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TAKING INTO ACCOUNT MOISTURE IN INCREASING THE ACCURACY OF CALCULATING HEAT LOSSES OF A BUILDING

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Abstract: A discrete-continuous approach was applied to the moisture transfer equation, which made it possible to obtain an analytical solution for the moisture potential. The new method was applied to study the unsteady-state moisture regime of the facade heat-insulating composite system with expanded polystyrene insulation and aerated concrete base. It was found that the mass moisture content of building materials achieved in the walls during the period of operation is lower than the mass moisture content used in construction regulations, which makes it possible to increase the accuracy of calculating the transmission heat losses of the building. Calculations of heat losses of a two-storey building in the climatic conditions of Moscow (Russia) showed a decrease in the heating system load by 5 %, and the reduction in heat losses for specific premises of the building ranged from 3.6 to 7 %.

Keywords: building envelope, effect of moisture on thermal conductivity, heat and moisture transfer, mathematical model, discrete-continuous approach

УЧЕТ ВЛАЖНОСТИ В ПОВЫШЕНИИ ТОЧНОСТИ РАСЧЕТА ТЕПЛОВЫХ ПОТЕРЬ ЗДАНИЯ

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Аннотация: К уравнению влагопереноса применен дискретно-континуальный подход, позволивший получить аналитическое решение для потенциала влажности. Новый метод был применен для исследования нестационарного влажностного режима системы фасадной теплоизоляционной композиционной с утеплителем из пенополистирола и основанием из газобетона. Было получено, что массовая влажность строительных материалов, достигаемая в стенах за период эксплуатации ниже массовой влажности, используемой в нормативных документах по строительству, что дает возможность повысить точность расчета трансмиссионных тепловых потерь здания. Расчеты тепловых потерь двухэтажного здания в климатических условиях г. Москвы (Россия) показали снижение нагрузки на систему отопления на 5 %, а для конкретных помещений здания снижения тепловых потерь составило от 3.6 до 7 %.

Ключевые слова: ограждающая конструкция здания, влияние влаги на теплопроводность, тепло- и влагоперенос, математическая модель, дискретно-континуальный подход

1. INTRODUCTION

1.1. The role of moisture in construction

The moisture regime of building envelopes is a highly sophisticated scientific problem in construction. Research on distribution of moisture over the thickness of fences has a huge applied relevance [1]. From a medical point of view, wet building material is a breeding ground for bacteria, which can cause various human diseases, such as asthma and allergy. A change in moisture content of a building material directly affects its

thermal conductivity and the heat-shielding shell of the building. Errors in assessing moisture state of building fences can lead to condensation and mold on the internal surfaces of building envelopes, as well as waterlogging of the wall material, which is directly related to the durability of the building [2,3].

1.2. Influence of moisture on heat losses of a building

It is a common knowledge that moisture content rise of a building material causes an increase in its thermal conductivity, which negatively affects thermal protection of buildings [4–7].

The dependence of thermal conductivity on moisture is described by the formula [4–7]:

$$\lambda_w = \lambda_0 + w \cdot \Delta\lambda_w. \quad (1)$$

where λ_w is a coefficient of thermal conductivity of the material at moisture w, W/(m·ºC); w is mass moisture content of the material, kg/kg; λ_0 is a thermal conductivity coefficient of dry material, W/(m·ºC); $\Delta\lambda_w$ is change in the thermal conductivity of the material when its mass moisture changes by 1 %, W/(m·ºC ·%).

There is a variety of methods for calculating the heat loss of a building.

In the general case, heat losses of the building premises are a sum of transmission and infiltration heat losses:

$$Q = Q_{tr} + Q_{inf}. \quad (2)$$

where Q is total heat loss of the building premise, W; Q_{tr} are transmission heat losses of the building premise, W; Q_{inf} is infiltration heat loss of the building premise, W.

