \varepsilon_{sm}\right)}$ At operational stage, at certain pitch of cracks $l_{crc} = 2L_0$, fullness ratio ω_τ is the sought value.

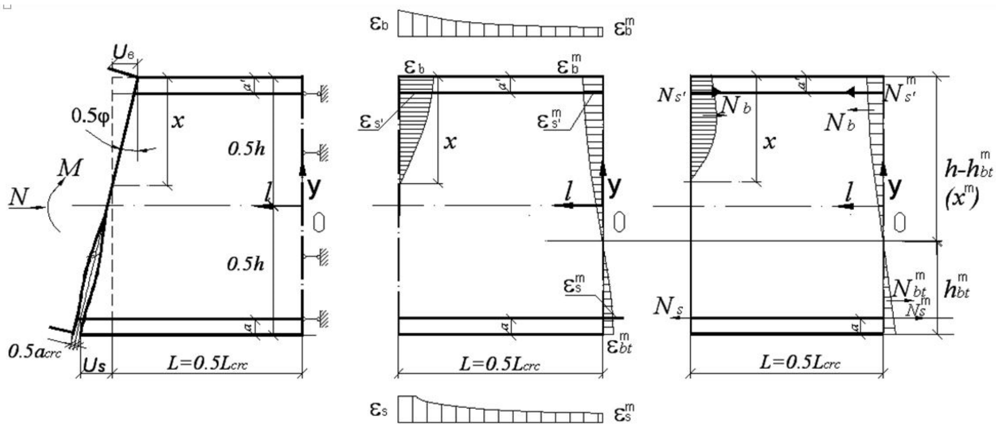

Figure 1. Design block with stress diagrams: 1) shifts, 2) relative strains, 3) internal forces

Work of concrete in single axis stress and strain state at impact of high temperatures is described by strain design diagram CEB-FIP.

Here concrete strain module depending on temperature is equal to $E_{bt} = E_b \cdot \beta_{b,t}$, where E_b is initial concrete strain module, $\beta_{b,t}$ is ratio considering concrete heating temperature influence. In accordance with [22]

$$\beta_{b,t} = \exp\left[-\beta_b \cdot \left(\frac{t_b - t_0}{1000}\right)^n\right], \tag{12}$$

is taken,

where t_0 is concrete monitoring temperature (t_0=200 ˚C); t_b is concrete temperature for the design moment of time; β_b Concrete strength decrease ratio $\gamma_{b,t}$ is also taken like in work [22]:

$$\gamma_{b,t} = \exp\left[-\gamma \cdot \left(\frac{t_b - t_0}{1000}\right)^m\right], \tag{13}$$

where γ, m are empirical parameters (γ=2.6, m=4 for heavy concrete on granite filling).

Relative strains of compressive and stretched concrete are summed up from force and temperature constituents:

$$\varepsilon_{b,tot} = \varepsilon_b + \varepsilon_{b,t} = \varepsilon_b + \alpha_{b,t}(t_b - t_0),\ \varepsilon_{bt,tot} = \varepsilon_{bt} + \varepsilon_{bt,t} = \varepsilon_{b,t} + \alpha_{bt}(t_b - t_0),$$

where α_{bt} is concrete temperature expansion ratio taken by [13]. For convenience of approximation, concrete temperature strains are expressed not via temperature expansion ratio, but as single dependency on the basis of premises similar to the ones accepted above:

$$\varepsilon_{b,t} = \varepsilon_a \cdot \left(1 - \exp\left[\frac{t_b - t_0}{1000}\right]^p\right), \tag{14}$$

where ε_a is limit value of temperature strains; p is empirical parameter (ε_a=2.3 %, p=2.5 for heavy concrete on granite filling).

Reinforcement elasticity modulus at high temperatures is equal to $E_{s,t} = E_s \cdot \beta_{s,t}$ where E_s is reinforcement elasticity modulus at normal operational conditions, $\beta_{s,t}$ is ratio considering reinforcement heating temperature influence taken by [13]. For keeping unity of dependencies, the following function is taken as basis by analogy:

$$\beta_{s,t} = \exp\left[-\beta_s \cdot \left(\frac{t_s - t_0}{1000}\right)^k\right] \tag{15}$$

Complicated physical processes at fire damages of "reinforcement-concrete" contact system are reflected by means of transformation of the local law of bond and decrease of active bond length.

Conclusions

The obtained parameters of stress and strain state of concrete and reinforcement within the limits of design block allow evaluating extended nomenclature of element limit states from methodologically uniform positions:

- reaching by stretching reinforcement in crack of yield strength $\varepsilon_s = \varepsilon_{s,el}$,
- exhaustion of bearing capacity of compressive concrete in section with crack, $\varepsilon_b = \varepsilon_{b,ul}$;
- spalling of concrete protective coating and loss of concrete-to-steel bond, $\beta = 1$;
- section layering with secondary longitudinal cracks, $\sigma_{spl} = R_{bt}$;
- excessive opening of normal crack, $a_{crc} = a_{crc,ul}$;
- excessive turning angle $\varphi = \varphi_{ul}$ and/or flexure $f = f_{ul}$.

The main advantages of resistance divergent model are:

- rejection of apriori definition of element destruction scheme; consideration of fire damage of concrete and reinforcement, including impact of damage irregularity at crack pitch; capability of determination of design and residual life of element; design provision of uniform fire-resistance of elements (due to provision of simultaneous occurrence of local limit states) and structure as a whole (by means of provision of equal life of its constituent elements); specified evaluation of bearing capacity of overreinforced elements: calculation of opening width of normal cracks at extended range of change of moments of flexure; substantiation of the necessity of fire protection use.

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Heat and Mass Transfer in Low-temperature Insulation in Moisture Conditions

Vyacheslav Polonnikov[1, a *] and Artem Habibulin[1, b]

[1]Tomsk Polytechnic University, Lenina av. 30, 634050, Tomsk, Russia

[a]polov@tpu.ru, [b]a.habibulin@mail.ru

Keywords: heat leakage, mathematical modeling, low-temperature insulation, phase transitions.

Abstract. The results of numerical simulation of heat and mass transfer in a low-temperature insulation in conditions of insulation freezing, a moisture migration to the front of phase transition and a condensation forming on an outer contour of interaction were obtained. Values of heat leakage were established.

Introduction

A protection of various low-temperature equipments (air conditioners, refrigerators, vessels of cryogenic liquids, etc.) from an environment exposure is an important problem [1, 2]. The one of features of a low-temperature insulation is a high probability of steam condensation on a surface or inside insulation and moisture freezing [3]. In this case, an accumulation of moisture at low-temperature insulation leads to a considerable increase of heat leakage [4].

Mathematical models and approaches to analysis of a low-temperature equipments thermal regimes [1, 2] are very simple. These models and approaches disregard a nonstationarity processes of heat and mass transfer, an insulation freezing, a condensation forming on an outer contour of interaction, etc. The aim of the present paper is a mathematical modeling of heat and mass transfer in a layer of low-temperature insulation in conditions of insulation freezing, a moisture migration to the front of phase transition and a condensation forming on an outer contour of interaction.

Problem statement

We consider a cylindrical layer of low-temperature insulation to be fixed to the surface of a metal pipe. A scheme of solution domain is shown in Figure 1. For the domain under consideration (Fig. 1) we solve a 1D non-linear and non-stationary problem of heat and mass transfer in a layer of low-temperature insulation in conditions of phase transitions and the dependence of insulation properties from volume concentrations of water and ice.

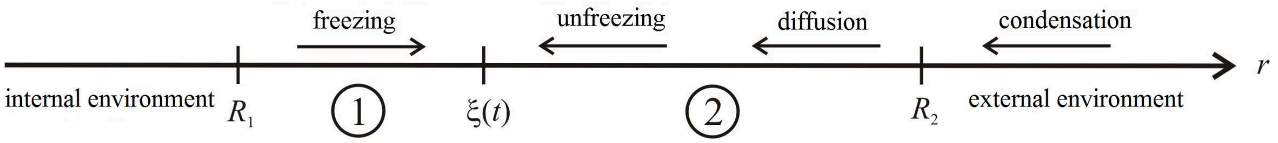

Figure 1. A scheme of decision domain:
1 – frozen zone of insulation; 2 – moistened zone of insulation.

The external contour of insulation interacts with a humid air. Water from the humid air condenses on the external contour (Fig. 1). A moisture transfer realizes only in a moistened zone by moisture migration to the freezing front by film-diffusion mechanism of moisture transfer.

The internal surface of the insulation R_1 (Fig. 1) has a constant temperature and the external surface R_2 has a convective heat and mass exchange with an environment. At the boundary of phase transitions $\xi(t)$ for problem of moisture transport was considered the condition of ideal waterproofing. The initial values of temperature T_0 and the relative moisture content of the insulation by volume W_0 in the domain of solutions (Fig. 1) have the constant values. Because of the insulation cooling is formed a variable thickness frozen layer (Fig. 1) and the movable boundary of phase transition has a constant temperature of freezing.

Formulating the problem, we used the following assumptions:

1. The heat transfer processes in the internal and the external environment are disregarded.
2. The thermophysical characteristics of materials used in the analysis are constant and known values.
3. The heat in the insulation layer is transferred only by conduction.

The listed assumptions, on the one hand, do not impose constrains of principle on the physical model of the system (Fig. 1), but, on the other hand, allow one to simplify in a certain manner the algorithm and method for solving the posed problem.

Mathematical model

In the proposed statement, the heat and mass transfer process in the considered decision domain (Fig. 1) in a 1D formulation is described:

$$\frac{\partial T_1}{\partial t} = a_{\text{ef},1}\left(\frac{\partial^2 T_1}{\partial r^2} + \frac{1}{r}\frac{\partial T_1}{\partial r}\right), \quad R_1 < r < \xi(t), \quad t > 0; \tag{1}$$

$$\frac{\partial T_2}{\partial t} = a_{\text{ef},2}\left(\frac{\partial^2 T_2}{\partial r^2} + \frac{1}{r}\frac{\partial T_2}{\partial r}\right), \quad \xi(t) < r < R_2, \quad t > 0; \tag{2}$$

$$\frac{\partial W_2}{\partial t} = D_2\left(\frac{\partial^2 W_2}{\partial r^2} + \frac{1}{r}\frac{\partial W_2}{\partial r}\right), \quad \xi(t) < r < R_2, \quad t > 0. \tag{3}$$

$$T = T_0, \quad R_1 \le r \le R_2, \quad t = 0; \tag{4}$$

$$W = W_0, \quad R_1 \le r \le R_2, \quad t = 0. \tag{5}$$

$$T_1 = T_{\text{in}}, \quad r = R_1, \quad t > 0; \tag{6}$$

$$-\lambda_{\text{ef},2}\frac{\partial T_2}{\partial r} = \alpha\left(T_2 - T_{\text{ex}}\right) - jQ, \quad r = R_2, \quad t > 0; \tag{7}$$

$$-D_2\frac{\partial W_2}{\partial r} = \beta\left(W_2 - W_{\text{ex}}\right), \quad r = R_2, \quad t > 0; \tag{8}$$

$$\frac{\partial W_2}{\partial r} = 0, \quad r = \xi(t), \quad t > 0; \tag{9}$$

$$\begin{gathered} \lambda_{\text{ef},1}\frac{\partial T_1}{\partial r} - \lambda_{\text{ef},2}\frac{\partial T_2}{\partial r} = \overline{W}Q\overline{\rho}\frac{d\xi}{dt}, \\ T_1 = T_2, \quad r = \xi(t), \quad t > 0. \end{gathered} \tag{10}$$

The thermophysical properties of insulation were determined from the well-known expressions [5] and the effective coefficient of thermal conductivity – by the formula

$$\lambda_{ef,1} = W_i\lambda_i + (1 - W_i)\lambda_{ins}, \quad \lambda_{ef,2} = W_w\lambda_w + (1 - W_w)\lambda_{ins}. \tag{11}$$

The mass transfer intensity was calculated by the formula

$$j = \frac{(p_{st} - p_s)}{k}. \tag{12}$$

Method of solution and initial data

The system of equations (refer with: Eqs. 1–12) was solved by the finite-difference method [6] using an iterational implicit difference scheme. The characteristic features of the problem solution were the discontinuity of the thermophysical characteristics and the presence of additional summands in boundary conditions (Eqs. 7 and 10).

The analysis was carried out for a cylindrical object with a diameter of nominal bore of 2400 mm; the object was manufactured from steel with thermal insulation from polystyrene (50 mm thick). The ambient temperature was equal to T_{ex}=290; 295 and 300 K and the temperature of the inner surface of the object was T_{in} = 230 K. The values of temperature and volume humidity in the considered region at the initial instant were T_0=T_{in} = 230 K and W_0 = 1 %. The relative air humidity of the environment was equal to φ=60; 80 and 100 % and the atmospheric pressure was p_{at} = 101325 Pa. The coefficient of heat transfer in all variants of the numerical analysis was $\alpha = 5$ W/(m^2·K) and the resistance of moisture exchange was $k = 96$ (MPa·s·m^2)/kg. The diffusion coefficient of moisture in the polystyrene was $D_2 = 2\cdot10^{-6}$ m^2/hr.

Table 1 contains values of thermophysical characteristics, which were used in the numerical investigations of thermal conditions of the system under consideration (Fig. 1).

Table 1. Thermophysical characteristics

Characteristic	λ, [W/(m·K)]	*C*, [J/(kg·K)]	ρ, [kg/m^3]
Water	0.6	4186	994.04
Ice	2.4	1924	916.8
Polystyrene	0.0342	1183	100

Results of numerical simulation

The main results of numerical modeling of thermal and mass conditions of the system under consideration (Fig. 1) are listed in Table 2 and in Fig. 2.

Table 2 lists the results of numerical experiments of heat leakage for: in conditions of insulation freezing (q_1) and without insulation freezing (q_2). Also Table 1 contains the relative calculation error δ_2, the thickness of frozen insulation δ, the volume humidity of the environment W_{ex} and the time of the steady-state condition t_{sta}.

Validity and reliability of the obtained results follow from tests of the methods for convergence and stability of solutions on multiple meshes, fulfillment of the energy balance conditions at boundaries of the calculation domain, and is also confirmed by comparison of the obtained results and the known experimental [1, 2] and theoretical [4] data obtained by other authors. The relative calculation error δ_2 in all versions of the numerical analysis did not exceed 0.5%, which is acceptable for investigations of thermal and mass conditions of the system under consideration (Fig. 1).

The numerical experimental results in Table 2 allow us to make the inference about the expected increase of heat leakage with growing a temperature of the ambient and the relative air humidity.

The data presented in Table 2 allow us to make the following conclusions:

1. The heat leakage q_1 increases by about 40 % compared with the heat leakage q_2. Therefore the role of insulation freezing in determining heat leakage becomes important.

2. The maximum value of the thickness of frozen insulation is δ = 44.7 mm. It corresponds to almost complete freezing of the insulation layer.

3. The thickness of frozen insulation changes by about 20 % depending on the values of the temperature and the relative air humidity of the environment.

