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INVESTIGATION THE EFFECT OF OUTDOOR AIR INFILTRATION ON THE HEAT-SHIELDING CHARACTERISTICS THE OUTER WALLS OF HIGH-RISE BUILDINGS

The presented article considers the influence of infiltrated outdoor air on the heat-shielding characteristics of the exterior walls of modern residential and public buildings. A review of the sources devoted to this problem confirmed its relevance at the present time, especially for high-rise buildings. The authors of the article analyzed the effect of longitudinal and transverse air infiltration on the heat-shielding characteristics of the outer wall of a 25-story building that was built in Samara. The results showed a significant reduction of the reduced resistance to the heat transfer of the outer wall when air is infiltrated through it. There are the results of full-scale examination of external walls to confirm the calculated data. Based on the results of the study carried out by the authors of the article, general recommendations on the internal finishing of the outer walls of high-rise buildings are given.

Keywords: *infiltration, breathability, external wall, resistance to heat transfer*

Рассмотрено влияние инфильтрирующегося наружного воздуха на теплозащитные характеристики наружных стен современных жилых и общественных зданий. Проведенный обзор источников, посвященных данной проблеме, подтвердил ее актуальность в настоящее время, особенно для высотных зданий. Авторами статьи проведен анализ влияния продольной и поперечной инфильтрации воздуха на теплозащитные характеристики наружной стены 25-этажного здания, построенного в г. Самаре. Результаты расчета показали значительное снижение приведенного сопротивления теплопередаче наружной стены при инфильтрации воздуха через нее. Для подтверждения расчетных данных приводятся результаты натурного исследования наружных стен. На основе результатов исследования даются общие рекомендации по внутренней отделке наружных стен высотных зданий.

Ключевые слова: *инфильтрация, воздухопроницание, наружная стена, сопротивление теплопередаче*

Today, following the implementation of an energy saving program in the construction industry in the Russian Federation, substantial changes have been made in the design of the external walls of high-rise buildings. In the construction of multistory buildings, the structures of external walls as presented in Fig. 1 are the most common.

However, as evidenced by the study results reported in [1], external winterization of the brick walls of buildings in the typically variable thermal conditions experienced by country cottages is inappropriate due to the high inertness of the brickwork.

The required thickness of the heat-insulating material or lightweight concrete–stonemasonry is determined based on the regulatory requirements for the thermal protection of buildings, guided by SP 50.13330.2012 “Thermal protection of buildings.”

The influence of longitudinal air infiltration on the heat-protective characteristics of external walls with ventilation facades are discussed in works by V.G. Gagarin, V.G. Kozlov, A.V. Sadchikov [1–4], Yu.S. Vytchikov [5–8], and M.R. Petrichenko [9]. The results of studies of the air permeability of materials and enclosing structures are presented in [10–18].

This goal of this study is to analyze the effect of outdoor air infiltration on the heat-protective characteristics of the external walls of modern high-rise buildings.

The effect of the transverse filtration of outdoor air on the heat transfer resistance of the external wall of a 25-storey building is assessed with respect to the structure shown in Fig. 1b.

The value of the heat transfer coefficient of the external wall, taking into account outdoor air infiltration, is determined using the following equation [6, 19]:

$$k = \frac{c_p \cdot G \cdot e^{c_p \cdot G \cdot R_0^{усл.}}}{e^{c_p \cdot G \cdot R_0^{усл.}} - 1}, \text{ W/(m}^2\text{·°C)}, \quad (1)$$

where cp is the specific heat capacity of air at constant pressure, J/(kg·°C); G is the air permeability of the external wall, kg/(m²·h); and

