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THE MOISTURE REGIME OF ENCLOSING STRUCTURES IN DIFFERENT CONSTRUCTION AREAS

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Abstract: Heat and mass transfer mathematical model is formulated. Solution of the moisture transfer equation was obtained by discrete-continuum approach, which gives an opportunity to obtain the new analytical solution. Algorithm for calculating the moisture regime according to the proposed mathematical model is given. Enclosing structure with aerated concrete base and expanded polystyrene insulation is chosen for moisture regime calculation. Moisture behaviour calculation is done in three construction areas (dry, normal, wet) for four different moisture regimes of building room (dry, normal, moist, wet). Calculation results were summarized in a table which engineers can use in their practical work.

Keywords: moisture regime, mathematical model, discrete-continuum approach, moisture potential, vapor permeability, sorption isotherm, enclosing structure

ВЛАЖНОСТНЫЙ РЕЖИМ ОГРАЖДАЮЩИХ КОНСТРУКЦИЙ В РАЗЛИЧНЫХ РАЙОНАХ СТРОИТЕЛЬСТВА

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Абстракт: Сформулирована математическая модель тепловлагопереноса. Получено решение нестационарного уравнения влагопереноса с помощью дискретно-континуального подхода, что дало возможность вывести новую аналитическую формулу. Приведен алгоритм расчета нестационарного влажностного режима по предложенной математической модели. Для расчета влажностного режима выбрана ограждающая конструкция с основанием из газобетона и утеплителем из пенополистирола. Проведен расчет влажностного режима в трех зонах влажности (сухая, нормальная, влажная) для четырех различных влажностных режимов помещения здания (сухой, нормальный, влажный, мокрый). Результаты расчетов сведены в таблицу, которую возможно использовать в практической инженерной работе.

Ключевые слова: влажностный режим, математическая модель, дискретно-континуальный подход, потенциал влажности, паропроницаемость, изотерма сорбции, ограждающая конструкция.

1. INTRODUCTION

Modern technology development improves some technique directions of our life. There are some innovations, which are introduced in building industry [1,2]. Although these innovations make modern level of live better than previously, the demand for calculation methods becomes higher because humanity works with complicated systems like passive and smart houses [3-5].

1.1. The complexity of the research of moisture transfer processes

One of the most complicated directions in building is the moisture transfer. This problem became crucial 100 years ago, when multilayer inclosing structures were included in building industry. Earlier there were no problems with the moisture transfer of building walls because all water vapour which penetrates inside inner surfaces of single-layer enclosing structures comes out through outer surfaces of enclosing

structures. However, if we talk about a multilayer inclosing structure, water vapour can diffuse through separate layers with different speed, so we can observe moisture accumulation on the border between the layers [6,7].
This problem is complemented by the fact that moisture consists of vapor and liquid components. Each component can move by different private gradients of transfer potentials: partial pressure gradient of water vapor, capillary pressure gradient of liquid moisture, temperature gradient, gradient of air filtration, etc. The moisture field constantly interacts with temperature distribution, which complicates the problem, so scientists usually tell about combined heat and moisture transfer [7].
The moisture transfer research gives opportunities to reduce the heat losses by building heat shield, increase the energy efficiency of the building including houses with insulation layers and gives additional comfort and safety to human [8]. Moreover, the moisture transfer research is investigated in different types of the HVAC (Heating, Ventilation, Air Conditioning) Systems.

1.2. Separate accounting of moisture transfer mechanisms and moisture potential
The first unsteady-state mathematical model was proposed by K.F. Fokin. This model takes into account moisture transfer under vapour gradient partial pressure only, so the solution of the moisture transfer equation exists in sorption zone [9].
However, this method has fundamental weakness. Water vapor partial pressure cannot be more than saturated water vapor pressure, so this equation has indeterminacy for calculations. K.F. Fokin developed another equation to solve this problem. The second Fokin's model takes into account water vapor and liquid moisture movements and they can be calculated in sorption zone and ultrasorption zone contemporaneously, but this model has another complicated problem, which requires working with the two separate moisture transfer potentials: capillary pressure gradient of liquid moisture and partial pressure gradient of water vapor [9].
Another approach to the moisture regime calculation is using the moisture potential. Instead of calculating the separate transfer potentials, the moisture potential allows to solve the problem with single transfer potentials [9].