Table 2. Results of numerical simulation

T_{ex}, [K]	φ, [%]	q_1, [W/m]	q_2, [W/m]	W_{ex}, [%]	δ, [mm]	$\frac{q_1 - q_2}{q_1} \cdot 100\%$	δ_2, [%]	t_{sta}, [hr]
290	60	447.6	282.6	1.14	44.7	36.9	0.36	21
	80	456.7		1.53	43.7	38.1	0.28	52
	100	466.8		1.91	42.7	39.5	0.25	56
295	60	479.7	306.1	1.56	41.6	36.2	0.34	72
	80	492.2		2.09	40.2	37.8	0.31	130
	100	511.0		2.61	39.0	40.1	0.36	138
300	60	516.7	329.7	2.11	38.5	36.2	0.24	149
	80	539.1		2.82	36.8	38.8	0.34	248
	100	563.4		3.54	35.2	41.5	0.26	309

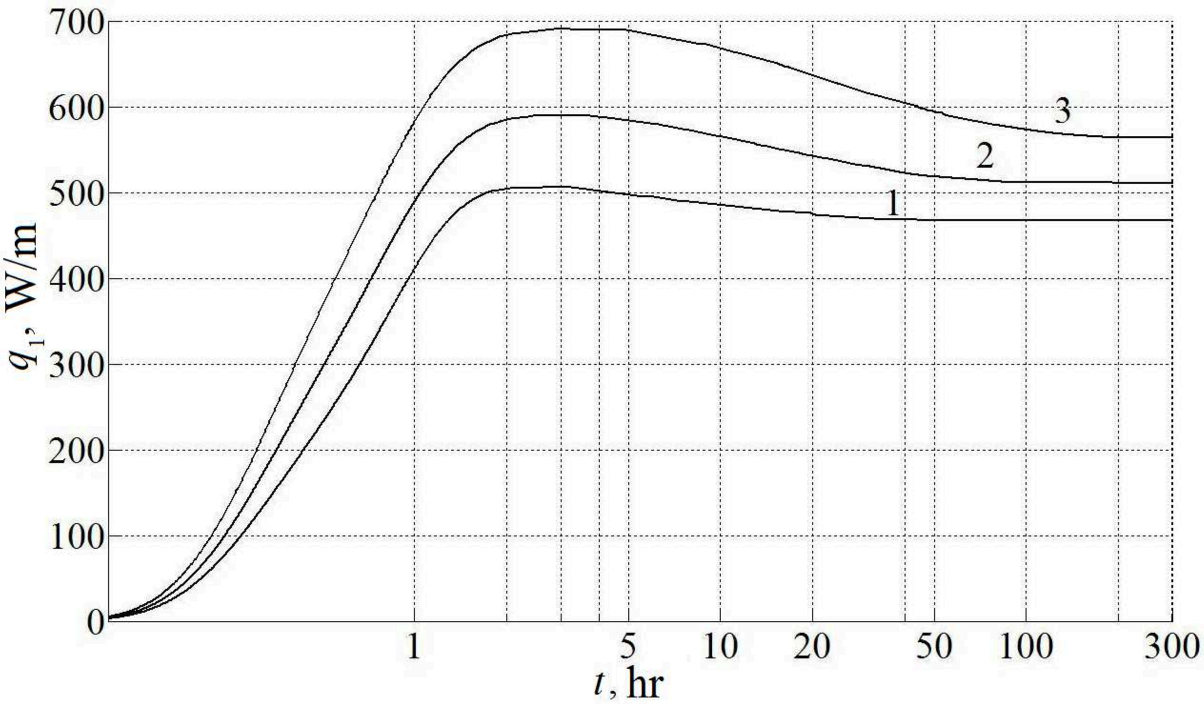

Figure 2. Temporal variation of the heat leakage (φ = 100%): 1 – 290 K; 2 – 295 K; 3 – 300 K

Figure 2 shows the nonstationary of heat and mass transfer of the system under consideration (Fig. 1). An analysis of nonstationary processes of heat and mass transfer of the system under consideration allow us to make the inference about what time to steady-state condition is from 21 to 309 hours (Table 2). From analysis of results shown in Fig. 2, it is seen that the process of heat and mass transfer turns out to be nonstationary.

Conclusion

We have carried out numerical analysis of thermal and humidity regimes and numerical analysis of heat leakage in a low-temperature insulation in conditions of insulation freezing, a moisture migration to the front of phase transition and a condensation forming on an outer contour of interaction.

It has been shown that the heat leakage increases by about 40 % and time to steady-state condition is from 21 to 309 hours.

In summary, the application of the proposed approach enables comprehensive analysis of thermal and humidity regimes of the system under consideration.

Notations

R – domain boundary; ξ – boundary of phase transitions; T – temperature, K; W – relative moisture content; a – thermal diffusivity, m^2/sec; t – time, sec; r – coordinate, m; D – diffusion coefficient, m^2/sec; λ – thermal conductivity, W/(m·K); C – heat capacity, J/(kg·K); ρ – density, kg/m^3; α – heat transfer coefficient, W/(m^2·K); j – mass transfer intensity, kg/(m^2·sec); Q – heat of phase transition, J/kg; β – mass-transfer coefficient, m/sec; φ – relative air humidity, %; k – resistance of moisture exchange, (MPa·s·m^2)/kg; p – pressure, Pa; t_{sta} – time of the steady-state condition, hr; δ_2 – relative calculation error, %; δ – thickness of frozen insulation, mm; q – heat leakage , W/m; $\overline{\rho} = (\rho_w + \rho_i)/2$ – mean density, kg/m^3; $\overline{W} = (W_w + W_i)/2$ – mean relative moisture content.

Indices: 1 and 2 – numbers of calculation domains (Fig. 1); 0 – initial time; ex – external environment; in – internal environment; ef – effective; i – ice; s – saturation, w – water; atm – atmospheric, st – steam; ins – insulation.

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Comparison of different types of transparent structures for high-rise buildings with a fully glazed facade.

Darya Nemova [1,a], Elisaveta Reich [2,b*], Svetlana Subbotina [3,c], Faina Khayrutdinova [4,d]

[1,2,3,4] St. Petersburg State Polytechnical University, 195251, St. Petersburg, Russian Federation

[a]darya0690@mail.ru, [b]lisa_reich@mail.ru, [c]svetlana.subbotina94@mail.ru, [d]khayrutdinova.f@mail.ru

Keywords: transparent structures, energy efficiency, post-bar glazing, structural glazing, spider glazing system, ventilated double-skin facade, heat loss, enclosing structures, energy savings

Abstract. Transparent structures are widely used in the construction of modern high-rise buildings. It is necessary to consider a number of important features in selecting of suitable design of the construction. These are energy efficiency, durability, simplicity of installation, exterior of the building, cost of the construction and payback period. The aim of this work is to determine the most appropriate transparent structure for high-rise buildings with a fully glazed facade according to these requirements. Accomplish this aim such challenges as comparison of characteristics of different methods of glazing, energy efficiency and cost-effectiveness problems were figured out. Basing on this comparison, most suitable transparent structures for the various priority factors have been identified.

Introduction

One of the topical issues of modern construction is energy efficiency. Many countries (every 2-3 years) reconsider and strengthen the requirements for the energy performance of buildings according to long-term plan. Detailed rules imposed in Russia are set in Federal Law № 261-FZ "On energy saving and energy efficiency." This is particularly affect high-rise buildings and their enclosing structures, as the main heat loss pass through them. Because of these losses, a lot of energy and money are spent on maintaining the temperature in the rooms. Every year new materials and technologies are developed. A lot of researches are carried out in order to optimize the construction technology of transparent structures to reduce heat loss.

The aim of this study is to determine the most appropriate design for facade glazing of high-rise buildings. It is necessary to figure out the following problems:

1. To compare the features of different types of glazing.
2. To calculate heat loss of each type of glazing and identify the most energy-efficient type of glazing.
3. To make an evaluation for each type of glazing, and to identify the most appropriate transparent structure for high-rise buildings with a fully glazed facade according to this evaluation.

Literature References

The issues of energy efficient of constructions with transparent structures and energy efficiency of buildings are viewed in reports [1-26]. A.V. Spiridonov in his work [9] consider development of application of these structures. Different types of full glazings are discussed in the papers [4-5]. Gorshkov A.S made a great contribution to the description of the energy efficiency of enclosing structures [2-3, 7, 25-26], he revealed the necessity to increase the level of the thermal shielding of building envelope, offered the methods of the simple and complex payback of the energy-saving measures.

Mullion-transom facade. Basis of this construction is an aluminum framework, which incorporates rising piers and longitudinal dwangs. Multiple glass is fixed with clamping straps to the outer side of the frame (Fig. 1). Decorative molding of various color and form can be used for overlapping straps. Installation of this construction is a quick and easy process. All bonds of the frame are situated inside of the building, so they are protected well from being weathering. It provides an adequate reliability and longevity of the present construction. In case of this type of glazing visual integrity lack has its influence on a building's exterior.

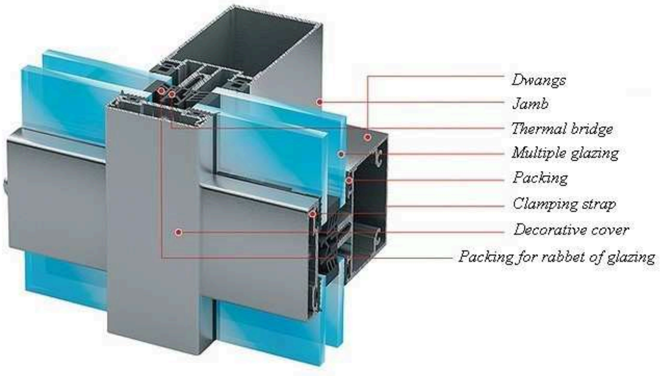

Figure 1. Schematic view of fixing of the glass in Mullion-transom facade

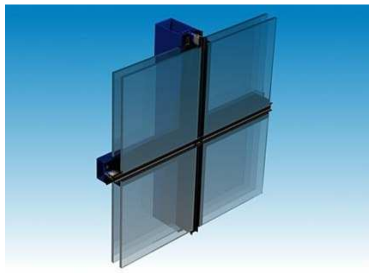

Figure 2. Structural glazing

Structural glazing. Basis of this construction features a steel framework (Fig. 2, [29]) Indoor glass is fixed to an aluminum section of the window. The connection between outdoor glass and basis should be made by applying a joint filler or a special PVC-membrane. Installation of this construction is a simple and relatively inexpensive process. The color of joint filler is usually same with the color of glass; it provides a visual integrity of the glazing. The deficiency of structural glazing is off-standard multiple glazing, because different sizes of outdoor and indoor glasses are used in the construction.

Figure 3. Point fixing

Spider glazing system (Point fixed glazing systems). Spider fitting equalize forces due to its elastic structure. It is hinged by dint of through holes in every glass. Also spider fitting can be attached to columns, dwangs, floor slabs or walls. Point fixing (Fig. 3, [30]) is distensible enough for thermal distortion compensation. The joint between glasses can be performed at any angle, that allows to fix glasses to any facade's form. Heat-strengthened glass is used for spider glazing system. The structure allows glass to bend under a strain, therefore, the glass fracture can be prevented. It provides an adequate longevity of the construction. Spider glazing system provides an all-round view due to absence of base frame between the panels and compartmentalization.

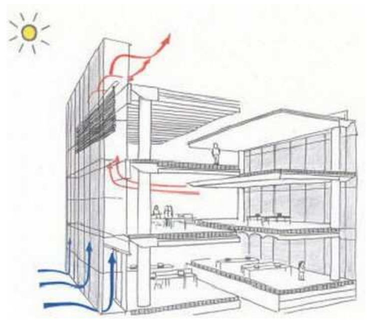

Figure 4. Ventilated double-skin facade

Ventilated double-skin facade. This is a sandwich construction consisted of an inner and outer glazings and air cavity between them (Fig. 4, [31]). It absorbs the wind forces well. For providing free ventilation some sashes of an inner glazing are opening light. In the air cavity between two facades circulation of the air causes the natural convection cooling of the building, that increases its energy efficiency. The construction of the ventilated double-skin facade increases the transparency of the building

and improves the lightning of the spaces. However, the visual integrity of the glazing is disrupted because the panels are divided into small glasses.
Installation of this construction is a complex and time-consuming process.

Bench-mark data for the study. Analysis is based on determination of the most suitable design for different types of full glazing and on the assumptions of the cost of constructions and cost savings by reducing heat loss in different cases of growth of tariffs (by 5%, 10% and 15%). For the study, 40-storey business center «Leader Tower» (Fig. 5), located at Moscow Avenue, St. Petersburg, was chosen. The area of the enclosing structure of this building is 18800 m^2.

Figure 5. Leader Tower

Design variables with allowances made for climate pattern of St. Petersburg are subjected to SNiP 23-01-99 [27] and presented in Table 1.

Value of the area and heat transmission resistance for enclosing structures are subjected to SNiP 23-02-2003 [28] and presented in Table 2.

Table 1. Design conditions

Index	Parameter label	Unit of measurement	Design value
1.1. Design ambient air temperature	t_o	°C	- 26
1.2. The average ambient air temperature during the heating season	t_h	°C	- 1.8
1.3. The duration of the heating season	z_h	day/year	220
1.4. Heating season degree-day	HSDD	°C·day/year	4796
1.5. Design indoor air temperature	t_{in}	°C	20
1.6 Design temperature underground	t_{un}	°C	5

Table 2. Value of area and heat transmission resistance for enclosing structures

Type of enclosing structure		The value of heat transmission resistance, [R_0^{tr}, m^2 * ° C/W]	Construction area A_i, [m^2]
2.1. Curtain wall – A_{cw}	2.1.1. Ventilated double-skin facade	0.9	18 480
	2.1.2. Structural glazing	0.57	
	2.1.3. Mullion-transom facade	0.55	
	2.1.4. Spider glazing system	0.48	
2.2. Entrance doors – A_{ed}		0.42	6.3
2.3. Roofing system – A_{rs}		3.34	1 008

2.4. Floor slab over an underground parking spaces – A_{fl}	2.83	1 008
Total area of enclosing structures of heated part of the building		20 502.3

Assumptions. For the calculation the following assumptions were made:

1. Rectangular shape of the building
2. Detached building

Heat loss through the enclosing structures. Most of heat loss are realized through the enclosing structures. Take a detailed look at structures mentioned above, their thermal insulation properties and cost. Calculate the payback period, and basing on it, identify the most energy-efficient type of a fully glazed facade.

Calculations of heat loss through the enclosing structures are calculated by the formula:

$$Q_{enc} = 0.024 * \text{HSDD} * \sum_i \frac{A_i}{R_i} * n \quad (1)$$

0.024 - converting factor of heat loss through the enclosing structures of W * day in kWh (1 day = 24 hours, 1 W = 0.001 kW, 1 W * d = 0.024 kWh);

HSDD - heating season degree-day for St. Petersburg, it is equal to 4796 ° C * d / year (see. Data Table 1);

A_i - area of an i-th type of enclosing structure (curtain walls, floor slabs, roofing system, etc.) for the given building from Table 2;

R_i - heat transmission resistance of the i-th type of enclosing structure;

n - coefficient, depending on location of the external surface of enclosing structures; for exterior walls, floor slabs over passages and under the bay windows; n is equal to 1 for the floor slab over an underground parking spaces, taking into account the temperature of air equal to t_{un} = 5 ° C; the coefficient of n is equal to 0.33.

Heat loss through the enclosing structures of different types of glazing are calculated by the formula (1). Example of one of the calculations:

$$Q_{enc} = 0.024 * \text{HSDD} * \sum_i \frac{A_i}{R_i} * n = 0.024 * 4796 * \left(\frac{A_{cw}}{R_{cw}^{tr}} + \frac{A_{ed}}{R_{ed}^{tr}} + \frac{A_{rs}}{R_{rs}^{tr}} + n * \frac{A_{fl}}{R_{fl}^{tr}}\right) = 0.024 * 4796 * \left(\frac{18480}{0.9} + \frac{6,3}{0.42} + \frac{1008}{3.34} + 0.33 * \frac{1008}{2.83}\right) = 2\,190\,915 \left(\frac{\text{kWh}}{\text{year}}\right). \quad (2)$$

The results of calculations of heat loss during the heating season, cost per square meter of the construction, and total construction cost are presented in Table 3.

