Theoretical researches of air permeability during development of cracks in building facilities

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Abstract. The article considers a mathematical model of air infiltration through cracks in building envelopes. Air movement for the given flow diagram of a continuous medium is described by the Navier - Stokes equations. As applied to thin layers of the air, assumptions are made that make it possible to compose a system of equations, including equations of dynamics and equations of continuity. The results of assessing the physical deterioration of residential buildings constructed according to standard designs taking into account their number of storeys and wall materials are presented. The influence of various damage to the building on the state of its heat balance is considered. The dependences of reducing thermal protection of building envelopes on the degree of wear in houses made of various materials are revealed. The main recommendations for improving the energy efficiency of buildings are proposed, which allow minimizing heat losses and ensuring comfortable microclimate parameters in the premises.

1. Introduction
During operation, building envelopes undergo changes, usually for the worse. The appearance of cracks, crevices, large pores as a result of aging of the structure violates the uniformity of external air intake through the fence and increases its infiltration, which affects a decrease in the temperature of the internal surfaces of the building envelope, a decrease in the internal temperature of the room, and an increase in air mobility [1]. The reasons for the formation of cracks in buildings are many and the most common of them are uneven settlement of foundations, excess of calculated values by loads, insufficient brick strength, poor filling of joints, leakage of sanitary systems, punching, etc.

2. Experimental
In order to identify the effects of physical deterioration on the air permeability and thermal efficiency of the enclosing structures of operated buildings, their technical examination was carried out. Residential buildings were selected according to the periods of construction, indicators of wear of the building envelope and wall materials. The general purpose of full-scale studies of the thermal efficiency of residential buildings was to obtain reliable data on the actual condition of building envelopes, the reasons for this condition, and information on the thermal efficiency of weak points for developing measures to reduce energy consumption during the operation of the house and its compliance with energy conservation requirements. When examining residential buildings, the following signs of physical deterioration of the building envelope were observed, presented in table.
Table. Observed defects reported for physical deterioration

| Depreciation, % | Signs of physical deterioration in brick houses | Signs of physical deterioration in panel houses |
|-----------------|-----------------------------------------------|-----------------------------------------------|
| 0-10            | Individual cracks up to 1 mm wide and potholes | Damage to parts of the facade on an area of up to 5%, in some places small potholes |
| 11-20           | Deep cracks up to 2 mm wide, up to 1/3 of the wall thickness, in places where the stucco falls, weathering the joints to a depth of 1 cm in an area of up to 10% | Cracks, weathering of the mortar from the joints, minor damage to the lining or texture layer up to an area 10%, traces of leaks through joints inside the building. |
| 21-30           | Weathering of joints to a depth of 2 cm in an area of up to 30%; weakening of masonry; loss of individual bricks; cracks in cornices and lintels with a width of more than 2 mm; wetting the surface of the walls | Mass exfoliation, weathering of the solution from the joints; damage to the cladding or texture layer of panels on an area of up to 20%; traces of leaks inside the building |
| 31-40           | Weathering of joints to a depth of 4 cm in an area of up to 50%; weakening of the brickwork of the walls with the loss of individual bricks; efflorescence and traces of moisture | Freezing of walls in 5% of rooms, destruction of joints |
| 41-50           | Through cracks in the lintels and under the window openings, bricks falling out, deviation from the vertical and bulging of walls within the room more than 1/200 of the height | Traces of leaks indoors 10%, external damage on the area up to 30, efflorescence |

When analyzing the data, it was found that the ratio of the number of cracks in brick and panel buildings with an average wear of building envelopes of 25% is 40% and 60%, respectively. In brick houses, cracking and stratification of masonry under the windows, at the ledges, multiple cracks throughout the building are found. In prefabricated buildings, mainly the depressurization of the joints of the butt elements occurs, accounting for 20% of the total number of cracks. A significant increase in air infiltration in the cold season occurs through window sills - up to 30% of all cracks.

An on-site examination revealed that the physical wear of assembly joints, joints of panels and window blocks, the formation of cracks and cracks in the enclosure significantly reduces the temperature of the internal surfaces of walls and internal air, reduces the heat-shielding characteristics of enclosing structures, and also increases the heat consumption for heating [2 -5].