1.3. Ways of calculating moisture value of building materials
Modern engineers use averaged data of moisture value which are included in different standards, but it will be possible to improve energy efficiency and energy saving if we predict exactly the value of building material moisture at the moment of maximum moisture accumulation.
There are some approaches to obtain the moisture value of building materials.
One of them is determining moisture value by field studies or laboratory experiments [10,11], but this way is too difficult and expensive.
Another path is prediction of moisture value of building material by mathematical model, which uses computer and numerical method [10,11]. In this case, we need to have a lot of experimental data and high qualification of engineers.
We can calculate steady-state moisture transfer equation and obtain moisture behaviour. Although we will receive required values, the accuracy of this approach will be not high.

2. THE PROBLEM

The aims of this paper are development of the new analytical formula for calculation the moisture behaviour using discrete-continuous approach.

3. MATERIALS AND METHODS

The moisture potential F was taken as the basis of the development of the mathematical model.

3.1. The mathematical model which is based on the moisture potential F

Let's formulate heat and mass transfer mathematical model:

$$
\begin{cases}
\dfrac{\partial^2 t}{\partial x^2} = 0 \ - \ \text{heat transfer equation} \\
\dfrac{\partial F(w,t)}{\partial \tau} = \kappa_{F0} \cdot E_t(t) \cdot \dfrac{\partial^2 F(w,t)}{\partial x^2} \ - \ \text{moisture transfer equation} \\
E_t(t) = 1{,}84 \cdot 10^{11} \cdot \exp(-\dfrac{5330}{273+t}) \ - \ \text{depends } E_t(t) \text{ on } t \\
0 \le x \le l, \ \tau > 0 \ - \ \text{space-time domain} \\
-\lambda \dfrac{\partial t}{\partial x}\Big|_{x=0} = \alpha_{ext}\left(t_{ext} - t_1\right) \ - \ \text{boundary condition} \\
\lambda \dfrac{\partial t}{\partial x}\Big|_{x=l} = \alpha_{in}\left(t_{in} - t_N\right) \ - \ \text{boundary condition} \\
-\mu \dfrac{\partial F}{\partial x}\Big|_{x=0} = \dfrac{1}{R_{m.ext}}\left(F_{ext} - F_1\right) \ - \ \text{boundary condition} \\
\mu \dfrac{\partial F}{\partial x}\Big|_{x=l} = \dfrac{1}{R_{m.in}}\left(F_{in} - F_N\right) \ - \ \text{boundary condition} \\
F(x,0) = f(x), \ 0 \le x \le l \ - \ \text{initial condition}
\end{cases}
\quad (1)
$$

3.2. Discrete-continuous approach for the moisture regime calculating

Discrete-continuous approach was used to solve the moisture transfer equation [12] in the system (1).

The system of equations (1) was presented in the form of a matrix equation which has an analytical solution.

As a result, the new analytical expression was obtained:

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

3.3. Algorithm for calculating the moisture regime according to the proposed mathematical model

The algorithm for calculating the unsteady-state moisture regime of enclosing structures using the discrete-continuous method is proposed:

1) The building enclosing structure is divided into sections along the *x* coordinate.

2) The initial distribution of the moisture potential over all sections of the building enclosing structure and the initial moment of time are specified.

3) Calculation of the distribution of moisture potential at the end of the month for a multilayer building enclosing structure is obtained by the formula (2).

4) The moisture regime of the building enclosing structure is determined at the end of the month using the moisture potential scales of the building enclosing structure materials according to the obtained moisture potential distributions.

5) The temperature field of the enclosing structure changes in accordance with the climatic conditions of the next month outside the enclosure.

6) The initial distribution of the moisture potential at the beginning of the next month is determined using the moisture potential scales according to the moisture regime of the building enclosing structure at the end of the previous month.

7) The calculation is repeated in clauses 3-6 for the required period.

In previous papers it was shown that formula (2) has higher accuracy than the analytical expression and this approach simplifies the solution of unsteady-state moisture transfer equation by the finite difference method using an explicit difference scheme [13].

4. RESULTS AND DISCUSSION

Moisture behaviour calculations in different construction areas for the enclosing structure with aerated concrete base and expanded polystyrene insulation are made.

4.1. Research of moisture behaviour in different construction areas

Three construction areas exist in Russia: dry, normal, wet.

We chose 18 cities (six cities in each construction area) for the moisture regime calculation (Table 1).