Table 3. Annual heat loss through the enclosing structures of different types of glazing and total construction cost

Type of glazing	Annual heat loss through the enclosing structures				Cost per m^2 of the construction, [RUB]	Total construction cost, [ths. RUB]
	[kWh/year]	[MJ/year *]	[Gcal/year **]	[ths. RUB/year***]		
Ventilated double-skin facade	2 190 915	7 887 293	1 884	2 653	15 000	277 200
Structural glazing	3 389 427	12 201 936	2 915	4 104	8 000	147 840
Mullion-transom facade	3 556 956	12 805 042	3 059	4 307	6 800	125 664
Spider glazing system	4 069 222	14 649 199	3 500	4 927	17 000	314 160

In Table 3 the following conversion factors of values of the heat energy were taken:
* 1 kWh/year = 3.6 MJ/year
** 1 kWh/year = 3600 kJ/year = 3.6 x 106 J/year = 3.6 * 106/4.187 cal/year = 3.6 * 10-3/4.187 Gcal/year = 86 * 10 -5 Gcal/year
*** 1 Gcal/year = 1408.01 rubles (as of 2014 in St. Petersburg)

According to Table 3 it can be said that total construction cost of Spider glazing system is the biggest and at the same time heat loss of this construction are max in comparison with the other types. Thus, it can be concluded that this construction is cost-prohibitive. The further consideration of Spider glazing system has no sense.

Compare three other types of glazing in order to determine the most cost-effective. For this purpose, calculate the cost of Ventilated double-skin facade in comparison with the cost of Structural glazing and cost of Structural glazing in comparison with the cost of Mullion-transom facade. Basing on data taken from Table 3 heat energy economies are presented in Table 4.

Table 4. Comparison of structural and heat energy saving

Compared structures	Difference between the cost of structures, [ths. Rub]	Heat energy economy per year, [ths. Rub]
Ventilated double-skin facade and Structural glazing	-129 360	1 451.26
Structural glazing and Mullion-transom facade	-22 176	202.86

Based on these datas it is possible to determine the payback period of the most energy-efficient structure in three different cases of growth of heating tariffs (5, 10 and 15%) (Fig.6, Fig.7, Fig.8). The results are presented in Table 5.

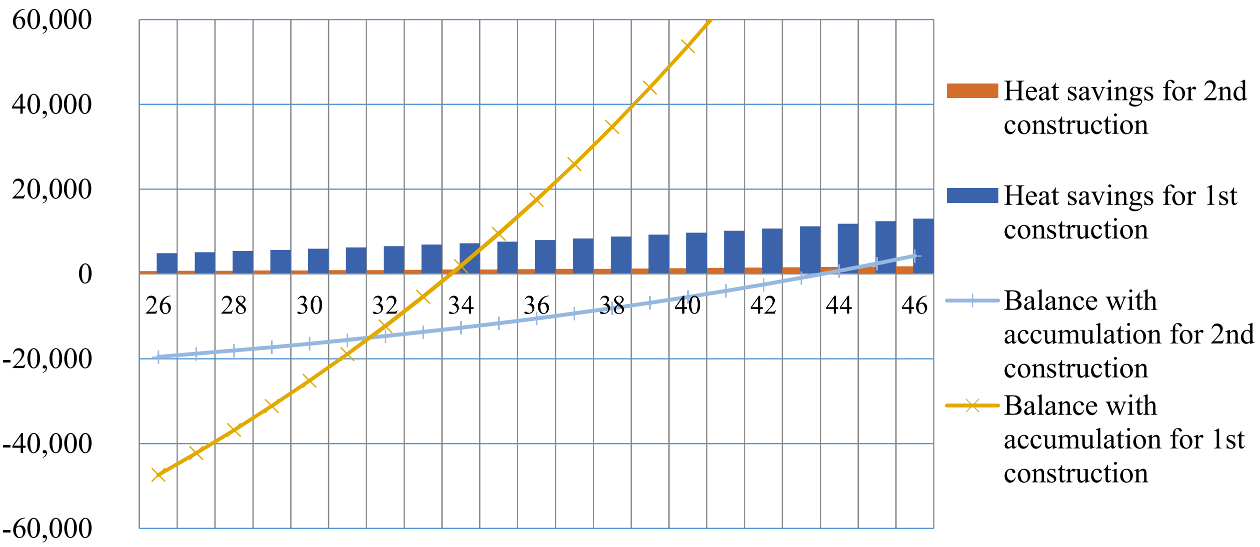

Fig.6 Payback period of the constructions at growth of tariffs by 5%

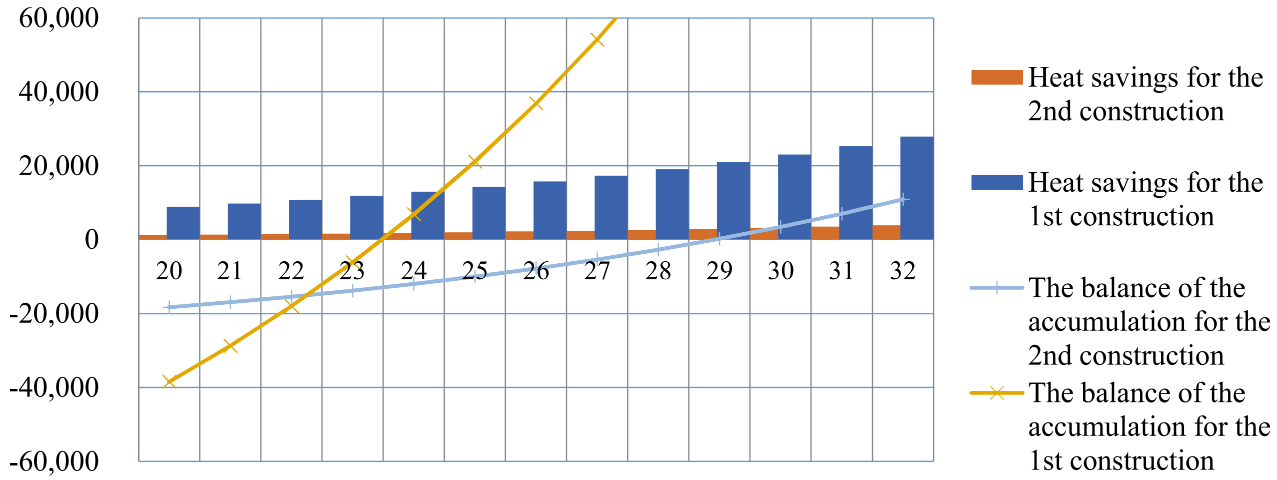

Fig.7 Payback period of the constructions at growth of tariffs by 10%

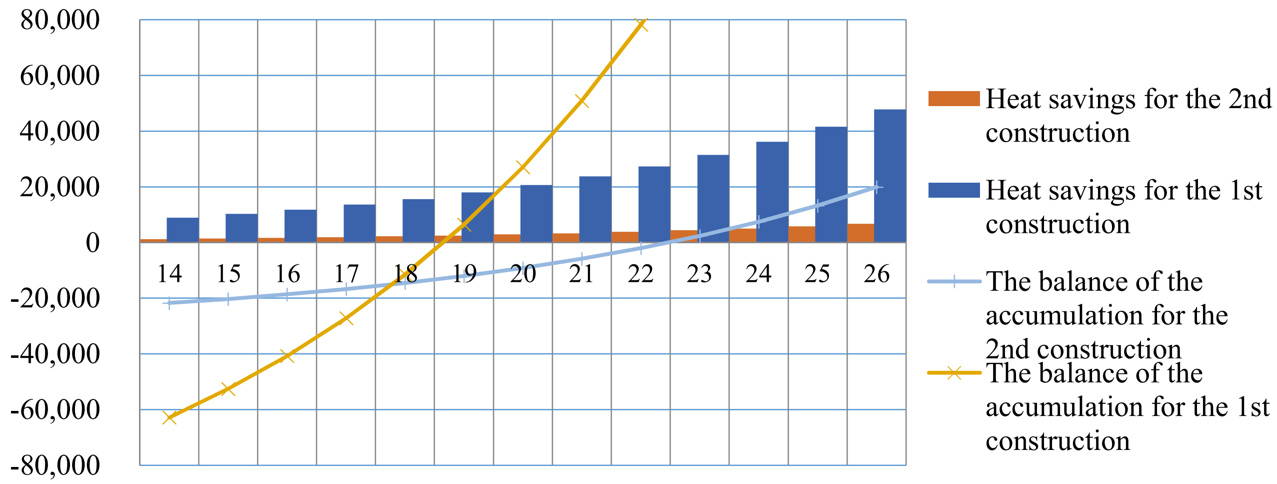

Fig.8 Payback period of the constructions at growth of tariffs by 15%

Table 5. Payback period of the most energy efficient structures

Compared structure	Payback period, years		
	growth of tariffs by 5%	growth of tariffs by 10%	growth of tariffs by 15%
Ventilated double-skin facade and Structural glazing	34	24	19
Structural glazing and Mullion-transom facade	44	29	23

Table 6. Total evaluation of each type of glazing

Criteria	Ventilated double-skin facade	Structural glazing	Mullion-transom facade	Spider glazing system
Exterior view	3	4	1	5
Load resistance	5	5	4	5
Erection speed and its simplicity	3	5	5	1
Cost	3	4	5	2
Thermal insulation properties	5	4	3	2
Energy efficiency (payback period)	5	4	3	2
Total:	24	26	18	17

Conclusions

In this paper, the properties of different types of full glazing were analyzed, evaluated heat loss through the enclosing structures for each type, identified the most energy-efficient and cost-effective types of glazing. According to research, the following results were obtained:

1. The total evaluation on such criteria as exterior view, load resistance, erection speed, energy efficiency and others determined that the most appropriate design for facade glazing of high-rise buildings are Ventilated double-skin facade and Structural glazing. The most unprofitable is Spider glazing systems, because heat loss, and payback period in this case are maximal.

2. Payback period was calculated for three different cases of growth of tariffs. In case of the rapid growth of tariffs (by 15%), such constructions as Ventilated double-skin facade and Structural glazing will be paid off in about 20 years, or (in case of the minimal growth of tariff by 5%), Ventilated double-skin facade is paid off in 34 years, Structural glazing - in 44 years. On average, in case of growth of tariffs by 10%, these types of glazings are paid off in 24 and 29 years accordingly.

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Prodrome In Experimental Investigation The Thermal Shielding Systems In Enclosure Structures

Nikolay Vatin[1, a], Issa Togo[2,b], Vladimir Bespalov[3, c *], Dmitriy Kuzmenkov[4,d], German Panteleev[5,e] and Dmitriy Smirnitskiy[6,f]

[1,2,3,4,5,6] St. Petersburg State Polytechnical University, St.Petersburg, 195251, Russian Federation

[a]vatin@mail.ru, [b]issatogo@mail.ru, [c]chanchullero@yandex.ru, [d]kuzmenkovdv1994@gmail.com, [e]german3730051@gmail.com, [f]ktoeto95@mail.ru

Keywords: energy efficiency, energy-savings, experimentation, engineering, construction, building materials, heat transfer resistance, heat losses, enclosure structure.

Abstract. This work is devoted to description the outset of research the modern thermal shielding systems on the model of house, and desired outcome. Results can be basement for modernisation of building regulation, in prospect. Experiment consists in tests conducting and drafting of troubleshooting guideline.

Introduction

In industrial countries modern buildings consumer more then 40% produced energy. 60% of this energy is used for heating, ventilation, air conditioning and lighting. Russian territory is located in three general climatic zones: arctic, sub-arctic and temperate. A lot of energy required for heating in civil and industrial objects. Therefore, in cold climate it required for cooling because average of temperatures can reach +30 °C. It's necessary to increase energy efficient of buildings and constructions in modern conditions of limitation economic resources. Heat energy economy is a potential way for energy-efficiency. More efficient would be events aimed at elimination of enclosure structures defects and heat energy efficient [1]. Now Russia is in the end of list world house thermal effectiveness. Currently new costeffective save-energy technology search is actual [2]. In year 2009 a law [3], pointing at necessity of a major upgrade in this province, was passed. Today there is no consensus about the most effective way of increasing building efficiency. There are two ways of heat insulation to increase energy efficiency of enclosing structures: external and internal. They both have favourers [4-8, 19, 20]. Moreover, there is analysis [9] approved that it's difficult to choose optimum heat insulating material.

Literature review

The work Gorshkov A.S. «Puti povysheniya energoeffektivnosti ograjdayuschikh konstruktsiy zdaniy» largely motivate our research [10]. Platonova M.A., Vatin N.I., Nemova D.V., Matoshkina S.A., Iotty D., Togo I. reviewed various methods of increase energy efficiency. [1, 5, 11]. As a heater for an external wall the heater for professional construction on the basis of flinty fiber ISOVER VENTI was chosen in article by D.A. Trubina, Z.S. Teplova, K.I. Solovyeva, D.V. Nemova, D.V. Petrosova. Article is devoted to the solution of an actual problem — to energy saving and increase of energy efficiency of buildings. Also in the article there is a definition of optimal and profitable width of insulation in a system of hinged ventilated facade [12]. Karin Buvik, Geir Andersen and Sverre Tangen described integrated modification and trial enclosure structures in cold climate(case study of Norvegian school) [13]. Kang, D.-H., Lorente, S., Bejan, A. show how to distribute multiple layers of insulation along a nonisothermal enclosure so that the total heat loss is minimal [14]. Nizovtsev, M.I. , Belyi, V.T., Sterlygov, A.N. describe a new thermal-insulating facade system for newly constructed and renovated buildings, based on heat-insulating panels with ventilated channels [15]. Moreover, Rahmi Andarini observes method of program simulating heat loss during building operation. It might be useful for energy-efficient evaluating structures in design stage [16].

Purposes and tasks

The paper had the following main objectives:
1) Create experimental platform in the laboratory based on a prototype house as close as possible to the parameters of real homes, using the most widely used materials for the creation of the enclosing structure.
2) Create a design for energy-efficient surface protection walling. Subsequently, an analysis and comparison of different systems for energy-efficient protection. With the purpose to ordering in the future and improve the parameters of materials and technologies that could be used in the regulations in the construction industry.

House-lab building

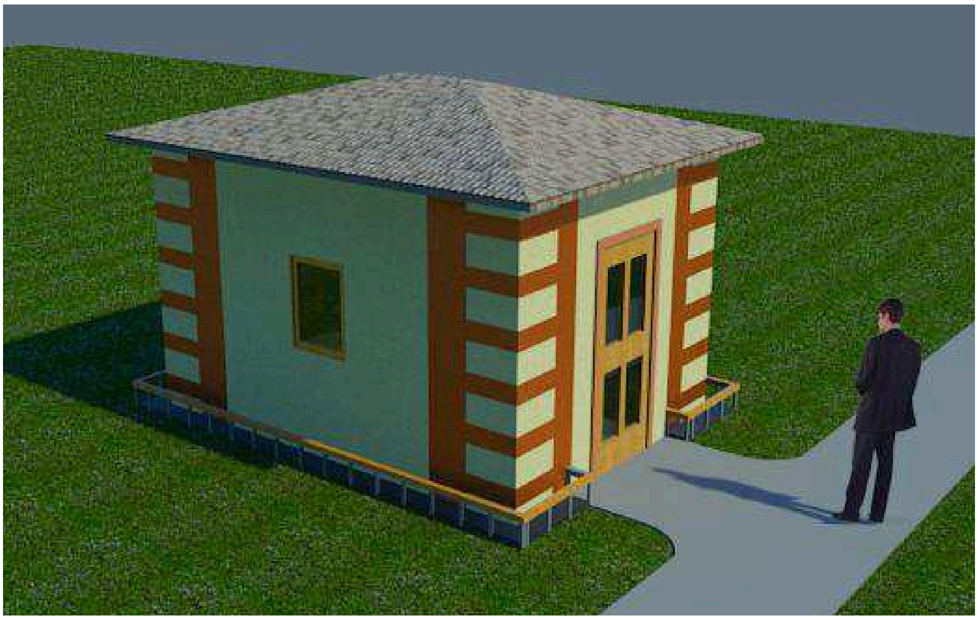

Figure 1. Final house-lab model, done in Autodesk Revit 2014

1 step. The model of house is erecting on special field (Fig. 1). Dimensions: mounting base 2000x3000 mm; ceiling height 2500 mm; rise 3500 mm; wall thicknesses 450 mm. Door way (1600x800 mm) and 2 window (600x600 mm) are enclosing. Four brickwork columns 250x250 have been raised on corners on prepared basement. They can be reinforced if it necessary. After that chases have been made in basement along the line of future walls between columns. Gas-concrete blocks have been set into chases (Fig. 2). Base of the walls is gas-concrete blocks 400x300x300mm. Roof, door and windows have been installed after heat-insulation system.