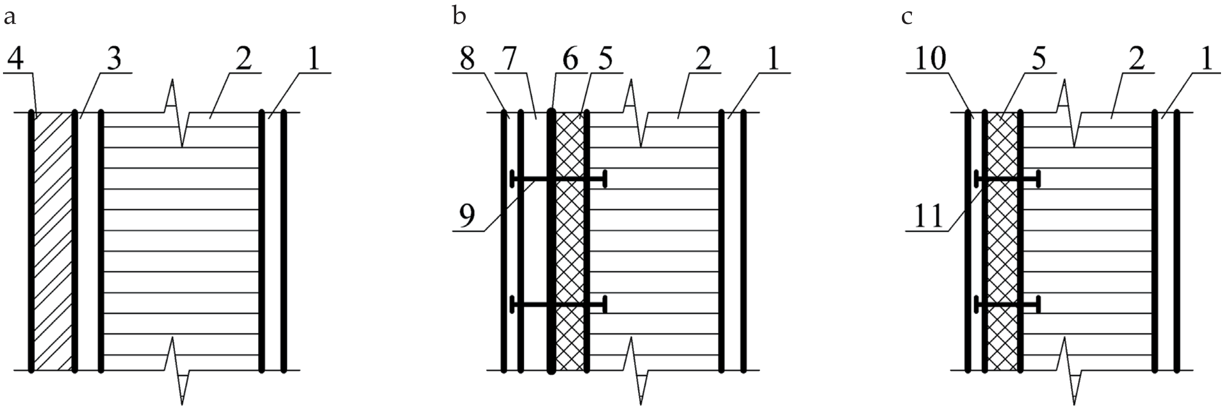


Fig. 1. Constructive solutions regarding the external walls of high-rise buildings: a — external wall made from masonry with lightweight concrete stones; b — external wall with a ventilated facade; c — external wall insulated by a facade system with thin-walled plaster: 1 — interior plastering; 2 — masonry of lightweight concrete stones in cement–sand or warm mortar; 3 — non-ventilated air space; 4 — facing ceramic bricks; 5 — heat-insulating material; 6 — windproof membrane; 7 — ventilated air space; 8 — ornamental panel; 9 — metal bracket; 10 — surface finish layer of the facade system; 11 — plastic dowel.

$R_0^{усл.}$ is the resistance to heat transfer of the external wall surface, (m²·°C)/W.

According to SP 50.13330.2012, the air permeability of an external wall can be determined using the following equation:

$$G = \frac{\Delta P}{R_u}, \text{ kg/(m}^2\text{·h)}, \quad (2)$$

where $R_u = \sum_{i=1}^{n} R_{ui}$ is the resistance to air permeability of the external wall, (m²·h·Pa)/kg; and Rиi is the resistance to air permeability of the i-th layer of the external wall, (m²·h·Pa)/kg.

To determine the air permeability of an external wall, information regarding the air permeability coefficients of the materials used is required, which can be referenced from the regulatory literature.

There is currently no information on the air permeability of facade systems using thin-walled plaster. Therefore, in a laboratory accredited for conducting thermotechnical tests at the Academy of Civil Engineering and Architecture of Samara State Technical University, the air permeability values of the most common heat-insulating materials were determined on an aerodynamic platform developed by laboratory personnel. The research results are presented in [6–11].

Tests of acryl and silicate surface finish layers of facade systems have revealed the absence of air permeability owing to their adhesive contents. Therefore, external walls insulated with facade systems of thin-walled plaster are essentially impermeable.

In addition to tests conducted to determine the air permeability of construction materials, researchers at the Academy of Civil Engineering and Architecture of Samara State Technical University conducted a thermovision study of the heat-protective characteristics of external walls with ventilated facades on a 25-storey building in Samara.

The thermal performance of the enclosing structures of the building was determined in accordance with the requirements of the standard GOST 31937-2011 "Buildings and structures. Rules for inspection and monitoring of technical conditions."

Here, we evaluate the effect of plaster layers on the resistance to air permeability of external walls with ventilated facades, as well as those protected by facing bricks.

A 25-storey building with a warm attic located in Samara is considered for the purposes of illustration. The external walls of this building are constructed with ceramic bricks using a cement–sand mortar 380-mm thick. From the outside, they are insulated with VENTI-BATTS basalt slabs 150-mm thick, and are protected by an Izospan A-type windproof membrane along with a ventilated facade of ceramic granite slabs.

As usable plasters, we considered cement–sand and lime–sand mortars and gypsum plaster in the form of gypsum panels. According to SP 50.13330.2012, the above plasters have their air permeability resistance values listed in Table 1.

The locations of the above materials in the external wall are shown in Fig. 1b. The heat transfer resistance of the external wall surface, calculated according to the method presented in SP 50.13330.2012, is $R_0^{усл.}$ = 4,34 (m²·°C)/W, and the reduced heat transfer resistance $R_0^{пр}$ = 3,47 (m²·°C)/W, which meets the regulatory requirements for residential buildings under construction in the Samara region ($R_0^{тр}$ = 3,47 (m² · °C)/W).

To determine the level of transverse air infiltration required for resistance to heat transfer of an unplastered external wall, we used Eqs. (1) and (2), the results of which are presented in Table 2.

$$\delta_2^{\min} = \lambda_2\left(\frac{t_{в1} - t_н}{r \cdot \alpha_в \cdot \Delta t_н} - \frac{1}{\alpha_в} - \frac{\delta_1}{\lambda_1} - \frac{\delta_3}{\lambda_3} - \frac{1}{\alpha_н}\right), \text{ m.} \quad (3)$$

Analysis of the influence of longitudinal infiltration on reducing the resistance to heat transfer of the considered external wall using the method described in [1], showed that for slabs of basalt fiber with a density of 80–90 kg/m3, the thermal effect coefficient of longitudinal filtration is close to 1 for a fairly high density.