3. Evaluation

The appearance of cracks, crevices, and large pores as a result of aging violates the uniformity of external air flow through the fence and increases its infiltration. Increased infiltration worsens the microclimatic conditions in the rooms: the temperature of the internal surfaces of the building envelope decreases, the values of the internal temperature of the room decrease, and the air mobility increases.

Infiltration of cold air lowers the temperature of the building envelope. When the properties of the body along the coordinate change insignificantly, it is permissible to take the corresponding
coefficients in the study of transport phenomena as constant or equal to their average effective values [6]. However, in some cases, the heterogeneity of the physical properties is so significant that it requires further study. Consider the wear of the outer wall in the form of a crack extending in an arbitrary direction.

For the design scheme presented in [7], the following assumptions are made: a crack can be represented as a gap of size $r$ filled with air; the linear dimensions of the surface formed by the crack significantly exceed the width of its opening $\delta \gg r$, $L \gg r$; air density is a constant, $\rho = \text{const}$; air flow in the air gap occurs at sufficiently small Reynolds numbers, therefore, the inertial terms in the basic equations of dynamics can be neglected.

For the model equation of convection-diffusion through a crack, we use the Galerkin method [8]. The initial parameters necessary for the calculation are the geometric dimensions of the investigated area and its sections (the linear dimensions of the surface formed by the crack significantly exceed the width of its opening $\delta \gg r$, $L \gg r$), the pressure drop on the inside and outside of the building.

In relation to thin layers of the air medium, a system of equations was compiled, including dynamic equations and continuity equations, which, after a series of transformations and integrations, taking into account the boundary conditions, is presented in the following form:

$$\frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} + \frac{12 \cdot Q \cdot \mu}{r^2 \cdot L^2 \cdot A} = 0, \quad (1)$$

where $P$ is the overpressure in the gap, Pa; $\rho$ - air density, kg / m$^3$; $\tau$ - time, s; $M = \frac{Q \cdot \rho}{A \cdot L \cdot r}$ - mass air flow per unit time per unit volume of the crack, kg / m$^2$s; $\mu$ is the dynamic viscosity of air, N s/ m$^2$; $A = \frac{\delta}{L}$, where $\delta$, $L$ are the characteristic dimensions of the crack, m; $Q$ - volumetric flow rate of air entering the air gap, m$^3$/s.

After a series of transformations, we obtain the dependence of the air flow through the crack on its dimensional characteristics and pressure:

$$Q = \frac{P \cdot r^3 \cdot L^2 \cdot A}{12 \cdot \eta \cdot B}, \quad (2)$$

where

$$B = \left( \frac{8}{\pi^2} \right)^{\frac{1}{2}} \cdot \sum_{i=1}^{N} \sum_{j=1}^{N} (-1)^{\frac{i+j}{2}} \cdot \left( \frac{i!}{i^2 + j^2} \right)^{\frac{1}{2}}$$

Equation (3) allows you to determine the flow characteristics of the outdoor air passing through the crack in the building envelope, taking into account its linear dimensions and the amount of overpressure. Further analysis shows that with a crack opening width of up to 1 mm, the air flow through the gap is not significant, i.e. as well as through the pores of the fence. With a crack opening width of more than 2 mm, the air flow through the fence increases sharply.

4. Conclusions

Based on the results, to prevent excess breathability, a number of measures must be taken:

- a set of repair and construction works and organizational and technical measures aimed at bringing the heat engineering parameters of all building envelopes to modern requirements;
- increase the efficiency of operational processes that allow, within the framework of current maintenance and repair, to improve the technical characteristics of existing structures, as well as attract owners to reduce the energy consumption of houses using energy-saving household appliances and equipment.

The installation of an effective insulation system can significantly reduce transmission losses of existing housing. Warming reduces not only heat loss, but also condensation in poorly insulated
houses. Modernization of thermal protection of the building makes it possible to reduce energy costs for heating. It is advisable to replace the existing window units with a two-chamber double-glazed window in a single polyvinyl chloride binding made of glass with a hard selective coating that has the best energy efficiency values of translucent structures.

The choice of energy saving measures should be based on generalized indicators of the state of real estate, its moral and physical depreciation, on the analysis of a combination of factors of global and regional conditions for the operation of objects. It has been established that carrying out sanitation measures increases the operating life of buildings by 10-15%, increases the period of effective operation and reduces the consumption of thermal energy by up to 30%, thereby solving both environmental and economic problems.

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