2 step. Previously, plinth wall set up for water disposal (Fig. 3). Plinth channel is 600 mm above the blind area, which match the height of capillary ascension of water in the Saint-Petersburg region. Plinth channel enable us to set thermal insulation slabs correctly and ensure them with extra stability.

3 step. Before installation, structural adhesive MAITE PAREXLANKO is applied on rock wool boards, dismensions 1000x1000x120. (Adhesive mixture trowel circuit-wise Fig. 4, a) Importantly, offsets are laying from the edge no less than 20 mm. Otherwise structural adhesive can force away between slabs.

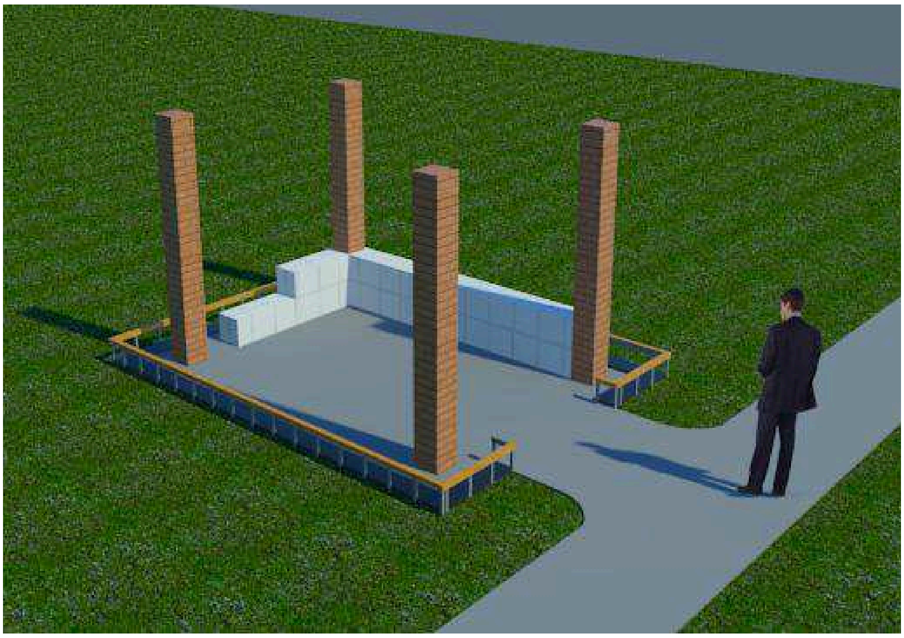

Figure 2. House-lab model at the stage of building, done in Autodesk Revit 2014

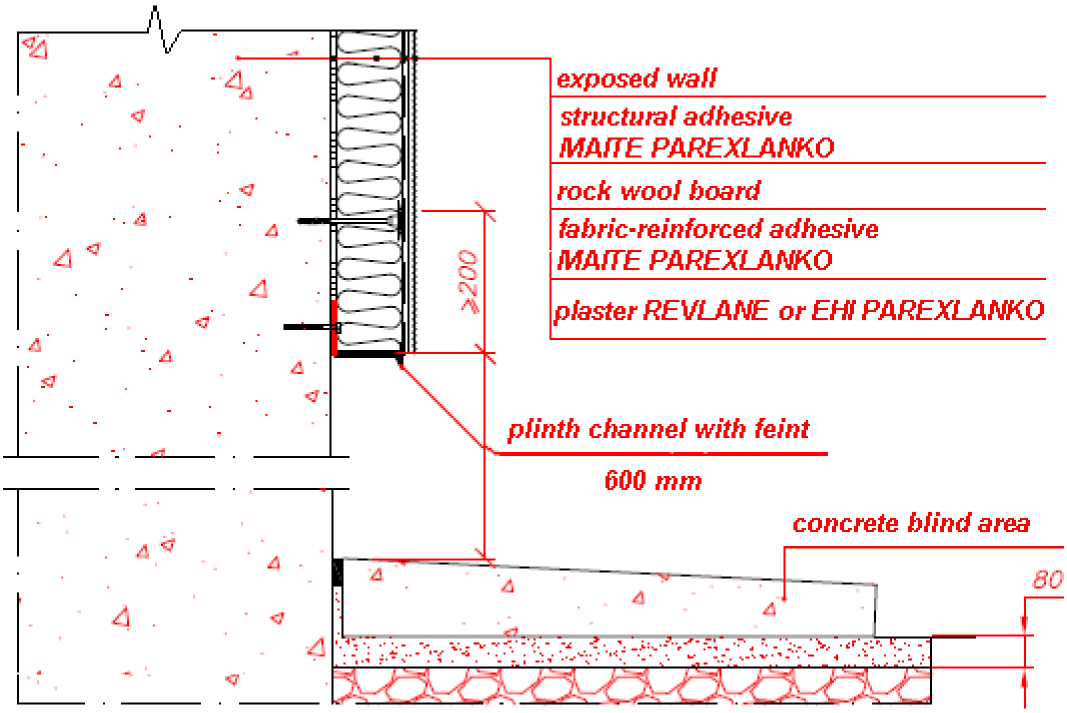

Figure 3. Plinth schematic illustration [17]

4 step. Rock wool boards are applied to the wall from the plinth channel to up, closely to each other. Significantly, boards must be fixed as two quarters (Fig. 4, b). Then boards are additionally fixed to the wall by rawplugs, 6 pcs/m^2. (Cavity brickwork and gas-concrete deteriorate by dynamic pressure. Therefore, rawplug holes should be made by drilling – Fig. 5).

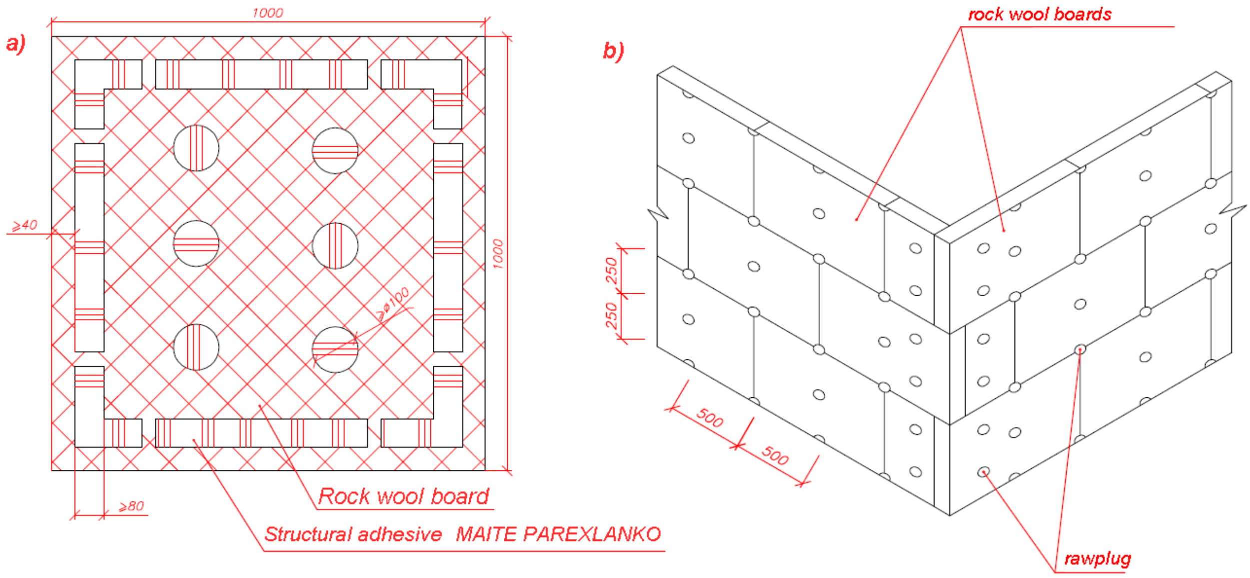

Figure 4. a) Structural adhesive applying; b) boards installation chart [17]

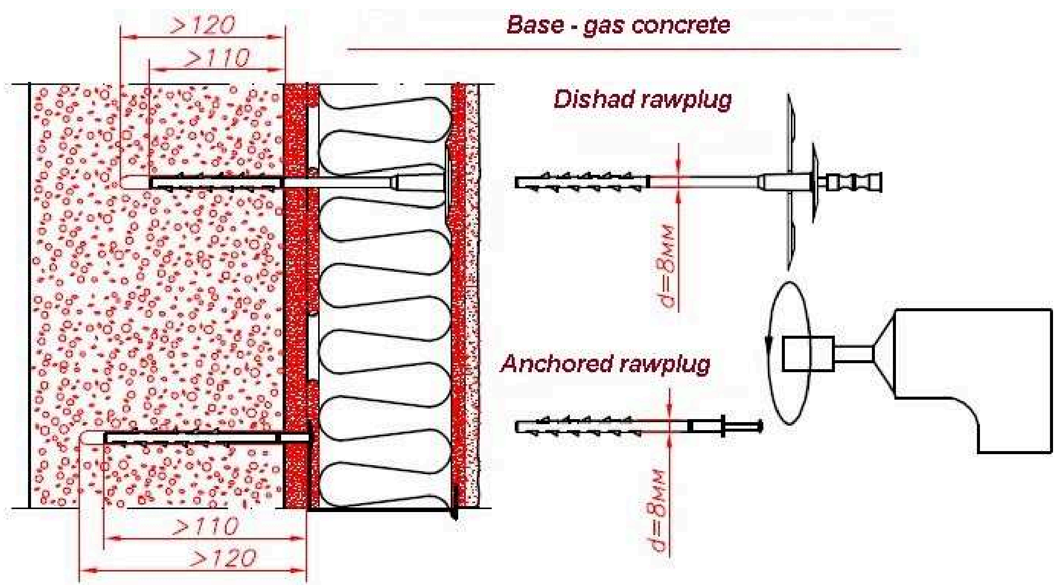

Figure 5. Drilling scheme [17]

5 step. Structural adhesive is applied on face of insulation boards. Then fiberglass grilliage steeps into adhesive and the second lay of structural adhesive is applied. Both lays are applied regulary.

6 step. On the second lay of structural adhesive dabbed heavy plaster EHI 8-12mm.

On the first stage of experiment we will research heat transfer of enclosure walls with described configuration (Fig. 6). In the future we are going to install few configurations of wall instead of previous and research theirs heat transfer and other parameters. Consequently, we could use house-lab many times.

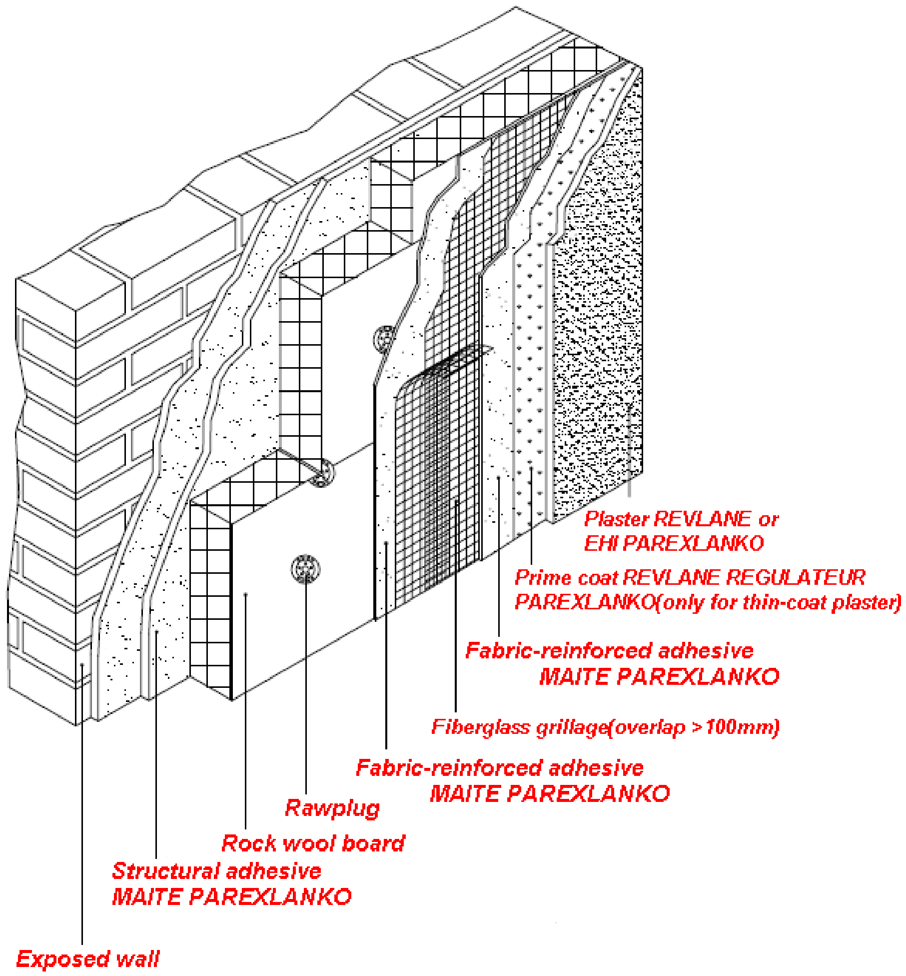

Figure 6. Cross section view of wall [17]

Thermotechnical calculation

It is expected that we would calculate pursuant to SNiP(Construction Norms and Regulations) II-3-79* [18], with the use of below-listed formulas:
Required thermal resistance

$$R_0^{req} = \frac{n(t_{\text{int}} - t_{ext})}{\Delta t_{ext} \alpha_{\text{int}}}, \tag{1}$$

where n - coefficient, depending on the position of the outside surface of the enclosure against the external air;
t_{int} – average temperature of internal air;
t_{ext} – temperature of external air during the cold period of year for city conditions St. Petersburg;
Δt_{ext} – regulatory temperature difference the internal air against the internal surface of enclosure;
α_{int} – coefficient of a thermolysis of an internal surface of a protecting design.

Thermal inertia of enclosure structure

$$D = R_1 s_1 + R_2 s_2 + \ldots + R_n s_n, \tag{2}$$

where R_i – Thermal resistance of one layer enclosure structure;
S_i – Thermal absorptivity of one layer enclosure structure.

Thermal resistance of one layer

$$R = \frac{\delta}{\lambda}, \tag{3}$$

where δ – thickness of a layer, m;
λ – coefficient of heat conductivity of a material of this layer.

Actual resistance to a wall heat transfer

$$R_0 = \frac{1}{\alpha_{\text{int}}} + R_k + \frac{1}{\alpha_{ext}}, \tag{4}$$

where R_k – Thermal resistance of the enclosure structure;
α_{int} – coefficient of a thermolysis of an internal surface of a protecting design;
α_{ext} – coefficient of a thermolysis of an external surface of a protecting design.

