International Journal for Computational Civil and Structural Engineering, 22(3) 127–134 (2026)

DOI:10.22337/2587-9618-2026-22-3-127-134

DEVELOPING THE METHOD FOR CREATING THE MAP OF APPLICATION ZONES OF THE BUILDING ENVELOPE BASED ON CALCULATIONS OF PROTECTION AGAINST WATERLOGGING

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Abstract: The main provisions underlying the creation of a method for the balance of moisture transfer have been given. Based on the balance of moisture transfer, a criterion for waterlogging of the building envelope was derived. The waterlogging criterion was calculated for 81 localities. The results obtained were plotted on a map of Russia, as a result of which three zones of application of the building envelope determining where the structure is permitted to be built were designed. Algorithms for constructing and applying a map of application zones of building enclosing structures have been presented. The effectiveness of the proposed approach is demonstrated for determining the balance of moisture transfer in three cities: Murmansk, Vorkuta and Tomsk. It is noted that the developed method is recommended for implementation in engineering work.

Keywords: humidity regime, moisture transfer equation, resistance to vapor permeation, temperature,map of humidity zones

РАЗРАБОТКА МЕТОДА СОЗДАНИЯ КАРТЫ ЗОН ПРИМЕНЕНИЯ ОГРАЖДАЮЩЕЙ КОНСТРУКЦИИ ЗДАНИЯ НА ОСНОВЕ РАСЧЕТОВ ЗАЩИТЫ ОТ ПЕРЕУВЛАЖНЕНИЯ

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Аннотация: Приведены основные положения, лежащие в основе создания метода по балансу влагопереноса. На основе баланса влагопереноса был выведен критерий переувлажнения ограждающей конструкции. Был произведен расчет критерия переувлажнения для 81 населенного пункта. Полученные результаты были нанесены на карту России, в результате чего были построены три зоны применения ограждающей конструкции, определяющие где конструкцию можно строить. Приведены алгоритмы построения и применения карты зон применения ограждающих конструкции здания. Эффективность предлагаемого подхода продемонстрирована для определения баланса влагопереноса в трех городах: Мурманск, Воркута и Томск. Отмечено, что разработанный метод рекомендован для внедрения в инженерную работу.

Ключевые слова: влажностный режим, уравнение влагопереноса, сопротивление паропроницанию, температура, карта зон влажности

1. INTRODUCTION

The design of buildings and structures is a complex technological process during which various engineering problems are solved. The main factors influencing the design are the choice of the optimal architectural and planning solution, the use of new and modern technologies, the calculation of various structures by temperature and pressure distribution, etc [1–5].

For the first time, the method of calculating protection against waterlogging was introduced

in 1963 in the Russian regulatory document SNiP II-A.7-62* “Construction Heat Engineering. Design standards". The calculation method was based on the differential equation of moisture transfer proposed by K.F. Fokin [6]:

$$\gamma_0 \cdot \frac{\xi_0(w)}{E_t(t)} \cdot \frac{\partial e(w,t)}{\partial \tau} = \frac{\partial}{\partial x}(\mu \frac{\partial e(w,t)}{\partial x}). \qquad (1)$$

where e, E_t – water vapor partial pressure and saturated water vapor pressure, *Pa*; μ – vapor permeability, *kg/(m·s·Pa)*; ξ_0 – relative vapor capacity, kg/kg; γ_0 – density, kg/m^3; τ – time, *s*; *x* – coordinate, *m*.

Equation (1) was solved in stationary and nonstationary formulations. As a result, formulas for the required vapor permeability resistance have been derived.

$$\begin{cases} R_{n1}^{req} = \frac{(e_{in} - E) \cdot R_{n.o}}{E - e_O} \\ R_{n2}^{req} = \frac{z_0 (e_{in} - E_0)}{\rho_w \cdot \delta_w \cdot \Delta w + \eta} \end{cases} \qquad (2)$$

Then the moisture transfer balance inequality which encompasses the comparison of vapor permeation resistances is used:

$$R_n \geq \mathrm{R}_n^{req} \qquad (3)$$

$$\mathrm{R}_n^{req} = \max[R_{n1}^{req}; R_{n2}^{req}] \qquad (4)$$

where R_n – vapor resistance, $m^2 \cdot s \cdot Pa/kg$; R_{n1}^{req}, R_{n1}^{req}, R_{n2}^{req} – required vapor permeation resistances, $m^2 \cdot s \cdot Pa/kg$.

