Position Control of Maximum Wetting Plane for Building Walls with Foam Polystyrene Heat Insulator

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Abstract. Current theory of moisture transfer, consisting in combined transfer of vapor in sorption wetting zone and liquid in oversorption zone, is reviewed. Moisture potential $F$, which is the basis for overwetting protection calculation of the enclosing structure, is described. A steady-state problem on moisture distribution along enclosing structure thickness is presented. Expression for maximum wetting plane position assessment in the enclosing structure thickness is described. It is proposed to tie origin of coordinates and exterior insulation surface. “Relative shift of the maximum wetting plane” criterion is developed for the new coordinate system. Maximum wetting plane position for the enclosing structure made of aerated concrete masonry base and expanded polystyrene insulation is calculated. One parameter varied and others were taken as constant to find out dependences between maximum wetting plane shift criterion, layers thickness, and interior micro climate parameters. It is found out that increase in base thickness, temperature or relative humidity of inside air results in maximum wetting plane shift inside the enclosure, and increase in insulation thickness results in maximum wetting plane shift outside the enclosure.

1. Introduction

Moisture affect on the building enclosing structure is of major importance. Calculation methods for unsteady-state moisture regime allows the most precise evaluation of this effect [1,2,3,4,5,6,7,8]. Experimental data on moisture diffusion coefficients [9,10,11,12], and verification of existing calculation patterns by field surveys [13] are required for application of these methods. Construction materials humidity influences on thermal protection [14], lifetime of buildings [15,16], and humans health [17,18].

In engineering practice it is much easier to calculate overwetting protection of enclosing structures, i.e. decide whether this structure can be operated or not. Overwetting protection calculation is based on moisture transfer balance, which is determined with respect to certain enclosing structure section – maximum wetting plane, which specifies the place of maximum moisture content in the enclosing structure.

According to existing theory, moisture transfer takes place in sorption wetting zone under the action of water vapor partial pressure gradient, and in oversorption zone – under the action of
humidity gradient. V.G. Gagarin and V.V. Kozlov developed moisture potential $F$, which is the sum of water vapor pressure and equivalent liquid moisture pressure [19]:

$$F(w, t) = E_i(t) \cdot \varphi(w) + \frac{1}{\mu} \int_{\zeta}^{w} \beta(\zeta) d\zeta$$

where $F$ – moisture potential, $Pa$; $w$ – material moisture content, mass percentage (1 kg/kg = 100 mass percentage); $t$ – temperature, °C; $E_i$ – saturated water vapor pressure, $Pa$; $\mu$ – vapor permeability coefficient, kg/(m·s·Pa); $\varphi$ – relative air humidity; $\beta$ – moisture conductivity coefficient, kg/(m·s·kg/kg).

Steady-state moisture potential distribution is studied based on this potential [19]:

$$\frac{\partial}{\partial x} \left( \mu \frac{\partial F(w, t)}{\partial x} \right) = 0$$

where $x$ – coordinate, $m$.

Research for equation (2) maximum results in reduced expression, which is used to define maximum wetting plane position in building enclosing structures [20]:

$$f_i(t_{m,n}) = \frac{5330 \cdot \left( t_i - t_{ext, neg} \right)}{R_i \cdot (e_i - e_{ext, neg})} \cdot \frac{\mu}{\lambda_i}$$

where $f_i$ – function that corresponding to the temperature of the layer $i$ in the maximum moisture zone «maximum wetting complex», (°C)/Pa; $r_{i,v}$ – enclosing structure water vapor permeability total resistance, (m²·s·Pa)/kg; $t_i$ – inside air average temperature, °C; $t_{ext, neg}$ – outdoor air average temperature in the period of monthly average temperature below zero, °C; $R_i$ – enclosing structure heat transfer total resistance, (m²·°C)/W; $e_i$ – partial pressure of inside air water vapor, $Pa$; $e_{ext, neg}$ – partial pressure of outdoor air water vapor in the period of monthly average temperature below zero, $Pa$; $\mu_i$ – vapor permeability coefficient of $i$-th layer material, kg/(m·s·Pa); $\lambda_i$ – thermal conductivity coefficient of $i$-th layer material, W/(m²·°C); $t_{m,n}$ – maximum wetting temperature, °C.

2. The problem
The expression (3) allows to define maximum wetting plane, then it is possible to evaluate moisture transfer balance and conclude whether the enclosing structure is suitable for operation or not. However this method does not give an answer to a question how will maximum wetting plane position change with variation of enclosure thickness or inner micro climate parameters.