Reduced total thermal resistance

$$R_a = \frac{F_1 + F_2 + \ldots + F_n}{\frac{F_1}{R_1} + \frac{F_2}{R_2} + \ldots + \frac{F_n}{R_n}}, \tag{5}$$

where F_i - Square plots certain structures (or it's part);
R_i - Thermal resistance of above-noted certain structures.

Performance of materials have taken from accompanying documents. It is expected that calculated data compare and contrast with those found by experiment. Then we will search the causes and conditions that have facilitated the dissonance.

Recommendations and conclusions

Much increase in energy saving is expected using materials and methods which were considered by the side of formerly used materials and methods. If the experiment would be successful, we will make recommendations about tried-and true materials and methods. New enclosure requirements would be recommended for include into building regulation.

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Improvement Of The Double Skin Facades

Mikhail Petrichenko [1, a], Nikolai Vatin [2, b], Darya Nemova[3, c*]

[1,2,3]St. Petersburg State Polytechnical University, 195251, St. Petersburg, Russia

[a]gidravlika@cef.spbstu.ru, [b]vatin@mail.ru, [c]darya.nemova@gmail.com

Keywords: numerical modeling, energy efficiency; external envelops; double skin facades; renovation of facades, thermogravitational convection

Abstract. Double skin facades very popular in this time. They are applied for construction of new buildings and for reconstruction. But double skin facades contains some defects. In the present paper concrete constructive changes in a design of the Double skin facades which are offered. This changes will can to normalize heatmoisture conditions in the building. All proposed solutions are proved by theoretical calculations and numerical simulation.

Introduction

Real designs are projected and built with a dense adjunction to a socle (Fig. 1). At first of all it is made for a beautiful general architecture. In this case the free access of external air in a design "is blocked". Such design decisions don't provide optimum a condition for thermogravitational convection and therefore for optimum work of double skin facades.

Figure 1. Real double skin facades

Real designs of the double skin facades in existence gaps between facing plates which are put in the project for compensation of temperature deformations. The sizes of rust make 8-10 mm and they become on all height of a facade in the vertical and horizontal directions between each element of facing.

The theoretical calculations presented in paper [1] were carried out for front systems into which air layer from the lower part air could get freely. That is adjunctions of front system to a socle was accepted leaky, between a socle and a facade there was a gap height to an equal one facing tile. Besides, in settlement systems there were no gaps. As showed calculations, in such designs optimum capacity can be realized, and in such systems the air stream will move vertically up that will promote removal of moisture from a design that is confirmed by also numerical simulation, presented in paper [2].

Studying of works of many scientists devoted to thermogravitational convection also confirms this theory. Thermogravitational convection as a whole and in protecting designs research Lorentz G. A., Ekkert E., Zhukovsky V.S., Sokovishin Yu.A., Murgul V., Gorshkov A.S., Petrichenko M.R., Vatin N.I., Borodinecs A., Kaklauskas A. and many others [1-27].

All this allows to make the assumption that real designs of the double skin facades can incorrectly work, without realizing all the potential.

It is necessary to prove or disprove this assumption and to determine the possible directions by improvement of double skin facades.

Description of work of real double skin facades

For real designs pressure lines for three cases were built: from windward and lee side of a facade for demonstration of influence of gaps on the movement of air and for option with considerable losses on an entrance, for demonstration of influence of a dense adjunction of front systems to a socle.

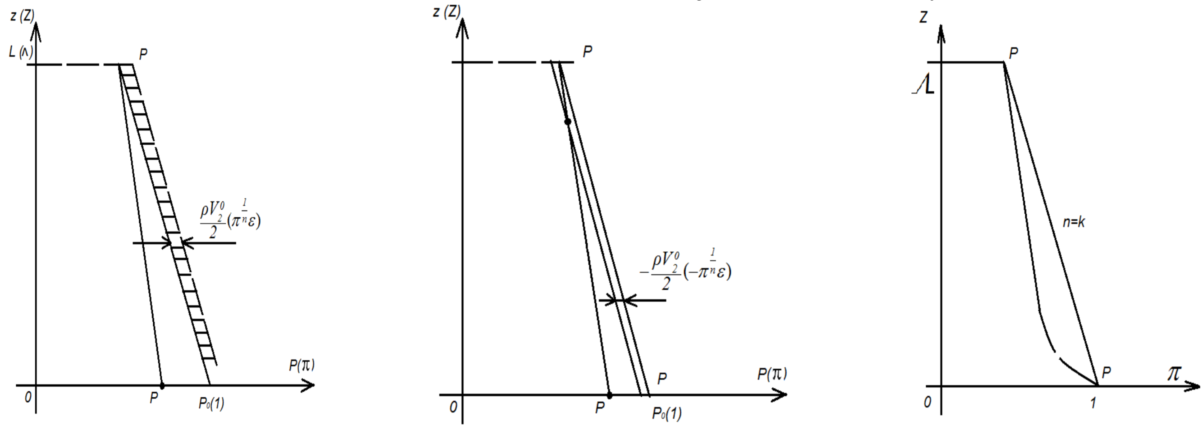

Figure 2. a,b,c. Pressure lines of flow.

How we can see from picture (Fig. 2. a) gaps between plates of facing connect an air layer with the atmosphere therefore on a windward side cold air is blown to the canal with shown in drawing by a high-speed pressure. It leads to violation of the movement of a stream vertical up and to degradate air output of in an air layer. It is a negative factor.

How we can see from picture (Fig. 2. b) on lee side air from an air layer flows away in the atmosphere. It too a negative factor as the air output degradation from below up decreases..

How we can see from picture (Fig. 2. c) the high-speed pressure changes from zero at a facade socle to the maximum value at the next gap between facing plates. The high-speed pressure doesn't reach values characteristic for ideal designs anywhere.

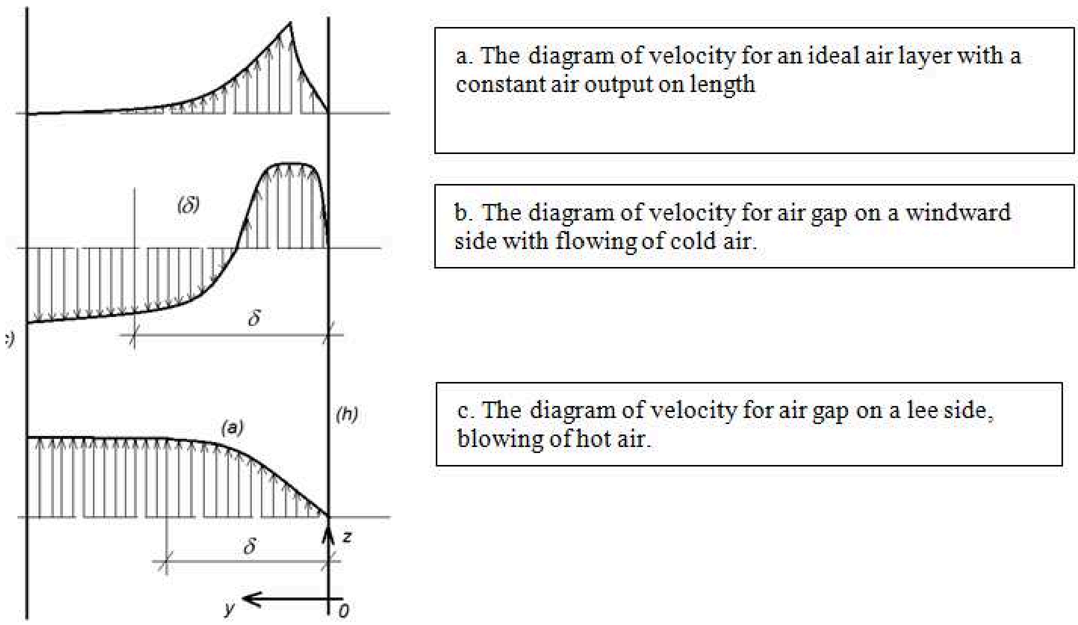

Figure 3. a,b,c. The diagrams of velocity for three cases

The ideal case provides gradual spreading of an diagram of velocity on all width of the channel and stabilization of a flow at height (The diagram a).

The worst case is shown on an diagram «b»: the air output in the ventilated air layer can reduce to zero and the directed movement from below up won't be.

Diagram «c» shows that the speed gradient at a wall falls, in proportion to a gradient the heat transfer decreases.

After the numerical experiment described in paper [2] was repeated with all same conditions, but the design already was same as real (Fig. 4-5).

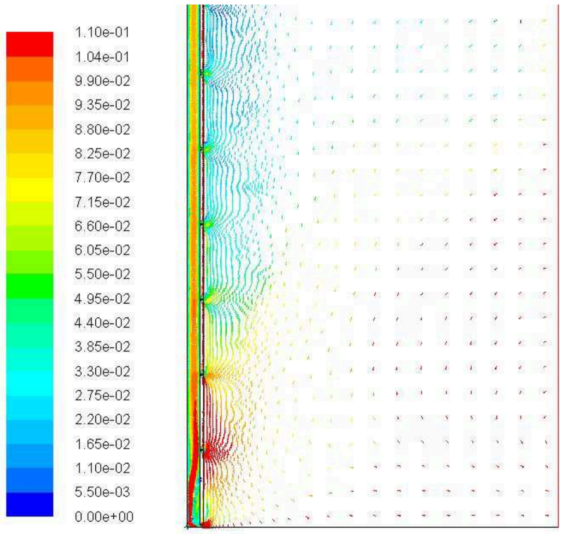

Figure 4. Speed vectors (numerical simulation for a real double skin facades)

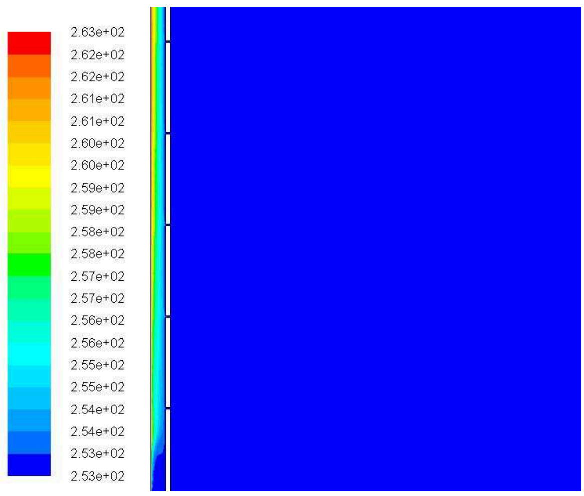

Figure 5. Temperature (numerical simulation for a real double skin facades)

Creation of numerical models of real designs showed considerable reserves in their improvement. When modeling real knots of an adjunction of systems to a building socle were considered, seams between facing plates (gaps 8-10 mm) were considered. And as it is possible to see in figures designs don't provide optimum conditions for course of thermogravitational convection without providing fully optimum heatmoist the building mode. Cold air in the bottom of a design has no free access in an air layer to provide the movement of an air stream vertically up (designers and producers of systems of double skin facades aspire to it). The air getting through seams between facing plates on all height of a facade, on the contrary, "lowers" warm air, again without allowing to move it vertically up.

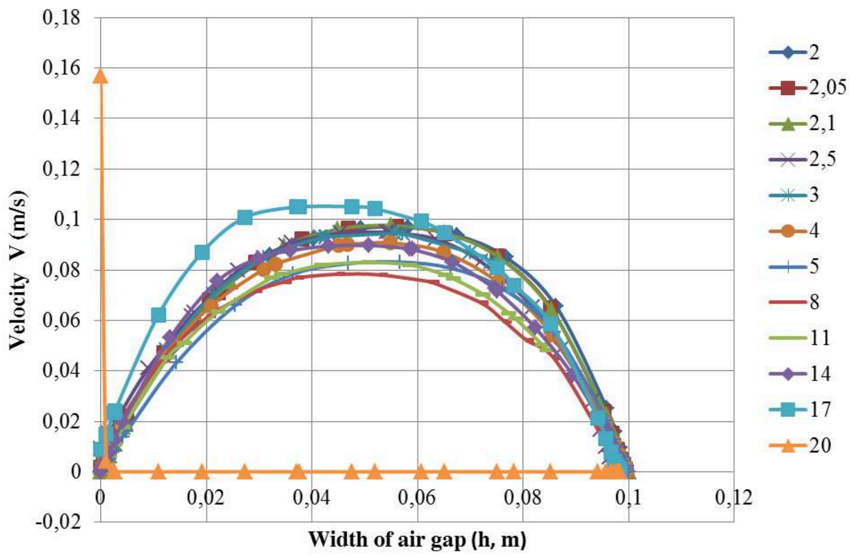

Figure 6. Dependence of velocity of flow from geometrical parameters of an air layer (numerical simulation of real double skin facades).

Velocity has much less, than and on the maximum mark speed becomes equal in an ideal (settlement) design to zero. In ideal designs velocity on width of an air layer is distributed rather evenly. In a real design the maximum of speed is reached only in one point - in the middle of a layer. The interface is distributed practically on all width of a layer, the coefficient of a heat transfer is small, removal of moisture the inefficient (Fig. 6).

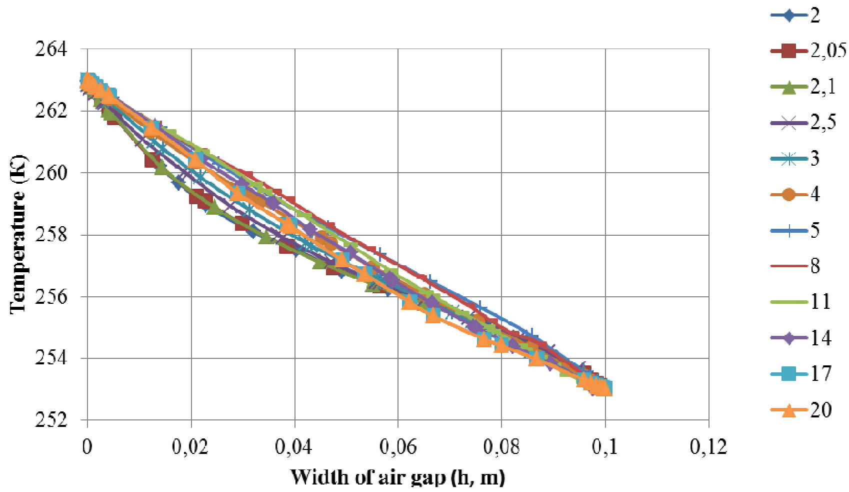

Figure 7. Dependence of temperature of flow from geometrical parameters of an air layer (numerical simulation of real Double skin facades).

From drawing it is visible that distribution of temperature in real designs almost linear.The interface is distributed practically on all width of a layer, the coefficient of a heat transfer is small, removal of moisture the inefficient (Fig. 7).

Decisions for improvement of the double skin facades

What solutions can be proposed for elimination of the found defects of double skin facades? First, it is necessary to provide free flowing of cold air in the lower part of a facade in order that it could accelerate an air stream in an air layer vertically up. It would ensure optimum functioning of this osystems. The moisture emitted in life wasn't condensed on a design, and was removed with air. Having it can be done made minor constructive change: having replaced the lower layer of tiles with ventilating grates on ordinary diffusers on all perimeter of the building (Fig. 8).

Figure 8. Improvement of designs of double skin facades

After it is possible to vary: to make lattices adjustable, depending on the wind force surrounding building temperatures, even from time of day and the mode of the building. It is possible with automatic or manual control.

Secondly, it would be possible to offer sealing of gaps between facing plates. They are arranged for compensation of temperature deformations if gaps were pressurized by some elastic material, it would allow to optimize double skin facades.

Even addition of the diffuser in a design, without sealing of rust, favorably affects its work. For the proof of this fact modeling in the program Ansys complex was carried out.Ansys.