Transmission heat losses through a certain enclosing structure are estimated using the following expression [4–7]:

$$Q_{tr} = k \cdot F \cdot \Delta t \cdot n \cdot (1 + \sum \beta). \quad (3)$$

where k is a heat transfer coefficient, W/(m^2·ºC); F is a heat transfer surface area, m^2; Δt is a temperature difference on different sides of the building envelope ºC; n is a coefficient that depends on the position of the building envelope in relation to the outer air, ºC; β are additional heat losses that are dependent on the orientation of the building envelope over the cardinal points.

The heat transfer coefficient in equation (3) is the reciprocal of the reduced resistance to heat transfer [4–7]:

$$k = \frac{1}{R_{act}}. \quad (4)$$

where R_{act} is reduced heat transfer resistance, m^2·ºC/(W).

The reduced resistance to heat transfer of the enclosing structure of the building wall is calculated with the formula [4–7]:

$$R_{act} = \frac{1}{\frac{1}{R_{con}} + \sum l_j \cdot \psi_j + \sum n_k \cdot \chi_k}. \quad (5)$$

where R_{con} is conditional heat transfer resistance, (m^2·ºC)/W; $l_j \cdot \psi_j$ are specific heat losses through a linear thermal inhomogeneity of the j-th type, W/(m^2·ºC); $n_k \cdot \chi_k$ are specific heat losses through point thermal inhomogeneity of the k-th type, W/(m^2·ºC).

Conditional resistance of heat transfer for the outer wall of the building is determined by the formula [4–7].:

$$R_{con} = \frac{1}{\frac{1}{\alpha_{in}} + \sum \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_{ext}}}. \quad (6)$$

where α_{in} is a coefficient of heat transfer between outer air and the outer surface of the wall, (m²·ºC)/W; α_{ext} is a coefficient of heat transfer between the indoor air of the room and the inner surface of the wall, (m²·ºC)/W; δ_i is the thickness of i-th material of the wall, m; λ_i is a coefficient of thermal conductivity of the i-th material of the wall, W/(m·ºC).

So, an increment of the calculation accuracy of mass moisture content w in the building wall will make the thermal conductivity coefficients of building materials by equation (1) more precise, which according to equations (2)-(6) will refine the heat loss of the building.

2. THE PROBLEM

Assessment of the impact of the building material operational humidity determined using the proposed method on the heat losses of the building.

3. MATERIALS AND METHODS

The mathematical model for the joint moisture transfer of vaporous and liquid moisture was proposed by V.G. Gagarin and V.V. Kozlov. V.G. Gagarin derived a necessary and sufficient condition for the potentiality of a vector field during the water vapor and liquid transfer, which thereafter allowed V.G. Gagarin and V.V. Kozlov to develop a formula for the moisture potential F [8]:

$$F(w,t) = E_t(t)\cdot\varphi(w) + \frac{1}{\mu}\int_0^w \beta(\zeta)\,d\zeta. \qquad (7)$$

where F is moisture potential, Pa; E_t is saturated water vapor pressure, Pa; φ is relative air humidity, %; μ is vapor permeability coefficient, *kg/(m·s·Pa)*; β is moisture conductivity coefficient, kg/(m · s · kg/kg), which depends on moisture, t is temperature, $^{\circ}C$; w is material moisture , % by weight (1 kg/kg = 100 % by weight).

Moisture transfer differential equation based on the moisture potential F can be formulated as:

$$\frac{\partial F(w,t)}{\partial \tau} = \left(\frac{1}{\mu}\beta(w) + \frac{\partial\varphi(w)}{\partial w}E_t(t)\right)\frac{\mu}{\gamma_0}\frac{\partial^2 F(w,t)}{\partial x^2}. \qquad (8)$$

The equation (7) can be solved in the following form using discrete-continuous approach [9–11]:

$$\overline{F} = p\cdot\left(\left(E_t\cdot A\right)^{-2}\cdot e^{E_t\cdot A\cdot\tau} - \tau\cdot\left(E_t\cdot A\right)^{-1} - \left(E_t\cdot A\right)^{-2}\right)\cdot \cdot \overline{L} + \left(E_t\cdot A\right)^{-1}\left(e^{E_t\cdot A\cdot\tau} - E\right)\cdot\overline{B} + e^{E_t\cdot A\cdot\tau}\cdot\overline{F}_0. \qquad (9)$$