The research goal is to develop dependences allowing to control maximum wetting plane position depending on layers thickness and inner micro climate parameters for the enclosing structure consisting of aerated concrete masonry base and expanded polystyrene insulation.

3. Materials and methods

3.1. Coordinate axis relation to the enclosing structure
Facade heat-insulating composite system, made of aerated concrete masonry base, expanded polystyrene insulation, exterior thin plaster layer, and interior sand-cement mortar layer, is examined. It is proposed to tie origin of coordinates and exterior insulation surface to assess maximum wetting plane position (Fig. 1).
3.2. Criterion development for maximum wetting plane position assessment

Criterion $\Delta$ is developed to assess maximum wetting plane position:

$$\Delta = \frac{\delta_x}{\delta_{im}}$$

(4)

where $\Delta$ – relative displacement coordinate of maximum wetting plane.

Physically, $\Delta$ reflects what fold distance between insulation exterior surface and maximum wetting plane coordinate is greater than insulation thickness. If $\Delta < 0$, then maximum wetting plane is located outside the enclosure or in exterior plaster layer; if $\Delta = 0$, then maximum wetting plane is located on external insulation surface; if $0 < \Delta < 1$, then maximum wetting plane is located inside insulation layer; if $\Delta = 1$, then maximum wetting plane is on internal insulation layer; if $\Delta > 1$, then maximum wetting plane is located on base layer or on interior plaster layer.

4. Results and discussion

The enclosing structure having characteristics presented in the table (Table. 1) was taken as initial for investigation of the maximum wetting plane position. Construction area: Moscow; purpose of the building - residential.

| Table 1. Characteristics of the enclosing structure, consisting of aerated concrete block masonry, insulation of expanded polystyrene plates, exterior and interior plaster layers. |
| Wall structure | Layer thickness, $m$ | Density, $kg/m^3$ | Thermal conductivity coefficient, $W/(m\cdot^\circ C)$ | Vapor permeability coefficient, $mg/(m\cdot$hour$\cdot$Pa) |
|----------------|-------------------|----------------|------------------|-----------------------------|
| Exterior plaster layer | 0.007 | 1260 | 0.93 | 0.13 |
| Insulation of expanded polystyrene plates | 0.12 | 25 | 0.044 | 0.05 |
| Base of aerated concrete masonry | 0.3 | 400 | 0.15 | 0.23 |
| Interior plaster layer | 0.02 | 1800 | 0.93 | 0.09 |

If inside air temperature is equal to 20 $^\circ C$, and relative inside air humidity is equal to 55 %, then criterion $\Delta = 0.208$. It is proposed to vary one of the parameters and keep other constant to investigate dependence of maximum wetting plane position on interior micro climate parameters and layers.
thickness. Thus, to find out dependence between $\Delta$ and insulation thickness, the base thickness, temperature and relative humidity of inside air were taken as constant, and insulation thickness was changed in increments of 0.01 m (Fig. 2). To find out dependence between $\Delta$ and base thickness, insulation thickness, temperature and relative humidity of inside air were taken as constant, and base thickness was changed in increments of 0.01 m (Fig. 3). To find out dependence between $\Delta$ and inside air temperature, layers thickness and inside air relative humidity were taken as constant, and inside air temperature was changed in increments of 1 °C (Fig. 4). To find out dependence between $\Delta$ and inside air relative humidity, layers thickness and inside air temperature were taken as constant, and inside air relative humidity was changed in increments of 1 % (Fig. 5).

The graphs show that increase in insulation thickness results in reduction of relative displacement coordinate of maximum wetting plane for the enclosing structure consisting of aerated concrete masonry, insulation of expanded polystyrene, exterior and interior plaster layers; increase in base thickness, inside air temperature, inside air relative humidity results in increase in relative displacement coordinate of the maximum wetting plane, i.e. maximum wetting plane shift inside the enclosure.

Thus, it is possible to control maximum wetting plane position by variation of interior micro climate parameters or layers' thickness.

5. Conclusion
Maximum wetting plane position in the enclosing structure made of aerated concrete masonry base and expanded polystyrene insulation was studied. Dependencies for maximum wetting plane position control depending on layer thickness and interior micro climate parameters were developed.
It is found out that increase in base thickness, inside air temperature or inside air relative humidity result in maximum wetting plane shift inside the enclosure, and increase in heat insulation thickness results in maximum wetting plane shift outside the enclosure.

The given results can be used in engineering practice for overwetting protection calculation of the enclosing structures.

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