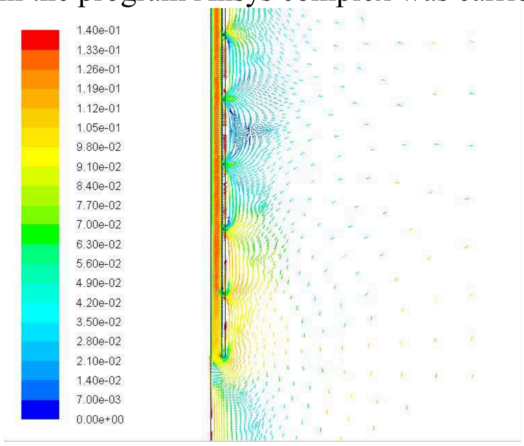

Figure 9. Speed vectors (numerical simulation for a real double skin facades with open access of air ((at use of the diffuser instead lower line of facing plates))

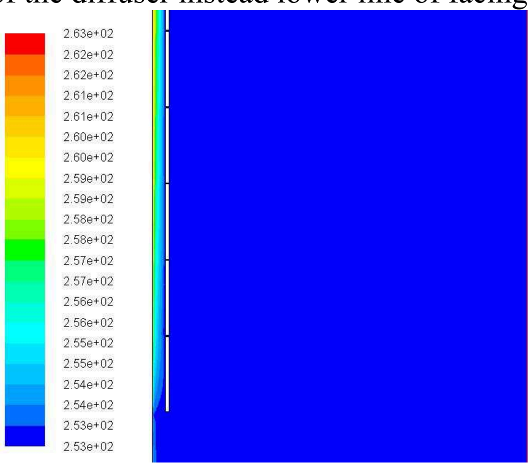

Figure 10. Temperature (numerical simulation for a real double skin facades with open access of air((at use of the diffuser instead lower line of facing plates))

As it is possible to see (Fig. 9-10) at addition of real double skin facades with the diffuser it is possible to observe positive effects. Velocity of flow become more, rates of change of temperature increase.

By results of modeling of real double skin facades with open access of air (with the diffuser) dependences of velocity and temperature on geometrical characteristics of an air layer were received (Fig.11, 12).

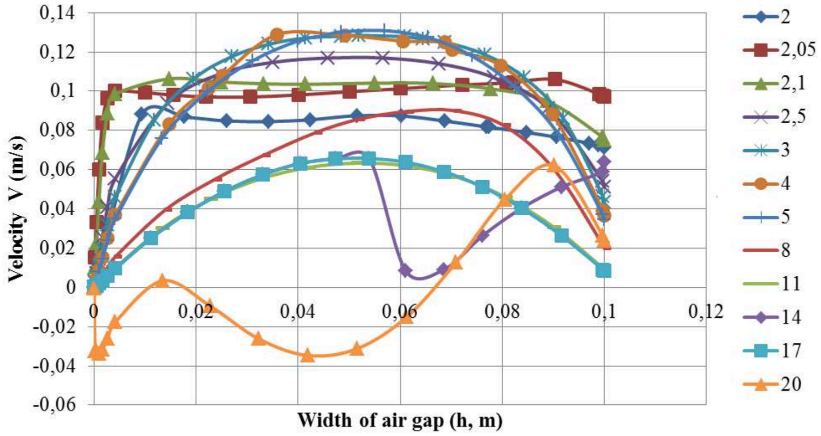

Figure 11. Dependence of velocity of flow from geometrical parameters of an air layer (numerical simulation for a real double skin facades with open access of air ((at use of the diffuser instead lower line of facing plates))

From pictures (Fig. 11) it is visible that at addition of a design with the diffuser, speeds increased, but open gaps between plates of facing lead to formation of zones of recirculation that not always allows to move to a stream in the necessary direction.

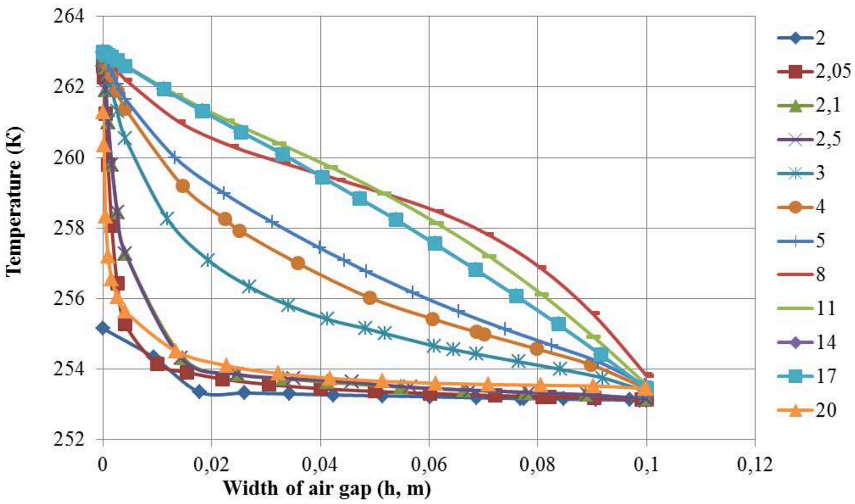

Figure 12. Dependence of temperature of flow from geometrical parameters of an air layer (numerical simulation for a real double skin facades with open access of air ((at use of the diffuser instead lower line of facing plates))

From pictures (Fig. 12) it is visible that distribution of temperature in an advanced design not linear, convection is present, temperature gradients on a hot wall grew, coefficients of a heat transfer increased, removal of moisture and warming up of air became more intensive in comparison with real designs.

It is noted that speeds in the settlement (offered) designs are made by not lower than 1 m/s, in real designs - 0.07-0.08 m/s, in real designs with open access of air of 0.1-0.14 m/s.

Summary

Numerical modeling of a flat stream in the conditions of thermogravitational convection was made. Lines of pressure for a stream with the movement up in the vertical flat channel for various conditions are built.

High-speed and temperature fields for an air stream for real double skin facades with gaps between plates of facing and the closed entrance for a stream to an air layer are constructed.

The directions are determined by practical application of the received results for adoption of optimum design decisions and to improvement of the existing double skin facades which consist in the following:

1. To alter a design of the double skin facades, having added it with the diffuser which is installed instead of the first row (lower) of facing plates in a design adjunction place to a socle on all perimeter of the building.
2. To provide sealing of rust with elastic material on all height of a facade in the vertical and horizontal directions.

It is noted that speeds in the settlement (offered) designs are made by not lower than 1 m/s, in real designs - 0.07-0.08 m/s, in real designs with open access of air of 0.1-0.14 m/s.

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Reduced Thermal Resistance of a Two-layer Wall Construction

Alexander Gorshkov[1,a], *Ekaterina Ivanova[2,b]

[1,2]Saint-Petersburg State Polytechnical University, Polytechnicheskaya, 29, 195251, St. Petersburg, Russia

[a]alsgor@yandex.ru, [b]Kat9304@yandex.ru

Keywords: Energy efficiency, thermal resistance, aerated autoclaved concrete, coefficient of heattechnical uniformity, two-layer wall construction, thermal protection, heattechnical heterogeneity

Abstract. The topic of the article regards to the development of new SP 50.13330.2012 "Heat protection of buildings" actualized edition of SNIP 23-02-2003. The article focuses on the reduced thermal resistance, which takes into account the influence of thermally conductive inclusions by the coefficient of heattechnical uniformity.

Introduction

At present one of the most common options for filling the outer thermal protection envelope of enclosure in the practice of designing and constructing buildings with monolithic reinforced concrete framework and floor-by-floor leaning exterior walls on monolithic or precast reinforced concrete floor slab is a constructive solution of the wall which consists of two layers (Fig. 1a)

– Internal nonstructural layer made of aerated autoclaved concrete blocks thickness of 300 – 400 mm, depending on the region construction and its climatic parameters;

– The external covering layer of the facing brick thickness in one or two bricks.

The overview

In recent years all over the world in the construction of residential buildings emphasis on low energy consumption and the construction of energy-efficient buildings. In the last decade in Europe, energy efficiency of buildings has been one of the main directions of development of the construction industry [1-9]. Standard documentation of the European countries contributes to this objective, in most developed countries of the world the norms of energy consumption by buildings constantly decreasing, and requirements to the level of thermal insulation enclosing structure increase [9-17].

There is an inverse dynamics in the Russian Federation. After the release of the federal law no. 261-FZ of November 23, 2009 "On Energy Saving and Raising of Energy Efficiency and on Introduction of Changes into Some Legislative Acts of the Russian Federation" [18], Ministry of Regional Development of the Russian Federation has approved the Code SP 50.13330.2012 [20], which applies from 2013. The Code SP 50.13330.2012 [20] is actualized edition SNIP (Construction Norms and Regulations) 23-02-2003 "Heat protection of buildings" [19]. The authors of the article «Influence of building envelope thermal protection on heat loss value in the building» [12] carried out a comparative analysis on the example of a 25-storey building. Heat losses were 20 % more through the exterior building envelope, which was built to the minimum requirements of the code SP 50.13330.2012 [20], than the same building, the design of which had the minimum requirements of the norms SNIP 23-02 [19].

The topic of the article regards to the development of new SP [20] for thermal protection. The article focuses on the reduced thermal resistance, which takes into account the influence of thermally conductive inclusions by the coefficient of heattechnical uniformity. The projects are transmission heat losses (losses through the exterior building envelope) are larger than the design, and the energy released by heating is not enough. [21-22].

The joint of the aerated autoclaved concrete blocks also affect to the reduced thermal resistance. In order to reduce the influence of masonry joints on the thermal homogeneity of the walls of concrete blocks and reduce the additional heat loss through the joints, masonry performed on glue with a minimum thickness of joints (2 ± 1 mm). It is also necessary to seek to decrease the coefficient of thermal conductivity of masonry mortar [23-25]. The authors of article "Influence of masonry mortar joints on the parameters of thermal homogeneity of the walls of aerated autoclaved concrete" [23] calculated the reduced thermal resistance of masonry walls of aerated autoclaved concrete blocks grade density D400 thickness of 375 mm, made with glue joints with an average thickness of 2 mm. Coefficient of heattechnical uniformity is r = 0.93.

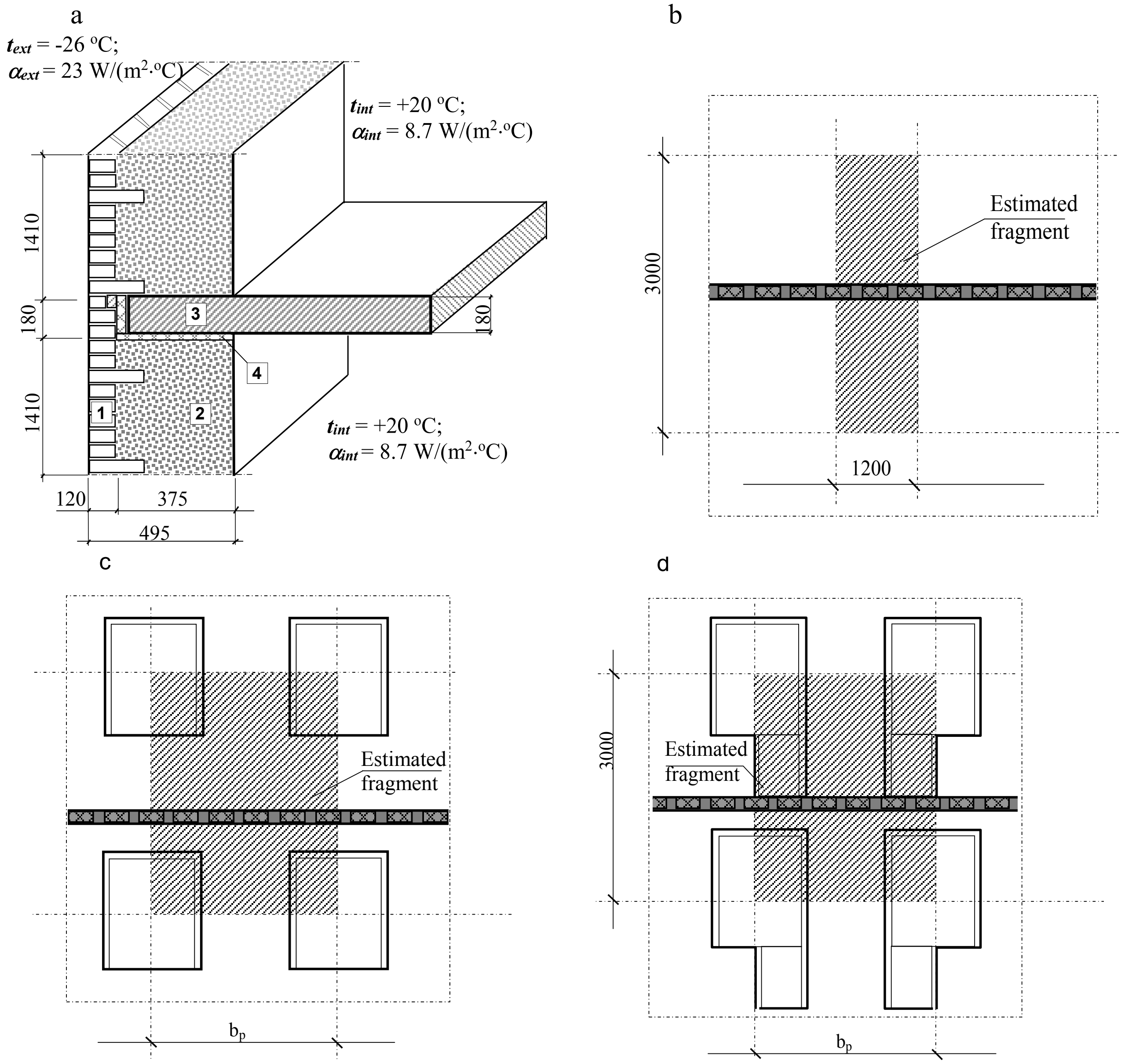

Figure 1. Constructive solution (a) and scheme of estimated fragments (b, c, d) of the external two-layer wall: 1 – brick masonry of ordinary clay bricks; 2 – masonry of aerated autoclaved concrete blocks grade density D400; 3 – reinforced concrete; 4 – layer of thermal insulation

Description of the construction of the wall fencing

In considered constructive solution the internal layer of the wall fencing performs the function of thermal insulation, the external layer performs the function of protection from climatic exposure, provides the desired durability of facades and architectural forms of the building. It is believed that this design solution meets the requirements of the thermal protection for the majority of regions of the Russian Federation. The traditional solution in St Petersburg is a wall enclosure, in which the thickness of the aerated autoclaved concrete is 375 mm. A schematic representation of this constructive solution is presented in Fig. 1

Regulatory Requirements

In accordance with SNiP 23-02 [19] installed three parameters of the thermal protection for buildings:

a) reduced thermal resistance of the individual elements of the building envelope;

b) Sanitary, including the temperature difference between the temperature of the inside air and on surfaces of enclosures, and the temperature on the internal surface above the dewpoint;

c) the specific consumption of thermal energy for heating the building, which allows to vary the quantities of thermal protection properties of different types of building envelopes with the space-planning arrangement of a building and the choice of microclimate control systems to achieve the rated value of this parameter.

In accordance with the requirement of item. 5.3 SNiP 23-02 [19], reduced thermal resistance R_0^r of the building envelope should be not less than rated values R_{req}, which is determined according to Table 4 SNIP 23-02 [19], depending on the degree-days heating period of the construction region.

