Thermal physical properties estimation of high-rise building fencing construction

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Abstract. Presentation and realization of according to the calculations, it is established that the process of water vapor condensation occurs in the three-layer structure of the outer wall for three months: December, January, February. The condensed moisture evaporates in the other months of the year. The increase in material humidity in the thickness of the structure in which moisture condensation can occur during the cold season is estimated. In this case, the layer is moistened because it is adjacent to the condensation zone on the inner surface of the wall by $\Delta w=1.05\%$. The estimated increase in the construction material humidity in the cold season $\Delta w=2.2\%$, exceeds the allowable for thermal insulation characteristics. Also, the distribution of fencing construction partial pressures at an outside air temperature of $-23^\circ C$ indicates moisture accumulation on almost the entire surface of the structure. Numerical implementation was carried out with the development of a constructive solution: the proposed air layer with the mandatory layer ventilation provision (convective air exchange). For this reason, given the inertia of the combined concrete wall, it is permissible to decide on the need for the wall interior of aerated concrete blocks.

1. Introduction
The bearing structures of buildings and structures must meet the requirements of strength, rigidity, stability, fire safety. To consider the processes of heat and mass transfer that occur during the formation of the temperature and humidity conditions of the premises, it is necessary to consider the following: requirements for the characteristics of the internal climate and factors affecting them; laws of interaction of fencing constructions with internal and external environments; heat and mass transfer processes on heating and cooling surfaces.

Calculation methods for limit states are used to determine the strength properties and characteristics of constructions, and the maximum permissible states of cooling and moistening of structures are used with new methods of building technology, building structure facilitation, and the use of new effective materials.

Considering nonsteady processes, such as building structure cooling, its hydration, we introduce the maximum permissible state of processes that affect the features of the structures operation.

Taking into account thermal inertia, heat resistance, and moisture content are one of the essential criteria for choosing a constructive solution to a fencing construction.
Analysis of recent research and publications. Farenyuk H.H. carried out research on the criteria of thermal failure and critical condition of the heat insulating building envelops; they offered methodological bases of establishment of normative thermotechnical indicators of heat insulating building envelops and its elements on the basis of energy costs optimization by constructive groups; they developed methodological provisions of analytical and experimental determination of the structural solution of the heat insulating building envelops according to the indicators of thermal reliability; they improved experimental methods for determining the thermophysical properties of building materials and products, thermal performance of fencing constructions and heat insulating building envelops, energy performance of buildings and structures; they proposed constructive principles for improving the energy efficiency of residential and public buildings in new construction and reconstruction [1, 2]. Today [2] the following structural and technological solutions of external walls with front heat insulation are applied:

- using plastering or artificial elements, in which the heat insulation is hinged and fastened to the wall base and a protective layer;
- using brick or wall stones, in which the heat insulation is self-supporting and is installed with an air gap between its external surface and a protective layer of brick or wall stones;
- using a ventilated air layer, in which the heat insulation is hinged on the load-bearing part of the wall and is placed with the formation of an air layer between its outer surface and the supporting layer of opaque thin-walled industrial elements;
- using transparent industrial elements, in which thermal insulation can be hinged or self-supporting and is installed with an air gap between its outer surface and the translucent outer layer. Large concrete wall blocks are also used for the exterior and interior walls of buildings and structures, for basement walls and basement, and in the form of special blocks (ventilation, for bathrooms, eaves, etc.).

Large wall blocks are divided:

a) by design: on solid and hollow (including with thermotechnically efficient voids);
b) by type of concrete used: on light concrete blocks with a volume weight of up to 1800 kg/m³ inclusive (light concrete on porous aggregates, cellular concrete, large-porous concrete on porous aggregates) and on heavy concrete blocks with a volume weight of over 1800 kg/m³ (heavy concretes, large-porous concretes on ordinary dense aggregates).

When designing the external fencing constructions of buildings and structures, it is necessary to calculate the moisture accumulation and moisture removal in the fencing constructions exposed to the influence of climatic factors.

S.L. Fomin [3] proposed to consider the impact of the climatic environment as a system of differential equations of heat conductivity of moisture transfer in concrete, the conclusion of which is based on the provisions of moisture conductivity theory of V.N. Bogoslovskyi (1-9).

For a random volume allocated inside the concrete body limited by the surface over a period of time, the amount of moisture enters:

$$W_1 = \int_{T_1}^{T_2} d\tau \int_S k(x,y,z) \frac{\partial \varphi}{\partial \eta} dS.$$  \hspace{1cm} (1)

Given that the coefficient of specific moisture capacity depends not only on the moisture potential, but also on other thermodynamic parameters, in particular on temperature, which change in time, it should be considered as a function of time.

