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Study of the temperature and moisture regime of building walls in various construction areas

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Abstract. The article is devoted to the problems of assessing the balance of moisture transfer when calculating protection against waterlogging of building envelopes. For the calculation, several localities have been selected in which the wall of a building with given climatic parameters and internal air parameters for a living space were modeled. In order to model protection against waterlogging, 3 cities were chosen: Smolensk, Izhevsk and Dudinka. A calculation to protect the building envelope from waterlogging has been carried out. The values of resistance to vapor permeation and heat transfer of each layer of a multilayer building envelope have been calculated. The complex of maximum humidification was assessed, on the basis of which the values of the temperature of the greatest humidification were determined. The values of the actual resistance to vapor permeation and the required resistance to vapor permeation were calculated relative to the plane. Three examples of possible moisture transfer balance were obtained. It was also determined that the construction of the building wall under study is permitted in Smolensk and Dudinka. The researched wall cannot be used in Izhevsk.

1 Introduction

The construction of buildings and structures entails a large number of different calculations and technical solutions that relate to various areas of the construction industry [1–3]. The key components are architectural and planning solutions [4–6], the use of various building materials [7–9], the study of the thermal insulation properties of the building envelope [10–12], the study of internal engineering [12–15], etc.

In building envelope design, particular attention is paid to the calculation of wall protection from waterlogging using a method that is comprehensively described in the Russian regulatory document Set of Rules 50.13330.2012 “Thermal protection of buildings”. Calculations are based on a comparison of two resistances: the resistance from the plane of greatest moisture to the internal surface of the structure and the maximum required resistance from the conditions of moisture accumulation or from operating conditions for one year (the required resistance No. 1 – R_{n1}^{req}), or for a period with negative temperatures for a month (the required resistance No. 2 – R_{n2}^{req}). If the inequation is met, the

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structure is protected from waterlogging, whereas if the ratio is not met, the structure under study will be subjected to waterlogging. Moreover, it creates a suitable environment for the development of mold, spores and other microorganisms that can be harmful for human health [16, 17].

Taking into account the facts described above, the importance to provide protection against waterlogging of the building structure seems obvious.

2 The Problem

Determining the possibility of constructing a building envelope in various populated areas by calculating protection against waterlogging of the fence.

3 Materials and Methods

The method for protecting against waterlogging consists of studying the inequation between the following physical quantities:

$$R_n \geq \max[R_{n1}^{req}; R_{n2}^{req}] \tag{1}$$

Calculation of the moisture transfer balance should begin with determining resistance to vapor permeation and resistance to heat transfer of each layer included in the building envelope. Then, the maximum moisture complex is calculated for each layer using the following formula:

$$f_n(t_{m.h}) = 5330 \frac{R_{e.n} \cdot (t_{in} - t_{n.neg})}{R_0^{con} \cdot (e_{in} - e_{n.neg})} \cdot \frac{\mu_n}{\lambda_n} \tag{2}$$

The value of the vapor permeation resistance is determined by adding up the vapor permeation resistance of the structure layers from the inner layer to the layer in which the plane of maximum moisture is located.

Thereafter, the required resistance (the required resistance No. 1 – R_{n1}^{req}) to vapor permeation is determined from the conditions of moisture accumulation over an operating period of one year using the formula:

$$R_{n1}^{req} = \frac{(e_{in} - E) \cdot R_{n.o}}{E - e_o} \tag{3}$$

The value of the required resistance (the required resistance No. 2 – R_{n2}^{req}) to vapor permeation is also found from the conditions of moisture accumulation for a period with average negative temperatures per month using the following formula:

$$R_{n2}^{req} = \frac{z_0(e_{in} - E_0)}{\rho_w \cdot \delta_w \cdot \Delta w + \eta} \tag{4}$$

According to inequation (1), which describes the balance of moisture transfer, one largest value of the two required resistances is selected and compared with the resistance calculated from the inner surface to the plane of maximum moisture. If the inequation is satisfied, this design passes the waterlogging protection test.

4 Results and Discussion

4.1 Description of the building structure under study

For further calculations, let us consider the building envelope consisting of internal and external plaster layers 6 and 11 mm thick, respectively, with a base of 300 mm thick aerated concrete blocks and insulation made of 100 mm thick mineral wool slabs (Fig. 1).
For each layer, the thermal conductivity under operating conditions A and B was selected based on the moisture conditions of the room and the humidity zone.