The calculation results presented in Table 2 reveal that when external walls are commissioned without interior finishing, which is a frequent occurrence, the heat-protective characteristics $(R_0^{усл.})_{ут}$ and $R_и$ greatly contravene regulatory requirements. Moreover, the greatest discrepancy occurs on the lower floors.

In addition to the calculated data, the negative influence of infiltration on the heat-protective characteristics of enclosing structures is confirmed by the results obtained by field inspections of the external walls of high-rise buildings. Figure 2 shows a thermogram of the inner surface of the external wall, which was obtained by a thermovision study of the enclosing structures of a fifth-floor residential apartment of a 25-storey residential building. The interior finishing of the external walls was plaster mortar, which does not have the required resistance to air permeability.

A thermovision study of the inner surfaces of the enclosing structures revealed the presence of low temperature zones in the lower part of the external wall. Low internal-air temperatures that did not meet regulatory requirements were also recorded.

For the external wall of a residential building to meet regulatory requirements, its inner surface must be covered with plaster.

Table 1.

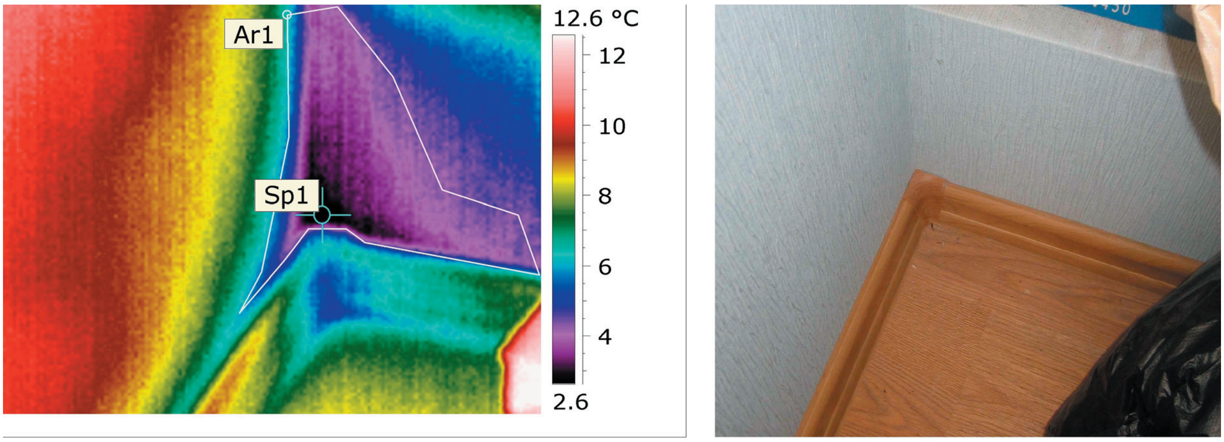
Heat-protective characteristics of finishing materials

Finishing material	Density in dry state ρ_0, kg/m^3	Layer thickness, m	Resistance to air permeability $R_и$, (m^2·h·Pa)/kg
Cement–sand mortar	1800	0.02	497
Sand-lime mortar	1600	0.02	189
Gypsum panels (gypsum lath)	800	0.0125	25

Table 2.

Calculated resistance to air permeability of a high-rise building with a ventilated facade

Floor number	H, m	ΔP, Pa	G, kg/m^2·h	k, W/m^2·°C	Heat transfer resistance under the influence of infiltration $(R_0^{усл.})_{ут}$, (m^2·°C)/W	Resistance to air permeability, (m^2·h·Pa)/kg		Difference of $R_и^{тр}$ - $R_и$, (m^2·h·Pa)/kg
						required $R_и^{тр}$	actual $R_и$	
1	79	119	4.96	1.380	0.720	238.0	24	214.0
3	73	110.9	4.62	1.290	0.780	221.8	24	198.0
5	67	102.8	4.28	1.197	0.835	205.6	24	181.6
7	61	94.7	3.95	1.107	0.903	189.4	24	165.0
9	55	86.6	3.81	1.020	0.980	173.2	24	149.0
12	46	74.5	3.10	0.880	1.140	149.0	24	125.0
15	37	62.3	2.60	0.760	1.320	124.6	24	101.0
20	22	42.1	1.75	0.553	1.810	84.2	24	60.0
25	7	21.9	0.91	0.378	2.650	43.8	24	19.8



Ar1 Средняя температура 4.0 °C

Fig. 2. Thermogram of the inner surface of an external wall.

Средняя температура	Average temperature

Conclusions

1. Based on the analysis of the calculated data, it can be concluded that the use of a cement–sand mortar as a finishing layer enables all the floors of a buildings to achieve the standard values required for heat transfer resistance. Lime–sand mortar can be recommended for the upper floors, starting from floor five.

2. Gypsum panels should not be used in buildings with a ventilated facade due to their low air-permeability resistance.

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