Degree-days heating period for residential buildings, located in the city of St. Petersburg, according to Table. 3 RMD (regional methodological document) 23-16-2012 "Saint Petersburg. Recommendations to ensure the energy efficiency of residential and public buildings" [26] are 4796°C·day, rated value of reduced thermal resistance to the exterior walls of residential buildings is 3.08 m^2·°C/W [26, Table. 9]. In this case, item.5.13 SNIP 23-02 [19] admits a reduction of the rated value of the reduced thermal resistance for walls of residential and public buildings by 37 % in the accomplishment requirements "c" item.5.1. Thus, in this case, the minimum permissible value of the reduced thermal resistance of the exterior walls of residential buildings, designed in the territory of St. Petersburg, should not be less than: R_{min} =0.63×3.08=1.94 m^2·°C/W [19, the formula (8)].

Purposes and research problems

According to the requirements of item. 5.6 SNIP 23-02 [19], reduced thermal resistance for exterior walls should be calculated for the facade of the building or to one of the intermediate floor with soffits without their fillings.

Consider a specific example of how this requirement is implemented in practice. To do this, perform the above calculation of the thermal resistance of exterior walls of the intermediate floor of the typical apartment building with a structural monolithic-frame scheme and two-layer exterior walls, schematically represented in Figure 1, and compare the value obtained with the regulatory requirements for thermal protection. To do this we will perform the calculation of the reduced thermal resistance of the exterior walls of the intermediate floor of a typical apartment building with structural monolithic framing and two-layer exterior walls, and compare the resulting value with the regulatory requirements for thermal protection. The general form of walls is shown schematically in Fig. 1.

The purpose of the research is to determine the reduced thermal resistance R_0^r of the exterior walls of the middle intermediate floor apartment building and compare the resulting value with rated R_{req} and minimally permissible R_{min} values reduced thermal resistance of exterior walls of a residential apartment building.

Initial data for calculation of thermal parameters

Initial data:
– The construction region – the city of St. Petersburg;
– Purpose of the building – residential;
– Design temperature of indoor air – t_{int} = 20°C;
– Design temperature of outdoor air – t_{ext} = -26°C;
– Zone of moisture – wet;
– Moisture conditions building space – normal;
– Operating conditions walling – "B".
Thermal feature of materials used in the composition of wall fencing:
– Cement-sand mortar γ_o = 1800 kg/m^3; λ_B = 0.93 W/(m^2×°C);
– Bricklaying of ordinary clay bricks on cement-sand mortar γ_o = 1800 kg/m^3; λ_B = 0.80 W/(m^2×°C);
– Masonry of wall aerated autoclaved concrete unreinforced blocks density γ_o = 400 kg/m^3; λ_B = 0.14 W/(m^2×°C).
Boundary conditions:
– heating capacity coefficient for interior side of a building envelope; α_{int} = 8.7 W/(m^2×°C);
– heating capacity coefficient for window unit; α_{int} = 8.0 W/(m^2×°C);
– heating capacity coefficient for exterior side of a building envelope under the conditions for the cold season, applicable for exterior walls and window; α_{ext} = 23.0 W/(m^2×°C);
The design schemes of the fragments of exterior walls are shown in Fig. 1b, 1c, 1d.

Results of calculation

The reduced thermal resistance of the considered fragments of thermal protection of the building envelope is calculated on the basis of calculation of the temperature fields. The essence of the method consists in the simulation of steady process heat transfer through the building envelope using computer programs. The method is designed to evaluate the temperature and the calculation of the reduced thermal resistance of building envelopes or parts of structural taking into account the geometrical shape, location and characteristics of the structural and thermal insulating layers, ambient air temperature, surface heating capacity coefficient. In this case, the calculation is made using the software package TEMPER 3D [28, 29].

Value of the reduced thermal resistance of the middle of intermediate floor R_0^r determined on the basis of the calculation of reduced resistance of several fragments $R_{0,i}^r$ taking into account the heat loss through the ends of the floor slabs, soffits window unit and balcony doors. In particular:
– Fragment of a blank wall without openings, dimensions of height is equal to the height of the floor h = 3.0 m, width is 1.2 m (Fig. 1b);
– Fragment of the wall with window openings, dimensions of height is equal to the height of the floor h = 3.0 m, width is equal to the distance between the axis of the window openings (Fig. 1c);
– Fragment of the wall with the balcony door, dimensions of height is equal to the height of the floor h = 3.0 m, width is equal to the distance between the axis of the piers (Fig. 1d).
The results are presented in Table 1.

Table 1. The characteristics of the estimated fragments of the exterior walls of the intermediate floor of a residential building

No. of fragments	Features a constructive solution of the wall	Reduced thermal resistance $R^{r}_{0,i}$, [m^2×°C /W]	Area, A_i, [m^2]
1	Fragment of the blank wall (without openings)	2.09	61.20
2	Fragment of the blank wall with a column (without openings)	1.73	94.68
3	Fragment of the wall with window openings (with insulation soffits)	1.76	82.12
4	Fragment of the wall with the balcony door (taking into account glazing balconies)	1.77	40.90

Reduced thermal resistance of exterior walls of the middle of the intermediate floor of an apartment building R^{r}_{0} with the fragments area of the walls on the facades of the building, calculated by formula (22) SP 23-101-2004 “Design of thermal protection of buildings” [27] is:

$$R^{r}_{0}=\frac{\sum\limits_{(i)} A_i}{\sum\limits_{(i)}\left(A_i/R^{r}_{0,i}\right)}=\frac{61.20+94.68+82.12+40.90}{\frac{61.20}{2.09}+\frac{94.68}{1.73}+\frac{82.12}{1.76}+\frac{40.90}{1.77}}=1.81\,(m^2\times°C/W), \quad (1)$$

By using the formula (8) SP 23-101 [27], we calculate conditional (excluding the influence of thermally conductive inclusions thermal homogeneity of the walls) thermal resistance R_o consider constructive solutions:

$$R_o=R_{si}+R_k+R_{se}=R_{si}+\sum_{i=1}^{n}\frac{\delta_i}{\lambda_i}+R_{se}=\frac{1}{8.7}+,\frac{0.375}{0.14}+\frac{0.12}{0.8}+\frac{1}{23}=2.99\,(m^2\times°C/W), \quad (2)$$

where $R_{si}=1/\alpha_{int}$, α_{int} – heating capacity coefficient for interior side of a building envelope, W/(m^2×°C), taken from Table. 7 SNIP 23-02 [19];

$R_{se}=1/\alpha_{ext}$, α_{ext} – heating capacity coefficient for exterior side of a building envelope under the conditions for the cold season, W/(m^2×°C), taken from Table 8 SP 23-101 [27];

R_k – thermal resistance of the enclosing structure with successive homogeneous layers (m^2×°C)/W;

δ_i – the thickness of the i-th layer of a multilayer enclosing structure, m;

λ_i – thermal conductivity of i-th layer of a multilayer enclosing structure, W/(m^2×°C), received for the conditions “A” or “B” depending on the Zone of moisture of the construction region and moisture conditions of the premises. [30]

Further on, one may determine the coefficient of heattechnical uniformity r of the exterior wall of a typical intermediate floor with the soffits without their fillings:

$$r=\frac{R^{r}_{0}}{R_0}=\frac{1.81}{2.99}=0.61\ , \quad (3)$$

The author of the work “Thermalphysic Problems of Contemporary Wall Enclosure Structures of Buildings” [31] had a similar design solution and got even lower the calculated value of the coefficient of heattechnical uniformity r = 0.48. Differences in the coefficients of heattechnical uniformity may be due to differences made in project design solutions, the quantitative and qualitative composition of the thermally conductive inclusions. Also the heattechnical heterogeneity of wall constructions depends on the quality of the installation. In the same paper [31], in particular, noted that the thermal resistance of a two-layer curtain wall, measured in natural conditions, from a survey of fifteen thermogram was 1.3÷1.5 (m^2×°C)/W (conditional thermal resistance of the wall fence R_o = 3.92 (m^2×°C)/W) [31]. This means that the actual coefficient of heattechnical uniformity may be even smaller than the calculated values (as considered in [31] example: $r = (1.3 \div 1.5) / 3.92 = 0.33 \div 0.38$). As one of the possible causes of discrepancy Gagarin [31] notes the poor quality construction, due to the fact that the construction site can enter blocks of irregular shape. Indeed, the presence of cracks, faults, potholes and other defects in products, can lead to a waste of mortar [32], which acts as an additional thermally conductive inclusions, which are not considered in the calculation.

It should be noted that the actual moisture of the aerated autoclaved concrete product may significantly exceed the design in the initial period of operation [32]. In this regard, the thermal conductivity of the products of the aerated autoclaved concrete may be provided is higher than the calculated values adopted in the project, since the thermal conductivity of the material depends on the moisture content of the mass.

Conclusion

In consequence of calculations formulated the following conclusions:

1. Reduced thermal resistance R_0^r of a two-layer wall construction consisting of an inner self-supporting layer of aerated autoclaved concrete unreinforced wall blocks grade density D400 and outer lining layer of ceramic facing brick thickness of 120 mm, calculated on the basis of the calculation of temperature fields for a typical intermediate floor of an apartment building is 1.81 m^2×°C/W.
2. The construction of the wall fencing considered in the article (Fig. 1) does not satisfy the regulatory requirements for thermal protection (R_{req} =3.08 m^2×°C/W.).
3. The construction of the wall fencing shown in fig. 1 does not satisfy the minimally permissible requirements of the thermal protection (R_{min} =1.94 (m^2×°C)/W).
4. Coefficient of heattechnical uniformity of the construction of the exterior walls made of masonry of the aerated autoclaved concrete blocks mark density D400 with the lining layer of facing bricks, does not exceed 0.61.
5. The actual value of the Coefficient of heattechnical uniformity considered constructive solutions, taking into account the quality of products delivered to the site and the quality of their installation [31], can be considerably smaller than the calculated value.
6. In order to ensure compliance with regulatory requirements for the thermal protection of the exterior walls of buildings as part of wall fencing (Fig. 1) should either increase the thickness of the aerated autoclaved concrete blocks as part of the two-layer wall structure, or use an intermediate layer of thermal insulating material with a calculated thermal conductivity of not more than 0.05 W/m·°C. Layer of thermal insulation should be placed between the aerated autoclaved concrete layer and facing layer.
7. In all cases, there should be ventilated gap between the thermal insulation layer and facing brick, the effective cross section of the gap (thickness) must be determined calculation. It is necessary for the efficient removal of moisture from the structure wall fencing.

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Unsteady Temperature Condition Of The Enclosure Structure

Mikhail Petrichenko[1,a], Darya Tarasova[2,b *], Darya Nemova[3,c]

[1,2,3] St. Petersburg State Polytechnical University, Polytechnicheskaya st. 29, 195251, St. Petersburg, Russia

[a]fonpetrich@mail.ru, [b]tarasovads@gmail.com, [c]darya.nemova@gmail.com

Keywords: External temperature fluctuations, energy efficiency, heating system, external enclosure structures, emidiurnal variations, energy consumption, thermal stability of cladding structures.

Abstract. In this article the influence of external temperature fluctuations on temperature of the enclosure structures are defined, a selection of optimum heating system for thermal energy saving are offered, thickness of penetration layer of a temperature wave are defined. Fourier's differential equation of heat conductivity process in a solid body is solved and analysed.

Introduction

To maintain constant air temperature in winter time it is required to supply space heating in a variable number according to the variations of temperature on the enclosure structure inside face caused by external temperature changes. Property of enclosure structure to resist temperature changes is called thermal stability of cladding structures [3-29].

If there were no windows it would be practically possible to maintain constant inside temperature in the building without heat supply changing of heating system during a day despite of diurnal variation of external temperatures [1].

The systems without automatic regulation of temperature are possible to use until the emidiurnal variations of external temperatures completely attenuate in enclosure structure.

The diurnal atmospheric internal temperature changes at a constant heat supply of heating will be the same as temperature changes of the unheated space. Heating will affect only the average room temperature [25].

The design of heating system with a condition that heating breaks were possible at any external temperatures can't be acquitted economically. However breaks in the interruption at a sufficiently high external temperatures will save energy consumption. How great will be the energy saving can be calculated knowing the curve of the winter temperatures.

Gagarin V.G. offered to use the integrated indicator (specific heat transfer coefficient of the enclosure structure) to normalize the thermal protection of the enclosure structure. The specific heat transfer coefficient includes data of thermal protection of all enclosure structure. The difference of proposed metric is that it does not include ventilation parameters, insulation, heat emission of the building. This approach to normalization of thermal protection will allow to determine the weakest elements of constructive solutions in thermal protection matters of the building. Application of this complex indicator will allow to increase significantly energy efficiency of the buildings .

V.N. Bukhartsev has proposed procedure that makes it possible to assign the rate of drop in water level in the upper pool which eliminates failure of earthen structures in the surveys [2-3].

V.N. Bukhartsev offered to replace the traditional Dupuis formula by the condition of the minimum of the functional reflecting the average quadratic norm of the departure of the curvilinear profile of the free surface from a straight line in the surveys.

V.N. Bukhartsev has derived an energy-balance equation for an integral flow with a variable flow rate over a particular length. The equation has been applied to the confluence of flows [4]. Other major factors have been also analyzed [5]. V.N. Bukhartsev has presented [6-8] an algorithm for the problem of flame propagation rate in combustion of a homogeneous fuel-air mixture in a cylinder of an internal combustion engine. The principles presented can be used as the basis of an algorithm for heat liberation rate in an internal combustion engine with external mixture formation.

The purposes of this work are definition of influence of external temperature fluctuations on temperature of the enclosure structures, a selection of optimum heating system for thermal energy saving , determination of thickness of penetration layer of a temperature wave.

For achievement of the purpose it is necessary to solve and analyse the Fourier's differential equation of heat conductivity process in a solid body.

The setting of the limit problem

The problem of instant distribution temperature of uniform solid body (in this case enclosure structure) is considered x>0 (Fig.1).

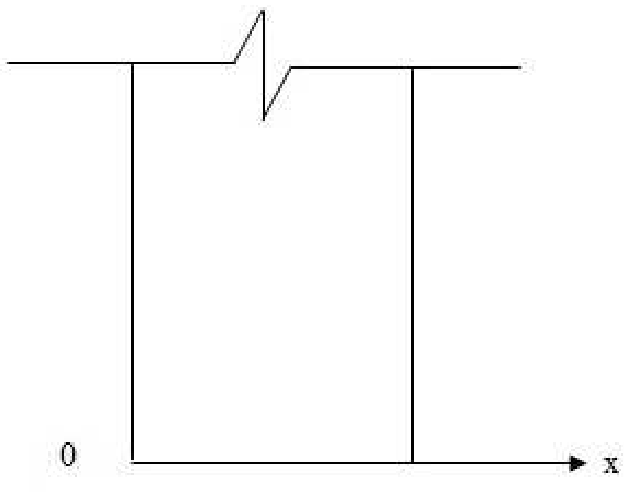

Figure 1.The uniform solid body (enclosure structure).

The heat extends according to linear Fourier's law. The heat transfer of enclosure structure with surrounding environment takes according to the law of external heat transfer. Any periodic change of external temperatures and heat supply is allowed. The limit Fourier's problem for periodic heat supply is:

$$\frac{\partial T}{\partial \tau}=\frac{\partial^2 T}{\partial \xi},D(T)=(-\infty<\tau<\infty,\xi>0),T\in C^{(2)}(D)$$
$$-\left(\frac{\partial T}{\partial \xi}\right)_{\xi=0}+h(\tau)(T(\tau,\xi)-T_e(\tau))=0, \tag{1}$$
$$T(\tau\pm 1,\xi)-T(\tau,\xi)=0.$$

From formula (1) $\tau:=\frac{t}{t_0},\xi:=\frac{x}{\sqrt{at_0}},h:=\alpha\sqrt{\frac{t_0}{\lambda\rho C_p}}$; T_e— external temperature; t_0-time period of temperature change. The frequency condition on time is equivalent to such entry condition:

$$T(-\infty,\xi)=0$$

The solution of the Fourier's equation

The temperature distribution is searched in the form:

$$T(\tau,\xi)=a(\tau)e^{-\xi}+b(\tau)e^{-2\xi} \tag{2}$$

The Fourier's equation with variable boundary conditions of the third kind (as in this problem) can not be solved by classical methods(spectrum analysis).