If inequality (3) is met, then, according to the calculation method, the structure is protected from waterlogging and is allowed to be built. Otherwise, the enclosing structure does not pass the waterlogging test [7–9].

The method of K.F. Fokin entered the modern regulatory framework with the modification of V.G. Gagarin and V.V. Kozlova. The balance of moisture transfer according to equation (3) is reduced relative to the plane of maximum moisture. This method has been introduced into the Russian regulatory document SP 50.13330.2024 "Thermal protection of buildings”.

Despite the effectiveness of the described method, its calculations are quite complex for engineering use. In this regard, development of the new methods of protection against waterlogging, which would let the balance of moisture transfer be assessed in a simplified manner, remains pertinent. In this article, a calculation method that provides the possibility to assess construction of a building envelope using a map of humidity zones has been developed.

2. THE PROBLEM

To develop a method for calculating protection against waterlogging of the external fences of a building using a map of application zones of enclosing structures.

3. MATERIALS AND METHODS

3.1. Derivation of a criterion for waterlogging of the enclosing structure

The analysis of a large number of calculation results for facade solutions of building walls showed that there are two most common options for the location of the plane of maximum moisture: the plane of maximum moisture is either in the insulation layer or at the boundary of the layers [7–9].

The most popular options of locating the plane of maximum moisture in the walls of buildings are presented. The location of the plane in the insulation layer (Figure 1A) and at the boundary between the insulation and the external plaster (Figure 1B) have been demonstrated.

Supposing plane of the greatest moisture is located inside the layer, then the required vapor permeation resistance is found according to formula 2 of the system of equations (2).

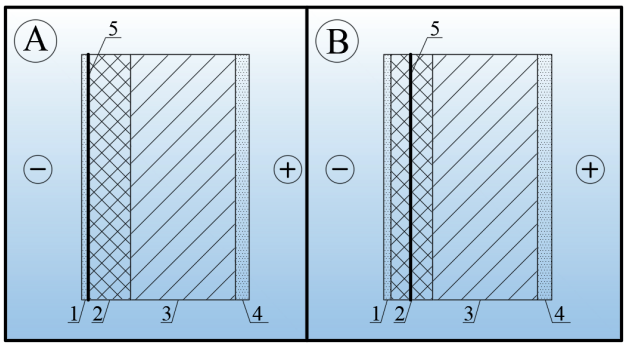


Figure 1. The most common options of the location of the plane of maximum moisture in the walls of buildings (A – position of the plane at the junction of insulation layers and external plaster; B – position of the plane inside the insulation layer; 1 – outer plaster layer; 2 – insulation layer; 3 – base of aerated concrete blocks; 4 – layer of internal plaster; 5 – plane of the greatest moisture)

If the plane of maximum moisture is located at the junction of the layers, the required vapor permeation resistance is determined by the formula:

$$R_{n2}^{req} = \frac{z_0(e_{in} - E_0)}{0.5 \cdot (\rho_{w1} \cdot \delta_{w1} \cdot \Delta w_1 + \rho_{w2} \cdot \delta_{w2} \cdot \Delta w_2) + \eta} \quad (5)$$

In order for the structure to be built, the inequality must be satisfied (3).

Let us divide both sides of equation (3) by R_n:

$$\frac{R_n^{req}}{R_n} \le 1 \quad (6)$$

Let us introduce a new criterion l – the criterion for waterlogging of the enclosing structure:

$$l = \frac{R_n^{req}}{R_n}. \quad (7)$$

We substitute the right side of equation (7) into the left side of inequality (6):

$$l \le 1 \quad (8)$$

Inequality (8) enables us to draw a conclusion about the possibility of building an enclosing structure.

The physical meaning of the waterlogging criterion l is that it indicates whether the structure is waterlogged or not.

The decision about the possibility of construction can be made in accordance with the values of the following system:

$$\begin{cases} l \le 1 - \text{ the structure can be built} \\ l > 1 - \text{ the structure cannot be built} \end{cases} \quad (9)$$

It was found that if the waterlogging criterion l is less than 1, the structure is protected from waterlogging, so it may be built. If the waterlogging criterion l is more than 1, the structure does not pass the waterlogging test, thus, it may not be built.

