Research of the dependence of the moisture regime in the walls of gas concrete on the characteristics of the external finishing

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Abstract. The laws of moisture condensation in the external enclosing structures of aerated concrete blocks of grades D350–D600, finished with various types of dry building mixtures, are investigated. The mathematical dependence of the temperature of the onset of condensation in the aerated concrete enclosing structure on the thermal conductivity and vapor permeability of the outer finish coating is obtained. It was revealed that when using the developed calcareous composition with the use of ash aluminosilicate microspheres for the finishing of aerated concrete blocks of grades D350–D600, moisture condensation begins at a lower outdoor temperature.

1. Introduction

In order to reduce energy consumption for heating newly constructed buildings, the requirements for thermal protection of their external building envelopes are being tightened. In this regard, in recent years there has been an increase in the output of aerated concrete blocks, allowing the construction of single-layer walls with sufficiently high heat-shielding properties. Walls of aerated concrete blocks are most often finished with dry building mixes (DBM), which improve the decorative qualities of external fencing and provide them with protection from various climatic influences [1].

If the DBM is incorrectly selected, detachment of fragments of the external finishing coating and the appearance of fine cracks on the coating are observed [2]. Moisture condensation on the plaster – aerated concrete boundary is one of the main causes of the destruction of the finish coating.

In the outer wall for minimize the amount of condensing moisture and reduce the likelihood of its occurrence, each subsequent layer in the direction from the inner to the outer surface should have greater vapor permeability and lower thermal conductivity compared compared with the previous layer.

This condition is difficult to apply to the exterior finish of aerated concrete, because a decrease in thermal conductivity and an increase in the vapor permeability of plaster composites can cause a deterioration in the operational properties of the resulting coatings. But the approximation value indicators of the vapor permeability and thermal conductivity of the finishing coatings to values indicators of the vapor permeability and thermal conductivity aerated concrete will significantly reduce the probability of moisture condensation [3].
2. Materials and methods

For decoration of exterior wall from aerated concrete a DBM was used. DBM made based on hydrated lime, modifying additive based on a mixture of hydrosilicates and calcium aluminosilicates, ash silica-alumina microspheres, white cement, milled aerated concrete production waste, Melflux 2651 F, VINNAPAS 8031 H, sodium oleate [4, 5].

Coatings based on the developed DBM are characterized by high vapor permeability $\mu = 0.150$ mg / (m $\cdot$ h $\cdot$ Pa), low thermal conductivity $\lambda = 0.137$ W / (m $\cdot$ K), a density close to the density of aerated concrete $\rho = 650$ kg / m$^3$ and good operational properties [6, 7]. It is assumed that the use of this DBM will reduce the likelihood of condensation and minimize its amount.

The probability of moisture condensation was determined using the Fokin-Vlasov graphoanalytic method [8, 9]. In this method, the distribution of $E_i$ and $e_i$ over the thickness of the enclosure at a certain temperature $t_{ext}$ is built. The disadvantage of this method is the dependence of the conclusion about the possibility of condensation on the choice of the calculated outdoor temperature. In various works, the average temperature of the coldest five-day period, the average temperature of the coldest month, and the average temperature of the entire period of the year with negative average daily temperatures are used for this. Depending on the temperature adopted, conclusions about the presence or absence of moisture condensation in this enclosure can vary greatly.

In the works of Kupriyanov V.N. it was proposed to assess the probability of moisture condensation in the external enclosure the temperature of condensation onset $t_{occ}$ [10, 11]. This temperature is equal to the maximum temperature at which moisture condensation begins in the external fencing. This technique has been used in research. Design scheme of the wall under study is shown in figure 1.