The differential Fourier's equation (Eq. 1) is replaced by the integral relation:

$$\frac{d}{d\tau}\int_0^{\infty} T(\tau,\xi)d\xi = -\left(\frac{\partial T}{\partial \xi}\right)_{\xi=0} \tag{3}$$

Procedure of data to an integral relation (Eq. 3) is equivalent to use of a thermal balance condition of a wall in general. This approach is applicable to nonlinear problems. In the left part of this equality the integral is calculated according to the theorem Bonn:

$$\int_0^{\infty} T d\xi = T_0\delta, \tag{4}$$

where δ=δ(t) - thickness of a temperature fluctuations layer, $T_0(\tau):=T(\tau,0)$.

Then to determine the coefficients of the functions a(τ), b(τ) get the equality:

$$\begin{aligned} a(t) &= T_0(t)(h+2) - hT_e(\tau), \\ b(\tau) &= hT_e(\tau) - (h+1)T_0(\tau), \end{aligned} \tag{5}$$

Besides $T_0\delta = T_0\frac{h+3}{2} - \frac{hT_e}{2}$.

Bonnet's theorem (Eq. 4) allows entering layer thickness fluctuations obviously and showing that whole structures except a layer of fluctuations remains with a constant temperature, i.e. it performs the function of warmth accumulator. This way easily adapts on multilayered walls and on nonlinear conditions of a heat transfer (radiation, an infiltration, etc.).

For determination of temperature on a wall surface $T_0(\tau)$ the linear equation of the first order with a zero initial condition turns out:

$$\frac{d}{d\tau}\left(T_0\frac{h+3}{2} - \frac{hT_e}{2}\right) + hT_0 = hT_e, T_0(-\infty) = 0 \tag{6}$$

Heat transfer coefficients h according to construction norms usually are constant, not time-dependent, not distributions dependent.

Let $\frac{2h}{h+3} := k, 0 < k < 2$.

It means:

$$\begin{aligned} T_0(\tau) &= \frac{k}{2}T_e(\tau) + \left(1-\frac{k}{2}\right)\left(1+\frac{1}{k}\frac{d}{d\tau}\right)^{-1} T_e(\tau) = T_e(\tau) - \left(1-\frac{k}{2}\right)\frac{1}{k}\frac{dT_e}{d\tau} + \ldots, \\ T_0\delta &= \frac{h}{2}T_e + \frac{h}{k}\left(1-\frac{k}{2}\right)\left(1+\frac{1}{k}\frac{d}{d\tau}\right)^{-1} T_e. \end{aligned} \tag{7}$$

The analysis of the received solution of the Fourier's equation

Let k→2-0 (h→∞). Then evenly on τ, $T_0 \to T_e$ (temperature of a wall surface trends to environment temperature).

Let h→0, k→0. Then it is approximate: $T_0(\tau) = T_e(\tau) + \frac{dT_e}{d\tau} - \frac{1}{2k}\frac{d^2T_e}{d\tau^2} + \ldots$ also the top and lower borders for a wall surface temperature assessment turn out.

The product $T_0\delta$ is proportional to warmth accumulation in a wall. With growth h accumulation increases $T_0\delta \to T_e h/2$, $\delta \to h/2$.

For tasks construction heating engineers h is limited and $T_0\delta$ changes proportionally to $\frac{3}{2}\left(1+\frac{3}{2h}\frac{d}{d\tau}\right)^{-1}T_e(\tau)=\frac{3}{2}T_e(\tau)-\frac{9}{4h}\frac{dT_e}{d\tau}+\ldots$.

In this case thickness of penetration layer of a temperature wave in shares $(at_0)^{1/2}$ makes:

$$\delta=\frac{\frac{3}{2}T_e(\tau)-\frac{9}{4h}\frac{dT}{d\tau}}{T_e(\tau)+\frac{dT_e}{d\tau}} \tag{8}$$

It turns out that:

1. accumulation capacity of the wall varies with changes of the external heat transfer. For large values of the external heat transfer coefficient the thickness of penetration layer of a temperature wave in shares $(at_0)^{1/2}$ make size of order h;
2. for heat-insulating materials thickness of a temperature fluctuations layer is small and temperature of material doesn't influence on wall temperature: in a wall there is a slow aperiodic mode of heating (cooling);
3. high-frequency (daily, week) fluctuations of temperature are localized in a thin fluctuations layer and don't cause noticeable change of average temperature of a wall on big times.

Resume

In the research the following conclusions were made:

1. the typical construction possesses considerable thermal stability of cladding structures. The high-frequency vibrations (daily, hour and week) of temperature aren't matter;
2. in this regard there are reserves for use of warmth accumulation of enclosure structure for realization of economy of energy saving in heating technology (on the simple: to heat the house periodically : to heat 2-3 hours in the afternoon, to block gates and not to heat at night).

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Unsteady Airway As An Effective Method Of The Ice Melting Prevention On The Building's Roof

Anna Suslova[1, a *], Aleksandr Sivokhin[2,b], Mikhail Petrichenko[3,c]

[1, 2, 3] St.Petersburg State Polytechnical University, Polytechnicheskaya, 29. St.Petersburg, 195251, Russian Federation;

[a]the_october_country@mail.ru, [b]A1sivokhin@gmail.com, [c]fonpetreich@mail.ru

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Abstract. The presence of ice crusts and icicles on roofs is an urgent problem since they influence on the people safety and property which could be situated under roof cornices. There are a lot of methods to stop icicle formation on the roofs. At present article is considered an efficiency of an unsteady airway. The unsteady airway can change its section area depending on the wind speed. Such a constriction allows entering into the attic a big volume of cold air. At that contribution is find a speed of snow melting on the roof featured by the unsteady airway. Speed of the snow melting influence the speed of ice crusting. By estimating these factors can be made a conclusion that the unsteady airway helps to reduce a quantity of ice dams.

Introduction

Heat loss through the building envelope is one of the most important problems in a building's operation. Heat transfer through outer walls increases heating costs, while heat losses through attic floor and roof (apart from the fact that temperature decreases in habitable rooms) cause snow melting on roofs in winter. Within the limits of daily variation of the temperature, water which is generated because of snow melting can freeze and transforms to ice. Consequently, roof of dwelling houses are covered by icicles. Annual roof cleaning measures require considerable expenses from municipal budget. At the same time they are not always effective or timely enough. Roofs are being cleaned as early as possible in order to prevent injuries from falling ice or snow. In the article [1] it is proposed that the way to avoid the ice formation on the roof is by organization of the unsteady airway. The cross-sectional area of this airway changes depending on wind speed and allows a larger amount of air to penetrate into the attic floor. This cold air cools the roof void well enough. The difference between simple and unsteady airway is related to the mobility of the cubicle division. The cubical division isn't made from solid material like plywood, but it is made from light and durable fabric, for example from tarpaulin. Applying rationality is being considered in the current article. For this purpose snow melting speed is calculated.

Literature review

Ice dam formation on the roof due to snow melting is a problem which is being explored by many authors not only in Russia [2-9], but also abroad [10-22]. There are a lot of different ways to reach a solution to the problem and large spectrum of methods can be used to attain such answers. Different authors have quite different ideas about measures for prevention of the ice formation. For example: renovation of the attic floor [8], aerated concrete used for heat insulation of slabs [6], cable heating system for changing the room heat and humidity regimen [19, 20], application of light thin-walled steelwork [3]. Most of these methods involve equipment installation costs, and furthermore, they require exploitation and repair costs. One of the easiest and the most economical ways to prevent ice formation on the roof is organization of the cold attic floor [4, 5, 7, 9-18, 21, 22]. This exact method is estimated in given article.

Setting up of a goal and problems of the work

The goal of work: to explore the possibility of reduction of ice formation on the roof with use of unsteady airways and also to determine the rationality of its usage.

To reach this goal we should set up the following problems:

1. Calculate the speed of ice melting on the flat roof.
2. Calculate water volume which could potentially be transformed into the ice as the temperature of the surrounding environment air is reducing.
3. Estimate the achievement probability of the critical amount of ice being on the roof.
4. Consider the effectiveness of using unsteady airway as a method of reducing the heat input on the roof.

Research description

To reach a decision of the formulated problems it is necessary to define conditions which stimulate snow melting on the specified building roof. Attic floor parameters are taken from the normative documents for residential buildings [23-29]: length 20 m, height 2 m, width 10 m. The slab between the attic floor and upper inhabited floor is made of concrete (thickness 200 mm). Walls are also made of concrete without insulation. The roof consists of sheet iron (thickness 5 mm) on the timber rafters.

According to experimental measurements the attic floor temperature is equal to 6°C while outside air temperature is equal to 0°C. In article [1] there is a conclusion that, using unsteady airways, the attic floor temperature should be equal to 3°C.

For estimation of the snow melting speed on the roof it is possible to use continuity equation for a heat flux which goes through the roof:

$$\frac{\partial h}{\partial t}+\frac{\partial \dot{q}}{\partial x}=0,$$

where $dh=\rho c_p dT$ - differential of the density enthalpy distribution, $\dot{q}=-\kappa\frac{\partial T}{\partial x}$ - heat flux density (can be calculated using Fourier's law). Ratio $a:=\frac{\kappa}{\rho c_p}$ - temperature conductivity coefficient. Owing to admixture conservation (temperature, enthalpy) divergent members absent.

We obtain:

$$\frac{\partial T}{\partial t}=\frac{\partial}{\partial x}\left(a\frac{\partial T}{\partial x}\right). \tag{1}$$

Assume D(T)=(0<t<∞, 0<x<∞), T(0,x)=T(t, x)-1=T(t,∞) – limit conditions for Eq. 1. Instead the simplest (typical) limit conditions it's possible to consider mixed limited conditions. In what follows, we shall accept that homeomorphism f exists: $(0,1)\to R^1$, $f\geq 0$, such that: $\alpha=\alpha_0 f(z)$. Expression $\zeta=\frac{x}{2\sqrt{\alpha_0 t}}$ brings limit task for Eq. 1 to the following view:

$$\frac{d}{d\zeta}\left(f(z)\frac{dz}{d\zeta}\right)+2\zeta\frac{dz}{d\zeta}=0, z(0)-1=z(\infty)=0. \tag{2}$$

Approximative solution Eq. 2 is known:

$$z=\sqrt{\mathrm{erfc}\,(\zeta)}. \tag{3}$$

We can introduce new variables: $\frac{dz}{d\zeta} = j(z), \varphi(z) = \int_0^z \zeta d\tau$, closing a limit task Eq. 1 to limit task Crocco:

$$2\varphi \frac{d^2\varphi}{dz^2} + f(z) = 0, \varphi(0) = \varphi'(1) = 0. \tag{4}$$

Actual equation in the limit task Eq. 1 is being brought to the view: $j\left(\frac{d}{dz}(f(z)j) + 2\zeta\right) = 0$.

Hence, or j=0, or $\frac{d}{dz}(f(z)j) + 2\zeta = 0$. Formally integrate:

$$f(z)j(z) = -2\varphi(z), \varphi(z) := \int_0^z \zeta(t)dt, \varphi(0) = 0, \zeta = \frac{d\varphi}{dz},\ \varphi'(1) = 0, j = \frac{1}{\varphi''(z)},$$

We decide Crocco's equation Eq. 4 on the limit task characteristic. Due to dependence obtained in the work [30] along the characteristic of a limit task the following conclusion is being carried out:

$$\mathcal{H}\left(T, \varphi, \frac{d\varphi}{dT}\right) = \frac{1}{2}\left(\frac{d\varphi}{dT}\right)^2 - \frac{f(T)}{2}\ln\frac{\varphi(1)}{\varphi} = 0, \tag{5}$$

Dividing variables of the differential equation Eq. 5:

$$\int_0^T \sqrt{f(\tau)}d\tau = \int_0^\varphi \frac{d\omega}{\sqrt{\ln\frac{\varphi(1)}{\omega}}}, \tag{6}$$

Due to some variables changes and derivation we obtain functional connection:

$$\int_0^T \sqrt{f(\tau)}d\tau = \sqrt{\pi}\varphi(1)\operatorname{erfc}\left(\sqrt{\ln\frac{\varphi(1)}{\varphi}}\right). \tag{7}$$

Applying Eq. 7 to solving of the task about snow melting on the flat roof of a dwelling house, considering that attic floor is equipped with unsteady airway. Temperature distribution is shown on the Fig. 1.

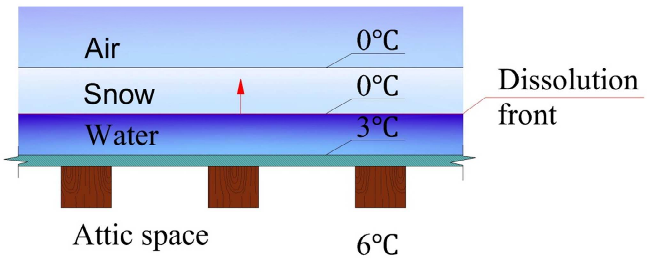

Figure 1. Temperature distribution on the flat roof.

Let us put characteristics for liquid and solid medium:

$$f(T)=f_0,\ 0<T<T_0,$$
$$f(T)=f_1,\ T_0<T<\Omega,$$

where $\Omega=\dfrac{T-T_0}{T_1-T_0}$,T - temperature at the moment, T_0 - snow melting temperature (0°C), T_1 - roof's surface temperature (3°C); f - transfer coefficient.

$$f_0=\alpha_0=\frac{\lambda}{\rho_0 c_{p0}} \text{ - snow;}$$

$$f_1=\alpha_1=\frac{\lambda}{\rho_1 c_{p1}} \text{ - water.}$$

It's necessary to find the front of a snow melting the given moment: $\zeta=\zeta_0$. Due to the ideal contact, there is identical equation:

$$T(\zeta_0-0)-T(\zeta_0+0)=0 \tag{8}$$

Decide Crocco's task on the first interval. It allows finding decision on the second interval. On the first interval task has following view:

$$\begin{aligned}&0<T<T_0,\ 2\varphi_*\varphi_*''+f_0=0,\\&\varphi_*(0)=\varphi_*'(1)=0,\end{aligned} \tag{9$_1$}$$

Moreover:

$$\varphi_*(1):=\Phi_*.$$

Limit task Eq. 9_1 has a decision:

$$\sqrt{f_0}T=\sqrt{\pi}\Phi_*\operatorname{erfc}\left(\sqrt{\ln\frac{\Phi_*}{\varphi_*}}\right). \tag{10$_1$}$$

From decision Eq. 10_1:

$$T_0=\sqrt{\frac{\pi}{f_0}}\Phi_*\operatorname{erfc}\left(\sqrt{\ln\frac{\Phi_*}{\varphi_*(z_0)}}\right). \tag{11$_1$}$$

On the interval $T_0<T<\Omega$ limit task has the following view:

$$\begin{aligned}&2\varphi^*\varphi^{*''}+f_1=0,\\&\varphi^*(z_0)-\varphi_*(z_0)=\varphi^{*'}(1)=0,\end{aligned} \tag{9$_2$}$$

By a similar way, it has decision:

$$\sqrt{f_1}(T_1-T_0)=\sqrt{\pi}\Phi^*\left(\operatorname{erfc}\left(\sqrt{\ln\frac{\Phi^*}{\varphi^*}}\right)\text{ - }\operatorname{erfc}\left(\sqrt{\ln\frac{\Phi^*}{\varphi_0}}\right)\right), \tag{10$_2$}$$