3.2. Calculation of moisture transfer criteria in different humidity zones in different cities

Let us look at the wall structure (Figure 1).

The physical characteristics of the studied enclosing structure are presented (Table 1).

To analyze the scope of application of the facade solution under consideration (Figure 1), 81 cities located in three different humidity zones have been considered. The cities and their corresponding humidity zones adopted for the study are presented (Table 2).

The waterlogging criterion of the enclosing structure was determined for each locality using formula (7), and the obtained values were plotted on a map of moisture zones. A map of moisture zones is presented with plotted values of the waterlogging criterion (Figure 2).

Table 1. Physical characteristics of the studied enclosing structure

Physical parameter	Value	
1. Layer of external plaster		
Layer thickness, m	0.006	
Density, kg / m^3	1260	
Thermal conductivity, $W / m\ ^\circ C$	А	0.76
	Б	0.93
Vapor permeability, $kg / m \cdot s \cdot Pa$	$3.6 \cdot 10^{-11}$	
2. Insulation made of mineral wool slabs		
Layer thickness, m	0.1	
Density, kg / m^3	150	
Thermal conductivity, $W / m\ ^\circ C$	А	0.04
	Б	0.042
Vapor permeability, $kg / m \cdot s \cdot Pa$	$8.3 \cdot 10^{-11}$	
3. Masonry base made of aerated concrete blocks		
Layer thickness, m	0.3	
Density, kg / m^3	400	
Thermal conductivity, $W / m\ ^\circ C$	А	0.113
	Б	0.117
Vapor permeability, $kg / m \cdot s \cdot Pa$	$6.9 \cdot 10^{-11}$	
4. Layer of internal plaster		
Layer thickness, m	0.011	
Density, kg / m^3	1800	
Thermal conductivity, $W / m\ ^\circ C$	А	0.76
	Б	0.93
Vapor permeability, $kg / m \cdot s \cdot Pa$	$2.5 \cdot 10^{-11}$	

Table 2. Cities and their corresponding humidity zones adopted for the study

Zones according to the "humidity zone map" in accordance with the regulatory document		
Wet	Normal	Dry
Murmansk	Kaliningrad	Belgorod
Saint Petersburg	Smolensk	Rostov-on-Don
Arkhangelsk	Moscow	Astrakhan
Naryan-Mar	Nizhny Novgorod	Volgograd
Petropavlovsk-Kamchatsky	Permian	Penza
Ayan	Vorkuta	Izhevsk
Poronaysk	Surgut	Ekaterinburg
Yuzhno-Sakhalinsk	Dudinka	Orenburg
Yuzhno-Kurilsk	Tomsk	Kurgan
Vladivostok	Tynda	Omsk
	Khabarovsk	Novosibirsk
	Magadan	Kyzyl
	Anadyr	Krasnoyarsk
	Blagoveshchensk	Irkutsk
	Erofey Pavlovich	Yeniseisk
	Okhotsk	Chita
	Keys	Mogocha
	Maykop	Kirensk
	Cherkessk	Bodaibo
	Nalchik	Tura
	Kursk	Lensk
	Vologda	Khatanga
	Cheboksary	Yakutsk
	Tobolsk	Verkhoyansk
	Kazan	Zyryanka
	Syktyvkar	Oymyakon
	Petrozavodsk	Srednekolymsk
	Troitsko-Pechorskoe	Saskylakh
	Urengoy	Olenek
	Dixon	Zhigalovo
	Nikolaevsk-on-Amur	Kosh-Agach
	Igarka	Rubtsovsk
	Aldan	Barnaul
	Totma	Samara
	Ukhta	Chelyabinsk
		Abakan

3.3.Plotting the values of the waterlogging criterion on a map of Russia

Three application zones for the considered building envelope were obtained. The first zone (marked green on the map) is the zone where the balance of moisture transfer (3) is carried out, here $R_{n2}^{req} > R_{n1}^{req}$. The second zone is a zone where the moisture transfer balance (3) is not met, which means that the enclosing structure does not pass the waterlogging test. The third zone is the zone where the moisture transfer balance inequality (3) is satisfied, here $R_{n2}^{req} < R_{n1}^{req}$.