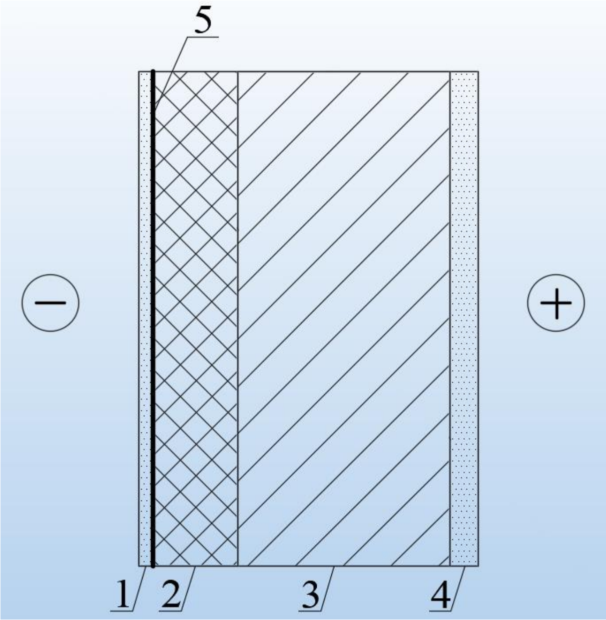

Fig. 1. Drawing of the building envelope (1, 2, 3, 4 – layers of the enclosing structure; 5 – position of the plane of greatest moisture).

4.2 Selection of localities and analysis of basic climate data

For the calculation, 3 localities were taken: Smolensk, Izhevsk and Dudinka.

The humidity zone of the construction area and the operating conditions of the building envelope were determined. The first city under consideration, Smolensk, is located in the second humidity zone (normal). Therefore, according to the calculation method, the operating conditions of the building envelope are conditions B. The second city, Izhevsk, is located in the third humidity zone (dry), which means that operating conditions of the wall are also B. The third city, Dudinka, is located in the second zone (normal), which corresponds to the operation of the building envelope – conditions B.

4.3 The case when the balance of moisture transfer is satisfied ($R_{n2}^{req} > R_{n1}^{req}$)

To calculate the building envelope located in Smolensk, the values of resistance to vapor permeation, the resistance to heat transfer of each layer, as well as resistance to vapor permeability of the entire structure and conditional resistance to heat transfer are calculated (Table 1).

Table 1. Calculation of the resistance of the building envelope

Layer number	Resistance to vapor permeation, $m^2 \cdot s \cdot Pa / kg$	Resistance to heat transfer, $\mathrm{m}^2 \cdot °C / W$	Resistance to vapor permeation of the entire structure, $m^2 \cdot s \cdot Pa / kg$	Conditional resistance, $\mathrm{m}^2 \cdot °C / W$
1	$0.166 \cdot 10^9$	0.006	$6.12 \cdot 10^9$	5.121
2	$1.2 \cdot 10^9$	2.381		
3	$4.32 \cdot 10^9$	2.564		
4	$0.439 \cdot 10^9$	0.012		

Then the values of the maximum moistening complex are determined for each layer of the building envelope and the value of the temperature of the greatest moistening is found using the determined value (Table 2).

Table 2. Finding the values of the complex and the temperature of the greatest moisture.

Layer number	Values of the complex, $°C / Pa$	Temperature of the greatest moisture, $°C$
1	6.83	54.31
2	349.1	-15.54
3	104.43	2.31
4	4.43	63

After that, the temperature at the boundaries between the layers is determined (Table 3).

Table 3. Значения температур на стыке слоёв

Layer Boundaries	Temperature values, $°C$
Air – layer of external plaster	-4.07
Layer of external plaster - insulation	-4.05
Insulation – aerated concrete base	7.24
Aerated concrete base - layer of internal plaster	19.4
Layer of internal plaster - air	19.46

Using the graphical method, the building envelope was drawn and the position of the plane of maximum moisture was determined. It was found that the plane is located at the junction between the layer of internal plaster and insulation made of mineral wool slabs (fig. 2).

Calculations of wall resistances and the values of required resistance to vapor permeation were obtained (Table 4).

According to the moisture transfer balance (1), the maximum of the two required resistances to vapor permeation was selected and compared with the value of the resistance to vapor permeation.

$$5.958 \cdot 10^9 \geq \max[0.198 \cdot 10^9; 2.088 \cdot 10^9] = 2.088 \cdot 10^9$$

$$5.958 \cdot 10^9 \geq 2.088 \cdot 10^9$$

It was found that the balance of moisture transfer in Smolensk is satisfied, therefore the structure is protected from waterlogging.