Then the amount of moisture necessary to change the moisture potential:$$\Delta \varphi = \varphi(x, y, z, \tau_2) - \varphi(x, y, z, \tau_1)$$ for time period$$d\tau$$ is equal to:

$$W_2 = \iiint \left[ \varphi(x, y, z, \tau_2) \eta(x, y, z, \tau_2) - \varphi(x, y, z, \tau_1) \eta(x, y, z, \tau_1) \right] \rho \, dv, \hspace{1cm} (2)$$
where \(\eta(x,y,z,\tau_1)\) and \(\eta(x,y,z,\tau_2)\) moisture capacity of concrete at the moment \(\tau_1\) and \(\tau_2\). Equations with boundary conditions compiled from data on changes in temperature and humidity potential of the medium completely determine the problem of calculating temperature and humidity fields in sections of reinforced concrete structures.

\[
\begin{align*}
[Q(x,y,z,\tau_2) \eta(x,y,z,\tau_2) - Q(x,y,z,\tau_1) \eta(x,y,z,\tau_1)] &= \int_{\tau_1}^{\tau_2} \frac{\partial(\eta\eta)}{\partial\tau} d\tau \\
W_z &= \int_{\tau_1}^{\tau_2} d\tau \iiint_v \rho \frac{\partial(\eta\eta)}{\partial\tau} dv \\
\end{align*}
\]

Setting up the moisture balance equation for the allocated volume

\[
\int_{\tau_1}^{\tau_2} d\tau \iiint_v \rho \frac{\partial\eta}{\partial\tau} dv = -\int_{\tau_1}^{\tau_2} d\tau \iiint_v k \frac{\partial\eta}{\partial\eta} dS
\]

and applying Gauss's and Ostrogradsky's formula to the integral over the surface, we obtain:

\[
\int_{\tau_1}^{\tau_2} d\tau \iiint_v \left[ \rho \frac{\partial\eta}{\partial\tau} - \rho \frac{\partial[\eta(Q,t)]}{\partial\tau} \right] dv = 0
\]

The heat equation for the general case

\[
\rho C(Q,t) \frac{\partial t}{\partial\tau} + \rho \frac{\partial C(Q,t)}{\partial\tau} t = \nabla[\lambda(Q,t)\nabla t]
\]

Assessment of fencing constructions failure in terms of moisture resistance, thermal conductivity and heat resistance is very relevant [4, 5, 6, 7].

Criteria for failures of fencing construction are given in table 1 [8, 9, 10, 11].

| Fencing function | Failure |
|------------------|---------|
| Power | under load bearing capacity |
| under deformation |
| Heat insulator | under heat protection |
| under resistance |
| under moisture vapor |
| Moisture protection | transmission |
| under resistance |
| Air shielded | under permeability to air |
| Sound protection | under sound insulating ability |

2. Main material
The purpose is to determine the thermophysical properties of high-rising building fencing construction.

Objectives of the study is to perform the calculation of fencing construction thermal state.
The object under consideration is a combined concrete wall consisting of an internal facing of aerated concrete blocks, a layer of concrete, a layer of expanded polystyrene and an external brickwork, which is fastened to the main layer of concrete with reinforcing bars (figure 1).

![Figure 1. Cross-sections of a four-layer block of apartment building bearing construction.](image)

The outer facing layer is made of M100 ceramic hollow brick on M100 solution. Fastening of the external facing layer to the concrete is made on flexible connections from Ø10 A400C reinforcement.

The three-layer blocks in the structure of external walls design are folded in combination with the inner lining of D400 aerated concrete blocks, which are delimited by a closed 10 mm thick air gap.

To consider the processes of heat and mass transfer that occur during the formation of the temperature and humidity conditions of the premises, it is necessary to consider: requirements for the characteristics of the internal climate and factors affecting them; laws of interaction of fencing constructions with internal and external environments; heat and mass transfer processes on heating and cooling surfaces. Considering nonsteady processes, such as building structure cooling, its hydration, we introduce the maximum permissible state of processes that affect the features of the structures operation. In the numerical solution of the task, the following initial data were taken: the calculated internal air temperature \( t_{in} = 22^\circ C \); design ambient temperature \( t_{ex} = -23^\circ C \); Poisson's ratio of concrete \( \nu = 0.17 \); coefficient of convective heat transfer on the inner surface \( \alpha_{in} = 8.7 \text{ W/m}^2{^\circ C} \); on the outer surface \( \alpha_{ex} = 23 \text{ W/m}^2{^\circ C} \). Three-layer blocks (figure 2) as part of the external walls design are put in combination with the inner lining of D400 aerated concrete blocks, delimited by a closed 10 mm thick air gap. The temperature distribution in fencing construction thickness is determined by the formula (10):

\[
t(x) = t_{in} - \frac{t_{ex} - t_{in}}{R_x} \left( \frac{1}{\alpha_{ex}} + R_x \right)
\]