4. RESULTS AND DISCUSSION

4.1. Application of a discrete-continuous approach to assess the unsteady-state moisture regime of a facade heat-insulating composite system with external plaster layers

The developed method for assessing the unsteady-state moisture regime was applied to study the facade heat-insulating composite system with external plaster layers with a 300 mm thick aerated concrete base and 120 mm thick expanded polystyrene insulation built in Moscow.

The change in the mass humidity of the building envelope along the wall thickness is presented (Figure 1).

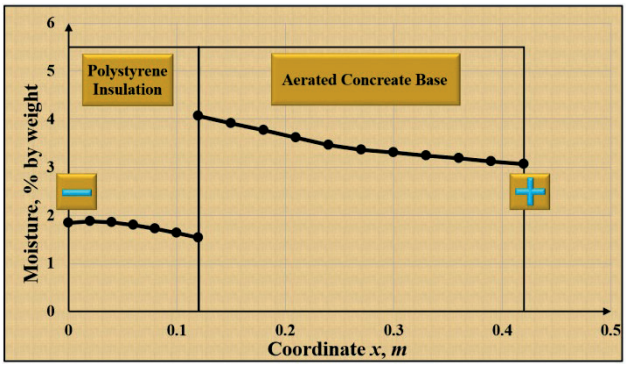


Figure 1. Change in the mass moisture content of the building envelope across the wall thickness

The change in the humidity of the insulation layer during the year was obtained according to the proposed method for assessing the unsteady-state moisture regime (Figure 2).

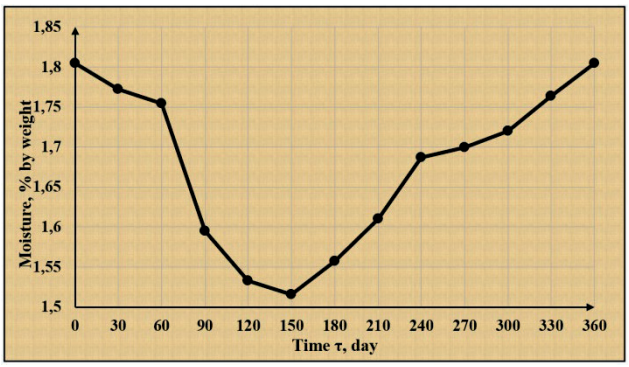


Figure 2. Change in the moisture of the insulation layer during the year according to the proposed method for assessing the unsteady-state moisture regime

As a result of the research, it was discovered that maximum moisture for the facade heat-insulating composite system with aerated concrete base and expanded polystyrene insulation will be observed at the beginning of January (Figure 2), which corresponds to the maximum temperature difference on different sides of the fence. This result is explained by the low inertia of the insulation layer. Consequently, it was discovered that for facade heat-insulating composite systems, the period of maximum moisture differs from the period of maximum moisture for enclosing structures that do not contain insulation.

4.2. Comparison of the operational moisture of the building wall obtained using the discrete-continuous approach with standard values

To evaluate the effect of the proposed method, the operating humidity was compared according to the proposed method for assessing the unsteady-state moisture regime with the values given in the official regulatory document Set of Rules 50.13330.2012 "Thermal protection of buildings" (Russian regulatory document).

The construction of the wall illustrated in Figure 1 was taken for the study.

Comparison of the operational moisture of a building wall with a base made of aerated concrete (aerated concrete layer thickness 0.3 m) and expanded polystyrene insulation (insulation layer thickness 0.12 m) obtained using the proposed calculation method based on a discrete-continuous approach with standard values (Table 1) was carried out.