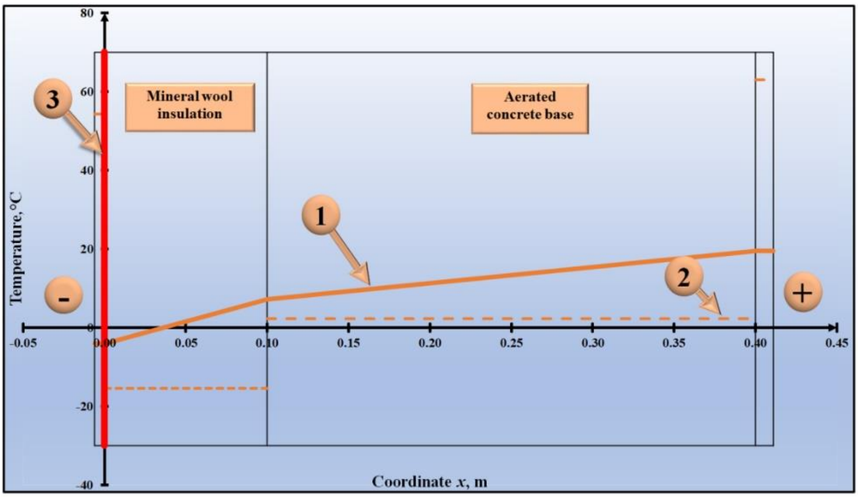

Fig. 2. Applying the temperature and temperature of maximum humidification for the building envelope (1 – temperature distribution; 2 – distribution of temperature of maximum humidification; 3 – position of the plane of maximum humidification).

Table 4. Calculation of wall resistances and the values of required resistance to vapor permeation

R_n, $m^2 \cdot s \cdot Pa / kg$	$R_{n.o}$, $m^2 \cdot s \cdot Pa / kg$	R_{n1}^{req}, $m^2 \cdot s \cdot Pa / kg$	R_{n2}^{req}, $m^2 \cdot s \cdot Pa / kg$
$5.958 \cdot 10^9$	$0.166 \cdot 10^9$	$0.198 \cdot 10^9$	$2.088 \cdot 10^9$

4.4 The case when the balance of moisture transfer is satisfied: ($R_{n1}^{req} > R_{n2}^{req}$)

The values of resistance to heat transfer, resistance to vapor permeability for each layer of the building envelope, resistance to vapor permeability of the entire wall and conditional resistance to heat transfer for the building envelope located in Dudinka were determined (Table 5).

Table 5. Calculation of the resistance of the building envelope

Layer number	**Resistance to vapor permeation,** $m^2 \cdot s \cdot Pa / kg$	**Resistance to heat transfer,** $m^2 \cdot °C / W$	**Resistance to vapor permeation of the entire structure,** $m^2 \cdot s \cdot Pa / kg$	**Conditional resistance,** $m^2 \cdot °C / W$
1	$0.166 \cdot 10^9$	0.006	$6.12 \cdot 10^9$	5.121
2	$1.2 \cdot 10^9$	2.381		
3	$4.32 \cdot 10^9$	2.564		
4	$0.439 \cdot 10^9$	0.012		

The value of the maximum moistening complex is found and the maximum temperature at which moistening will occur is found using interpolation and according to the table (Table 6).

Table 6. Finding the values of the complex and the temperature of maximum humidification

Layer number	Values of the complex, $°C / Pa$	Maximum humidification temperature, $°C$
1	8.74	48.76
2	446.67	-18.89
3	133.62	-1.54
4	6.052	57.11

Following this, temperature values at the joints between the layers of the building envelope under study are calculated (Table 7).

Table 7. Temperature values at the joints between layers of the building envelope

Layer Boundaries	Temperature values, $°C$
Air – layer of external plaster	-18.52
Layer of external plaster - insulation	-18.47
Insulation – aerated concrete base	-0.41
Aerated concrete base - layer of internal plaster	19.04
Layer of internal plaster - air	19.13

In order to use the graphical method on a wall structure, we plot the obtained temperature values at the joints between layers and the values of the highest temperature at which humidification occurs. As a result, we find that the plane of greatest moisture is at the junction of two layers (Fig. 2).

The resistance to vapor permeability from the plane to the inner surface of the wall, the resistance to vapor permeation from the plane to the outer surface of the wall, and the required resistance to vapor permeation were determined according to the formulas, and the following values were obtained (Table 8).