![Figure 1. The design scheme of the wall: 1 – layer 1, interior decoration; 2 – layer 2, aerated concrete; 3 – layer 3, exterior finish.](image)

As an interior finish (figure 1, layer 1), cement-slag plaster was adopted. Aerated concrete blocks of grades D350, D400, D500, D600 are accepted as the main material of the wall (figure 1, layer 2). As the exterior finish (figure 1, layer 3), 3 types of DBM were used:
- cement-sand plaster: density $\rho = 1800$ kg / m$^3$, thermal conductivity coefficient $\lambda_A = 0.760$ W / (m $\cdot$ K), vapor permeability coefficient $\mu = 0.090$ mg / (m $\cdot$ h $\cdot$ Pa);
- Knauf GRUNBAND: $\rho = 1100$ kg / m$^3$, $\lambda_A = 0.350$ W / (m $\cdot$ K), $\mu = 0.100$ mg / (m $\cdot$ h $\cdot$ Pa);
- developed dry mix DBM: $\rho = 650$ kg / m$^3$, $\lambda_A = 0.155$ W / (m $\cdot$ K), $\mu = 0.150$ mg / (m $\cdot$ h $\cdot$ Pa).
The calculated parameters of the indoor air are taken equal to the parameters of the indoor air for residential buildings: temperature $t_{in} = 20.0 \, ^\circ C$; relative humidity $\varphi_{in} = 55\%$ [12]. The calculated parameters of outdoor air: average temperature of the heating period $t_{h.p.} = -2.5 \, ^\circ C$; the duration of the heating period $zh.p. = 200$ days; the humidity zone is dry [13].

3. Research results

In the work, the influence of the external finishing coating on the temperature of the beginning of condensation $t_{c.o.}$ for walls of buildings located in the city of Voronezh is assessed.

For walls made of aerated concrete blocks of grades D350, D400, D500, D600 for the conditions of the city of Voronezh, the minimum allowable thickness of the aerated concrete layer in building envelopes was preliminarily determined (table 1).

| Aerated concrete brand | D350 | D400 | D500 | D600 |
|------------------------|------|------|------|------|
|                        | 0.40 | 0.40 | 0.50 | 0.60 |

To simplify further, the following conventions are used in the work for various of enclosing structures:

$$\frac{x}{y}$$

where $x$ is the density of aerated concrete;
$y$ – the density of the outer finishing layer.

As an example, the humidity mode in the aerated concrete structure 400/1800 are investigated. Each wall layer is characterized by its vapor permeability resistance $R_{p.r.}$ and heat transfer resistance $R_{t.r.}$, determined by the formulas:

$$R_{p.r.} = \frac{\delta_i}{\mu_i}$$

Where $\delta_i$ is the thickness of the layer, m;
$\mu_i$ – coefficient of vapor permeability of the layer, mg / (m $\cdot$ h $\cdot$ Pa).

$$R_{t.r.} = \frac{\delta_i}{\lambda_i}$$

where $\lambda_i$ is the thermal conductivity of the layer, W / (m $\cdot$ K).

Figure 2 shows a graph in which the abscissa shows the vapor permeation resistance of the entire enclosure $\sum R_{p.r.} / R_{p.en.}$ in relative units, and the ordinate axis shows the heat transfer resistance $\sum R_{t.r.} / R_{h.en.}$ of the entire fence in relative units.

In figure 2, the inner surface of the enclosure is indicated by point A, the outer surface by point O. For the embodiment of the enclosure 400/1800, the relationship between the heat transfer resistance and the resistance is a broken line with a kink at point V, the boundary between the interior and aerated concrete, and a kink at point B, the border between aerated concrete and exterior finish (figure 2, curve 1). Points V and B are characteristic for schedules of all considered fencing options.
Figure 2. The graph of the relationship between the resistance to heat transfer and resistance to vapor permeation: 1 — 400/1800; 2 — diagonal of proportionality.