As we can see from Table 1, the actual values of the operating moisture content of building materials obtained by the proposed formula are significantly lower than the moisture content of building materials taken according to the standards. According to the formula (1), a decrease in the mass moisture content of building material leads to a decrease in its thermal conductivity. Thus, it gives a possibility to save energy when determining the exact amount of mass moisture in the building envelope materials by taking into account the refined thermal conductivity coefficient.

Table 1. Comparison of the operational humidity of a building wall with aerated concrete base and expanded polystyrene insulation obtained using the proposed calculation method based on a discrete-continuous approach with standard values

Material	Regulatory values for operating humidity, % by weight	The result of calculating the unsteady-state moisture regime according to the proposed formula (9), % by weight
Aerated concrete	12.0	3.4
Expanded polystyrene	10.0	1.8

4.3. Increasing energy savings by improving the calculation accuracy of heat losses of a building

To assess the reduction of heat losses in the building envelope, two calculations of heat losses were made for a two-storey cottage building in Moscow (Russia). The first calculation was carried out at standard values of humidity, whereas the second one was carried

out in agreement with the calculated values that were obtained during the modeling of the non-stationary state of the enclosing structure of the building wall (Table 1).
The temperature of the coldest five-day period was set as the outside temperature according to the climatological data of the construction area.

Comparison of the composition of the transmission heat losses of the wall of a cottage house building according to the standard values and according to the proposed method for defining the unsteady-state moisture regime with the aid a discrete-continuous approach is presented (Figure 3).

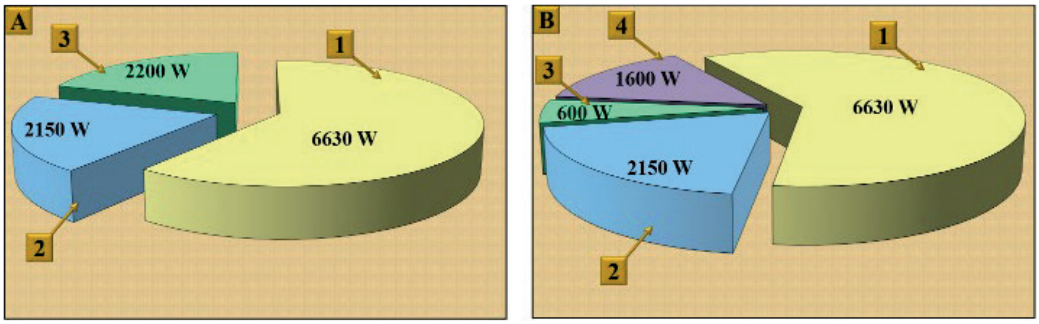


Figure 3. Comparison of the transmission heat losses composition of the wall of the cottage house building: A – distribution of heat losses in the wall obtained in the calculation at the moisture content of materials taken according to the standard values; B – distribution of heat losses in the wall that were obtained when making calculations at the values of the moisture content of materials determinated from the results of the assessment of the unsteady-state moisture regime (1 – heat losses of the wall along the surface of the wall through dry material; 2 – heat losses of the wall through heat engineering inhomogeneities; 3 – heat losses of the wall due to moisture; 4 – energy saving achieved by taking into account the unsteady-state moisture regime)

As may be inferred from Figure 3, taking into account the unsteady-state moisture regime led to energy savings of 1600 W due to a decrease in transmission heat losses.
Transmission heat losses through building walls are not the only source of building heat losses. In order to estimate the overall reduction of heat losses in the total costs of the building for heating and ventilation, it is also essential to determine the transmission heat losses through the floor, ceiling, windows and doors of the building as well as heat losses for heating the infiltrated air.
The comparison of the results of the calculations of heat losses at the moisture content of the building wall materials taken according to standard values as well as at the moisture content of the building wall materials gained from the results of the assessment of the unsteady-state moisture regime using the proposed method is presented (Table 2).