Table 1. Cities for the moisture regime calculation

No.	Dry construction area	Normal construction area	Wet construction area
1	2	3	4
1	Krasnodar	Moscow	Petropavlovsk-Kamchatsky
2	Samara	Kaliningrad	Ayan
3	Omsk	Nizhny Novgorod	Vladivostok
4	Novosibirsk	Tomsk	Murmansk
5	Irkutsk	Khabarovsk	Yuzhno-Kurilsk
6	Volgograd	Perm	Arkhangelsk

In each construction area there can be four types of moisture regime of building room: dry, normal, moist, wet.

Temperature and relative humidity were chosen for each moisture regime of building room for the moisture behaviour calculation (Table 2).

Table 2. Temperature and relative humidity for each moisture regime of building room

No.	Type of moisture regime of building room	Temperature and relative humidity inside a room
1	2	3
1	Dry	$t_{in} = 22$ °C; $\varphi_{in} = 50$ %
2	Normal	$t_{in} = 22$ °C; $\varphi_{in} = 60$ %
3	Moist	$t_{in} = 22$ °C; $\varphi_{in} = 75$ %
4	Wet	$t_{in} = 22$ °C; $\varphi_{in} = 90$ %

4.2. Research of moisture behaviour in different construction areas

Moisture behaviour calculations in different construction areas for the enclosing structure with aerated concrete base and expanded polystyrene insulation are made.

The moisture regime calculation of enclosing structure with aerated concrete base and expanded polystyrene insulation is presented for cities of dry construction area (Krasnodar, Samara, Omsk, Novosibirsk, Irkutsk, Volgograd) for different moisture regimes of building room (Fig. 1).

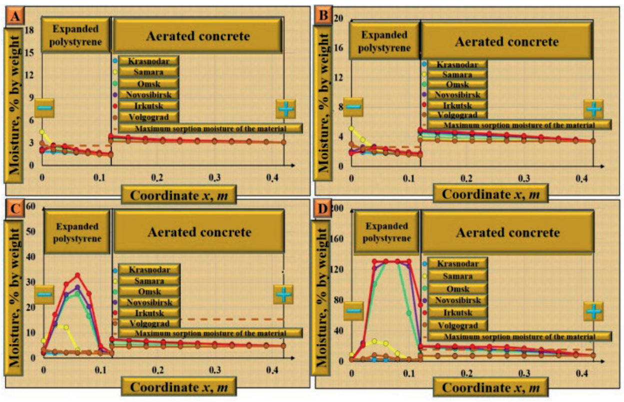


Figure 1. The moisture regime calculation of enclosing structure with aerated concrete base and expanded polystyrene insulation for cities of dry construction area (Krasnodar, Samara, Omsk, Novosibirsk, Irkutsk, Volgograd) for different moisture regimes of building room: A is dry; B is normal; C is moist; D is wet

The moisture regime calculation of enclosing structure with aerated concrete base and expanded polystyrene insulation is presented for cities of normal construction area (Moscow, Kaliningrad, Nizhny Novgorod, Tomsk, Khabarovsk, Permian) for different moisture regimes of building room (Fig. 2).

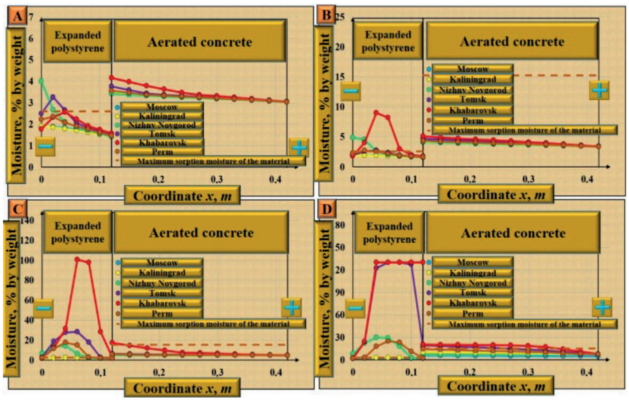
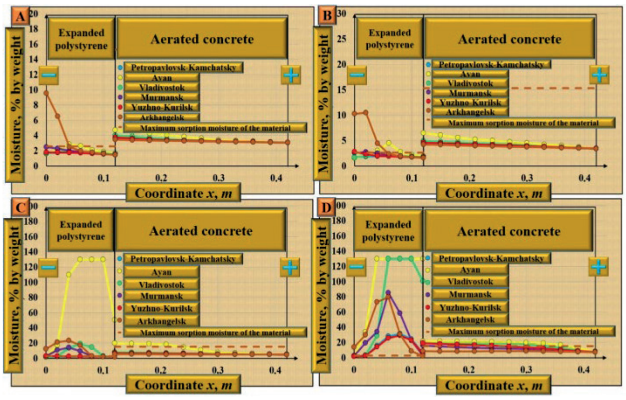