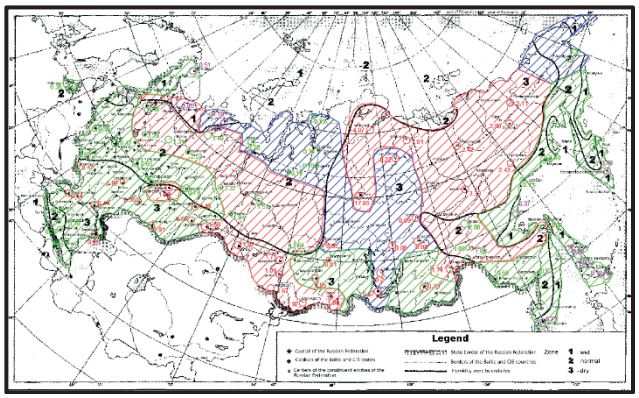


Figure 2. Map of moisture zones with plotted values of the waterlogging criterion (green and blue zones show areas in which the structure has been protected from waterlogging; red zone displays areas where the structure cannot be built)

3.4.Algorithm for applying the proposed approach

To create a map of the application zones of the building envelope based on calculations for protection against waterlogging, the following actions have been taken:

1.The required design has been selected;

2. The criterion for waterlogging of the enclosing structure has been calculated using formula (7);

3. The values of this criterion have been plotted on the map of Russian humidity zones for the cities in accordance with Table 2.

4. 3 zones have been defined on the map: the first green zone and the third blue zone are those where you can construct a building envelope and the second red zone is the zone where the structure under study cannot be built, since it does not pass the waterlogging test.

A number of maps of application zones for various building envelopes are constructed.

To calculate protection against waterlogging using a map of application zones of building envelopes, the following measures have been taken:

1. A map corresponding to the calculated enclosing structure has been selected;

2. The city in which the calculation is performed has been chosen;

3. If the structure falls into the green or blue zone, it means that it has passed the waterlogging test and is allowed to be built. If the structure falls into the red zone, the wall under study does not pass the waterlogging test, therefore, it cannot be built.

4. If the structure falls into the red zone (it has not passed the test for protection against waterlogging), it is necessary to replace the structure with another one or install a vapor barrier on the inner surface of the structure and re-calculate the protection against waterlogging.

4. RESULTS AND DISCUSSION

Options for constructing a building wall with parameters in accordance with Table 1 for three cities, such as Murmansk, Tomsk and Vorkuta were calculated.

4.1.Assessment of the moisture transfer balance using the classical method of calculating the moisture transfer balance

In Murmansk, building envelopes are operated under conditions **A**, whereas in Tomsk and Vorkuta operating conditions are **B**.

It was found that for all three cities, the position of the plane of maximum moisture corresponds to Figure 1A – the junction of external plaster and insulation.

Resistance to vapor permeation from the inner surface to the plane of maximum moisture, as well as the required resistance to vapor permeation for Murmansk is:

$$\begin{cases} R_n = 5.958 \cdot 10^9 \ m^2 \cdot s \cdot Pa / kg \\ \mathrm{R}_{n1}^{req} = 0.608 \cdot 10^9 \ m^2 \cdot s \cdot Pa / kg \\ \mathrm{R}_{n2}^{req} = 3.024 \cdot 10^9 \ m^2 \cdot s \cdot Pa / kg \\ 5.958 \cdot 10^9 \geq \max[0.608 \cdot 10^9; 3.024 \cdot 10^9] \end{cases} \quad (10)$$

Let us determine the values of the waterlogging criterion using the formula (7):

$$l = \frac{3.024 \cdot 10^9}{5.958 \cdot 10^9} = 0.507 \leq 1 \quad (11)$$

Since the waterlogging criterion is less than one, the building envelope in Murmansk has passed the waterlogging rest successfully.

Similar to that, let us determine the same for Vorkuta:

$$\begin{cases} R_n = 5.958 \cdot 10^9 \ m^2 \cdot s \cdot Pa / kg \\ \mathrm{R}_{n1}^{req} = 1.469 \cdot 10^9 \ m^2 \cdot s \cdot Pa / kg \\ \mathrm{R}_{n2}^{req} = -18.612 \cdot 10^9 \ m^2 \cdot s \cdot Pa / kg \\ 5.958 \cdot 10^9 \geq \max[1.469 \cdot 10^9; -18.612 \cdot 10^9] \end{cases} \quad (12)$$

$$l = \frac{1.469 \cdot 10^9}{5.958 \cdot 10^9} = 0.247 \leq 1 \quad (13)$$

Since the waterlogging criterion is less than one, the building envelope in Vorkuta has also passed the waterlogging test successfully.