where \( t_{in} \) – internal temperature of the room, \(^\circ C\), which is determined depending on the purpose of the room according to Annex D of DBN B.2.6-31 or according to building design documentation; \( t_{ex} \) - estimated outside air temperature, \(^\circ C\), determined by DSTU-N B 1.1-27, depending on the region of Ukraine for which the average monthly air temperature is calculated; \( R_x \) - fencing construction resistance of heat transfer, \((\text{m}^2\cdot\text{C})/\text{W}\); \( \alpha_{ex} \) - coefficient of heat transfer of fencing construction inner surface, \(\text{W/(m}^2\cdot\text{C})\), is accepted according to Annex E of the DBN B.2.6-31; \( R_x \) - resistance of heat transfer of fencing construction layers, \((\text{m}^2\cdot\text{C})/\text{W}\), located to the plane for which the calculation is made, starting from the room (figure 3).
The heat transfer resistance of a thermally homogeneous opaque fencing construction is calculated by the formula (11):

\[
R_\Sigma = \frac{1}{\alpha_{ex}} + \sum_{i=1}^{n} R_i = \frac{1}{\alpha_{in}}
\]  

(11)

where \(\alpha_{ex}\), \(\alpha_{in}\) - coefficients of heat transfer of the inner and outer surfaces of the fencing construction, \(\text{W/}(\text{m}^2\text{K})\), which are accepted in accordance with Annex E; \(R_i\) - thermal resistance of the construction i-layer, \(\text{m}^2\text{K/}\text{W}\).

The calculation of the building construction hydrothermal state is done graphically using software for typical structural decisions of building fencing construction.

The calculation of the increase in moisture \(\Delta w\) in the material layer in which condensation occurs is made by the formula (12)

\[
\Delta w = \frac{W}{\delta \cdot \rho} \times 100
\]

(12)

where \(\delta\) - thickness of the material layer, m, in which moisture accumulates, m; \(\rho\) - density of the material layer in which moisture condensation occurs, kg/m³.

Figure 2. Experimental fencing construction under consideration.

Calculation of temperature inertia of a three-layer fencing construction:

\[
D = R_1 \cdot s_1 + R_2 \cdot s_2 + R_3 \cdot s_3 = 3.6 \text{ W/m}^2\text{K}
\]

where \(s_i\) - heat transfer coefficient of concrete layer under design operating conditions, \(\text{W/}(\text{m}^2\text{K})\); \(s_2\) - heat transfer coefficient of polystyrene foam insert, \(\text{W/}(\text{m}^2\text{K})\), \(s_3\) - brick heat absorption coefficient, \(\text{W/}(\text{m}^2\text{K})\). As \(1.5 \leq D \leq 4\) - low inertia construction.

Calculation of temperature inertia of the combined concrete wall, consisting of the inner facing of aerated concrete blocks, a layer of concrete, a layer of expanded polystyrene and the outer brickwork, fixed to the main layer of concrete by reinforcing bars:

\[
D = R_1 \cdot s_1 + R_2 \cdot s_2 + R_3 \cdot s_3 + R_4 \cdot s_4 = 4.97 \text{ W/m}^2\text{K}
\]
Figure 3. Temperature distribution in the fencing constructions at outdoor air temperature -23°C.

where $s_1$ - heat transfer coefficient of concrete layer under design operating conditions, $W/(m^2K)$; $s_2$ - heat transfer coefficient of polystyrene foam insert, $W/(m^2K)$; $s_3$ - brick heat absorption coefficient, $W/(m^2K)$; $s_4$ - heat absorption coefficient of aerated concrete, $W/(m^2K)$. As $D \geq 4$ - inertial construction.

3. Conclusions

According to the calculations, it is established that the process of water vapor condensation occurs in the three-layer structure of the outer wall for three months: December, January, February. The condensed moisture evaporates in the other months of the year. The increase in material humidity in the thickness of the structure in which moisture condensation can occur during the cold season is estimated. In this case, the layer is moistened because it is adjacent to the condensation zone on the inner surface of the wall by $\Delta w = 1.05\%$. Therefore, according to [5], humidity increase during the cold season is acceptable. However, the thermal resistance of the construction under consideration $R = 2.95$ m$^2$K/W indicates that the structure must be brought to the present thermal resistance for today.

Also, calculations of material humidity increase in a construction layer thickness in which moisture condensation can occur during the cold period of the year. This construction layer is of the combined concrete wall consisting of the internal facing of aerated concrete blocks, a layer of concrete, a layer of expanded polystyrene and an external brick laying, the outer brick laying, reinforcing bars.

The estimated increase in the construction material humidity in the cold season $\Delta w = 2.2\%$, exceeds the allowable for thermal insulation characteristics.

The calculation of the hydrothermal condition showed the relative applicability of the design solutions, but it should be noted that the thermal resistance of the considered structure is too high 4.8 m$^2$ K/W (at normalized – 3.3 m$^2$ K/W), which indicates that the decisions made are not economical. Also, the distribution of fencing construction partial pressures at an outside air temperature of -23°C indicates moisture accumulation on almost the entire surface of the structure.

Numerical implementation was carried out with the development of a constructive solution: the proposed air layer with the mandatory layer ventilation provision(convective air exchange). For this reason, given the inertia of the combined concrete wall, it is permissible to decide on the need for the wall interior of aerated concrete blocks.
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