Figure 2. The moisture regime calculation of enclosing structure with aerated concrete base and expanded polystyrene insulation for cities of normal construction area (Moscow, Kaliningrad, Nizhny Novgorod, Tomsk, Khabarovsk, Perm) for different moisture regimes of building room: A is dry; B is normal; C is moist; D is wet

The moisture regime calculation of enclosing structure with aerated concrete base and expanded polystyrene insulation is presented for cities of wet construction area (Petropavlovsk-Kamchatsky, Ayan, Vladivostok, Murmansk, Yuzhno-Kurilsk, Arkhangelsk) for different moisture regimes of building room (Fig. 3).



<u>Figure 3.</u> The moisture regime calculation of enclosing structure with aerated concrete base and expanded polystyrene insulation for cities of normal construction area (Petropavlovsk-Kamchatsky, Ayan, Vladivostok, Murmansk, Yuzhno-Kurilsk, Arkhangelsk) for different moisture regimes of building room: A is dry; B is normal; C is moist; D is wet

The results of moisture regime calculation are combined in the table. The maximum calculation values are presented in each gap (Table 3).

<u>Table 3.</u> The obtained moisture values in different construction area for different moisture regimes of building room

Moisture behavior of the building room	Material moisture content determined according to the unsteady-state moisture behavior calculation in various moisture areas, mass percent (1 - insulation layer; 2 – base layer)					
	Dry		Normal		Wet	
	1	2	1	2	1	2
Dry	2.2	3.8	2.2	3.5	3.6	3.7
Normal	2.6	4.2	4.3	4.3	4.7	4.8
Moist	16.1	5.9	39.4	8.7	81.2	11.1
Wet	88.0	16.0	96.7	17.1	97.9	18.3

Obtained values are possible to use in an engineering method to calculate the exact value of the thermal conductivity coefficient and these values exist in all areas of Russia.

4.3. Comparison of the obtained results with results of other authors

If we take into account moisture values which are presented in the regulatory standard Set of Rules 50.13330.2012 "Thermal protection of buildings", we will compare proposed results with modern view of construction industry.

For the enclosing structure with aerated concrete base and expanded polystyrene insulation moisture values, according to the standard, can be written as (Table 4).

<u>Table 4.</u> The moisture values in different construction areas for different moisture regimes of building room determined according to the Set of Rules 50.13330.2012 "Thermal protection of buildings"

Moisture behavior of the building room	Material moisture content determined according to Set of Rules 50.13330.2012 «Thermal protection of buildings» in various moisture areas, mass percent (1 - insulation layer; 2 – base layer)					
	Dry		Normal		Wet	
	1	2	1	2	1	2
Dry	2.0	8.0	2.0	8.0	10.0	12.0
Normal	2.0	8.0	10.0	12.0	10.0	12.0
Moist	10.0	12.0	10.0	12.0	10.0	12.0
Wet	10.0	12.0	10.0	12.0	10.0	12.0

As we can see, the obtained moisture values determined according to the unsteady-state moisture behavior calculation can differ from moisture values determined according to the Set of Rules 50.13330.2012 "Thermal protection of buildings". The use of proposed method improves the accuracy of moisture calculation and can achieve energy saving because in dry and normal construction area moisture content is less than in regulatory standard.

4.4. Comparison of the obtained results with results of other authors

In current paper we predict moisture content and it gives opportunities not to do field studies [10,11] in each construction area.

The accuracy of moisture regime calculation by proposed method is higher than the accuracy by steady-state method [6]. Moreover, we do not need to use numerical method, which simplifies calculations [12].
This article proposes Table. 3, which we can use without additional calculation and it is better than to determine unsteady-state moisture behaviour in each instance.

5. CONCLUSIONS

The new effective method for calculating unsteady-state moisture regime has been developed. Proposed method allows to calculate moisture transfer by analytical expression with higher accuracy than steady-state method, but without using numerical method.
The moisture behaviour calculations in different construction areas for the enclosing structure with aerated concrete base and expanded polystyrene insulation are given. This approach allows to obtain the table with moisture value data. Engineers can use obtained data when they calculate heat conductivity coefficients of building materials of inclosing structures. This article allows to clarify the moisture values in the regulatory standard.

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