Table 2. Comparison of the results of heat loss calculations at the moisture content of the building wall materials taken according to standard values as well as at the moisture content of the building wall materials gained from the results of the assessment of the unsteady-state moisture regime using the given method is presented

Building envelopes	Heat loss according to the standard humidity values, *W*	Heat loss according to the calculated humidity values, *W*
Walls	10980	9380
Windows	8470	8470
Roof coating	3030	3030
Doors	1070	1070
Floor	1405	1405
Infiltration	6075	6075
Total heat losses	31030	29430

Thus, for the building under consideration, energy saving when calculating heat losses by taking into account the unsteady-state moisture regime of the building wall using the method for calculating the unsteady-state moisture regime suggested in this article is 1600 W (5%).

To illustrate the reduction of heat losses in each separate room, a plan of the second floor of a two-storey cottage house is presented with heat losses calculated at the temperature of the coldest period of five days (figure 4).

As can be noticed from Figure 4, the reduction of heat losses of the building is large for each room and can be presented as a table 3.

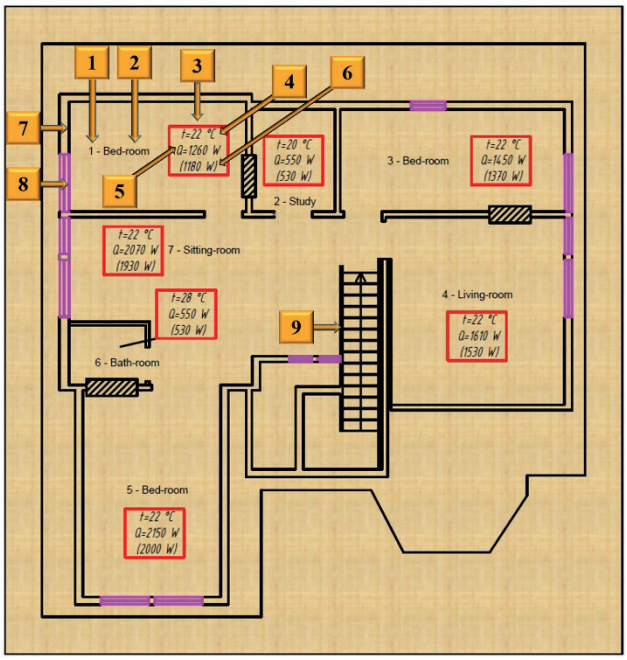


Figure 4. Plan of the second floor of a two-storey cottage house with heat losses calculated at the temperature of the coldest period of five days (1 – room number; 2 – purpose of the room; 3 – table with parameters of the room; 4 – indoor air temperature in the room during cold season (winter); 5 – heat loss of the room determined at the normative humidity of the building materials of the wall; 6 – heat losses of the room at the moisture content of the building materials of the wall determined by the calculation of the unsteady-state moisture regime; 7 – the outer wall of the building; 8 – the window of the building; 9 – stairs)

Table 3. Reduction of heat losses due to the assessment of the unsteady-state moisture regime by the suggested method

No.	Room name	Heat loss according to the standard humidity values, *W*	Heat loss according to the calculated humidity values, *W*	Percentage of heat loss reduction, %
1	Bedroom	1260	1180	6.3
2	Study	550	530	3.6
3	Bedroom	1450	1370	5.5
4	Living-room	1610	1530	5.0
5	Bedroom	2150	2000	7.0
6	Bathroom	550	530	3.6
7	Sitting-room	2070	1930	6.8

As is obvious from Table 3, the actual heat losses obtained during the modelling are from 3.6 to 7.0 % less than those calculated for different rooms from, which is significant when projecting buildings.

5. CONCLUSIONS

The assessment of the unsteady-state moisture regime made allows us to make a conclusion that moisture content in the thickness of the building envelope materials is lower than is accepted according to regulatory documents. The energy saving of the building was assessed by applying the proposed methodology by calculating heat losses of the building. Comparative calculations for the studied two-storey building showed a total reduction of the building's heat demand for heating and ventilation in the amount of 5 %. At once, the reduction of heat loss can reach from 3.6 to 7 % depending on the room.

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