Table 8. Calculation of wall resistances and required resistances to vapor permeation

R_n, $m^2 \cdot s \cdot Pa / kg$	$R_{n.o}$, $m^2 \cdot s \cdot Pa / kg$	R_{n1}^{req}, $m^2 \cdot s \cdot Pa / kg$	R_{n2}^{req}, $m^2 \cdot s \cdot Pa / kg$
$5.958{\cdot}10^9$	$0.166{\cdot}10^9$	$2.027{\cdot}10^9$	$-7.99{\cdot}10^9$

Let us use the moisture transfer balance inequation (1) and analyze the obtained values of resistance to vapor permeation:

$$5.958 \cdot 10^9 \geq \max[2.027 \cdot 10^9; -7.99 \cdot 10^9] = 2.027 \cdot 10^9$$

$$5.958 \cdot 10^9 \geq 2.027 \cdot 10^9$$

Analysis of the results obtained shows that the balance of moisture transfer in Dudinka will be met, therefore, the building structure will be protected from waterlogging.

4.5 The case when the moisture transfer balance is not satisfied

The construction of the wall in Izhevsk was examined. The values of resistance to heat transfer, resistance to vapor permeability for each layer of the building envelope, resistance to vapor permeability of the entire wall and conditional resistance to heat transfer were determined (Table 9).

Table 9. Calculation of the resistance of the building envelope

Layer number	**Resistance to vapor permeation,** $m^2 \cdot s \cdot Pa / kg$	**Heat transfer resistance,** $\mathrm{m}^2 \cdot °C / W$	**Resistance to vapor permeation of the entire structure,** $m^2 \cdot s \cdot Pa / kg$	**Conditional resistance,** $\mathrm{m}^2 \cdot °C / W$
1	$0.166 \cdot 10^9$	0.006	$6.12 \cdot 10^9$	5.121
2	$1.2 \cdot 10^9$	2.381		
3	$4.32 \cdot 10^9$	2.564		
4	$0.439 \cdot 10^9$	0.012		

Using the formula, the values of the maximum moisture complex for each layer of the wall are found and the temperature of maximum moisture based on the found numerical values is determined (Table 10).

Table 10. Finding the values of the complex and the temperature of maximum humidification

Layer number	**Complex values,** $°C / Pa$	**Maximum humidification temperature,** $°C$
1	7.38	52.55
2	377.22	-16.6
3	112.84	1.08
4	5.11	61.09

Subsequently, calculation of the temperatures at the joints between the layers of the building envelope is performed (Table 11).

Table 11. Temperature values at the joints between layers of the building envelope

Layer Boundaries	**Temperature value,** $°C$
Air – layer of external plaster	-8.97
Layer of external plaster - insulation	-8.94
Insulation – aerated concrete base	4.65
Aerated concrete base - layer of internal plaster	19.28
Layer of internal plaster - air	19.35

Calculation of wall resistances and required resistances to vapor permeation is presented (table 12).

Table 12. Calculation of wall resistances and required resistances to vapor permeation

R_n, $m^2 \cdot s \cdot Pa / kg$	$R_{n.o}$, $m^2 \cdot s \cdot Pa / kg$	R_{n1}^{req}, $m^2 \cdot s \cdot Pa / kg$	R_{n2}^{req}, $m^2 \cdot s \cdot Pa / kg$
$5.958 \cdot 10^9$	$0.166 \cdot 10^9$	$0.223 \cdot 10^9$	$6.4 \cdot 10^9$

Let us use the moisture transfer balance inequation (1) and analyze the obtained values of resistance to vapor permeation:

$$5.958 \cdot 10^9 \geq \max[2.232 \cdot 10^9 ; 6.4 \cdot 10^9] = 6.4 \cdot 10^9$$

$$5.958 \cdot 10^9 \leq 6.4 \cdot 10^9$$

In accordance with the obtained values, it is evident that the balance of moisture transfer will not be fulfilled in Izhevsk, therefore, the building structure will be waterlogged.

5 Conclusion

A method of protecting the building envelope from waterlogging has been considered. The calculation was performed in three different localities. An inequation describing the balance of moisture transfer, for which the corresponding physical quantities were found, has been used. When analyzing the results, three fundamentally different cases of moisture transfer balance were identified. The first case: the balance of moisture transfer is maintained when the required resistance No. 2 is greater than the required resistance No. 1 ($R_{n2}^{req} > R_{n1}^{req}$). The second case: the structure can be protected from waterlogging when the required resistance No. 1 is greater than the required resistance No. 2 ($R_{n1}^{req} > R_{n2}^{req}$). Third case: moisture transfer balance is not satisfied ($R_n < R_{n1}^{req}$ and $R_n < R_{n2}^{req}$). Thus, when performing calculations for building envelopes, it is worth using this method of protecting building envelopes from waterlogging.

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