The difference between the designs for these two cities is that in Murmansk the determining condition for the balance of moisture transfer is the required resistance to vapor permeation R_{n2}^{req}, whereas in Vorkuta the required resistance to vapor permeation is R_{n1}^{req}.

While performing the calculation for Tomsk, we get the following:

$$\begin{cases} R_n = 5.958 \cdot 10^9 \ m^2 \cdot s \cdot Pa / kg \\ \mathrm{R}_{n1}^{req} = 0.328 \cdot 10^9 \ m^2 \cdot s \cdot Pa / kg \\ \mathrm{R}_{n2}^{req} = 9.144 \cdot 10^9 \ m^2 \cdot s \cdot Pa / kg \\ 5.958 \cdot 10^9 \geq \max[0.328 \cdot 10^9; 9.144 \cdot 10^9] \end{cases} \quad (12)$$

$$l = \frac{9.144 \cdot 10^9}{5.958 \cdot 10^9} = 1.535 \geq 1 \quad (13)$$

It was found that the criterion *l is* greater than one, therefore, the wall in Tomsk will be waterlogged, since the balance of moisture transfer is not satisfied.

4.2. Assessment of moisture transfer balance using the proposed approach

We select three cities under study on the map with areas of application of enclosing structures. Three cities under study on the map of areas of application of enclosing structures are presented (Figure 3).

Figure 3 illustrates that Murmansk is located in the green zone (which means that it is possible to build here and $\mathrm{R}_{n2}^{req} > \mathrm{R}_{n1}^{req}$), Vorkuta is located in the blue zone (also allowed to build here and $\mathrm{R}_{n1}^{req} > \mathrm{R}_{n2}^{req}$), whereas Tomsk is in the red zone (no construction allowed).

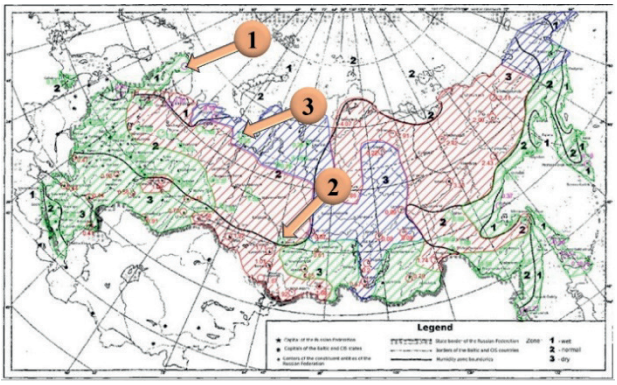


Figure 3. Three cities under study on the map of areas of application of enclosing structures (1 – Murmansk; 2 – Vorkuta; 3 – Tomsk)

A comparison of the classical and proposed approaches demonstrates the superiority of using a map with application zones of the building envelopes. The main advantage of the proposed method is that there is no need to make calculations. This method, in comparison with various methods for assessing the balance of moisture transfer, can be applied by manufacturers of building materials for enclosing structures. The manufacturer can develop a series

of maps of application zones for enclosing structures proposed in this study for their products and implement them into the engineering work of design organizations. This approach will reduce the time spent on designing buildings and structures, eliminate errors in calculations, and make decision support for a particular design more intuitive.
Future work involves a detailed study of three different zones obtained (Figure 1).

5. CONCLUSIONS

In the current study, a new effective method for determining the balance of moisture transfer using a map of application zones of the enclosing structure based on a newly introduced value, namely, the criterion of waterlogging of the enclosing structure, has been developed. The values of the waterlogging criterion have been plotted on the map, then three zones have been identified depending on the value of the criterion and the determining resistance to vapor permeation. An algorithm for constructing and using a map of the applicability of a building envelope is presented. This method can be used by engineers when calculating and assessing the building envelope protection against waterlogging.

6. FUNDING

The research was funded by a grant from the Russian Science Foundation, project number 25-79-00205, https://rscf.ru/en/project/25-79-00205/.

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