We draw an auxiliary diagonal of proportionality connecting the points A and O (figure 2, curve 2). This line shows the relationship between heat transfer resistance and vapor permeation resistance, typical for single-layer structures. At the intersection of curve 1 and 2, we mark point K. The segment AVK is located below the proportional diagonal, therefore, the inequality will be fulfilled throughout the length of this zone in the wall:

\[
\frac{\sum R_p}{R_{p.en.}} > \frac{\sum R_h}{R_{h.en.}} \tag{4}
\]

The segment of the KBO is located above the proportional diagonal, therefore, the following inequality will be fulfilled for the entire length of this zone in the wall:

\[
\frac{\sum R_p}{R_{p.en.}} < \frac{\sum R_h}{R_{h.en.}} \tag{5}
\]

The most likely condensation plane in the enclosure will be point B, which is the boundary between the aerated concrete and the exterior, as this point is farthest up from the proportional diagonal. In point B, for this enclosure, the following equality holds:

\[
\frac{\sum R_h}{R_{h.en.}} - \frac{\sum R_p}{R_{p.en.}} = max \tag{6}
\]

Let's look at fragments of the graphs of the relationships between heat transfer resistance and vapor permeability for enclosure 400/1800, 400/1100, 400/650 within 0.8 < \sum R_p / R_{p.en.} < 1.0, 0.8 < \sum R_h / R_{h.en.} < 1.0 (figure 3).
Figure 3. A fragment of the graph of the relationship between the heat transfer resistance and the vapor permeation resistance in the range of $0.8 < \frac{\sum \bar{R}_{p,i}}{R_{p,em}} < 1.0$, $0.8 < \frac{\sum \bar{R}_{h,i}}{R_{h,em}} < 1.0$: 1 – single-layer fencing; 2 – 400/1800; 3 – 400/1100; 4 – 400/650.

When using cement-sand plaster as the exterior finish, point $B_1$ is located as far as possible from the diagonal of proportionality (figure 3, curve 2). Based on this, it can be assumed that moisture condensation in the enclosure 400/1800 will begin at the highest temperature. When using DBM Knauf GRUNBAND, point $B_2$ is located closer to the proportional diagonal in comparison with point $B_1$ (figure 3, curve 3).

Based on this, it can be assumed that moisture condensation in the enclosure 400/1100 will begin at a lower outdoor temperature, while points $B_1$ and $B_2$ are close, therefore, the difference between $t_{o.c.}$ for these enclosure will not be significant. When using the developed DBM as an external finish, point $B_3$ is located as close as possible to the proportional diagonal (figure 3, curve 4). Based on this, it can be assumed that moisture condensation in the 400/650 enclosure will begin at the lowest temperature.

To determine the temperature of the onset of condensation $t_{o.c.}$ for each of the studied structures, the profiles of saturated water vapor pressure $E_i$ and partial pressure of water vapor $e_i$ were constructed. Then, $t_{o.c.}$ was determined by successive approximation. The results of the calculations are presented in figure 4.

Moisture condensation in the enclosing structure 600/1800 starts at –8.0 °C (figure 4, curve 1). When using DBM Knauf GRUNBAND, the temperature of the onset of condensation $t_{o.c.}$ decreases by only 1 °C to –9.0 °C (figure 4, curve 2), when using the developed DBM, the temperature of onset of condensation $t_{o.c.}$ decreases by 3.6 °C to –11.6 °C (figure 4, curve 3). With a decrease in the density of aerated concrete is increasing the onset temperature of condensation $t_{o.c.}$. Condensation onset temperature $t_{o.c.}$ in the enclosure 350/650 lower by 6 °C than the temperature of the beginning of condensation $t_{o.c.}$ in the enclosing structure 350/1800.
It has been established that in building enclosing structure plastered with a cement-sand composition, condensation will form at average monthly temperatures in December, January and February in walls from aerated concrete blocks of grades D350, D400.

Figure 4. The dependence of the temperature of the onset of condensation \(t_{\text{o,c.}}\) from the density of aerated concrete: 1 – cement-sand plaster; 2 – Knauf GRUNBAND; 3 – developing DBM.

Condensation also forms at average monthly temperatures in January and February in walls from aerated concrete blocks of grades D500. In the enclosing structures finished by the developed DBM, conditions for the formation of condensate will not be created.

4. Conclusion
The conducted studies prove that due to the use of the developed DBM for decorating walls from aerated concrete blocks of grades D350–D600, the temperature of the onset of condensation \(t_{\text{o,c.}}\) is reduced. This will significantly limit or completely eliminate the formation of condensate in such building envelopes.

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