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DRAWING THE NOMOGRAM FOR OVERHUMIDIFICATION OF THE BUILDING ENVELOPE

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Abstract: In the current paper, a new method of protecting building envelopes from waterlogging based on the construction of specialized nomograms has been developed. During the analysis of the Russian climate, it was determined that for the entire territory of the country the period of moisture accumulation does not exceed 8 months. It was found that the criterion of waterlogging of the building envelopes depends on three main parameters: temperature and relative humidity of the outside air during the period with negative average monthly temperatures, and the duration of the period of moisture accumulation. Based on the critical value of criterion l, a nomogram of waterlogging of the enclosing structure was constructed, according to which a decision on the construction of the designed building can be taken. An algorithm of constructing and applying a nomogram of waterlogging of a building envelope has been presented. The effectiveness of the proposed method is shown in comparison with the classical approach by calculating protection against waterlogging in such cities as Blagoveshchensk and Yerofey Pavlovich.

Keywords: protection against waterlogging, operating conditions, temperature, relative humidity, duration of moisture accumulation

ПОСТРОЕНИЕ НОМОГРАММЫ ПЕРЕУВЛАЖНЕНИЯ ОГРАЖДАЮЩЕЙ КОНСТРУКЦИИ ЗДАНИЯ

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Аннотация: В статье разработан новый метод защиты от переувлажнения ограждающих конструкций зданий, основанный на построении специализированных номограмм. В ходе анализа климата России было определено, что для всей территории страны период влагонакопления не превышает 8 месяцев. Получено, что критерий переувлажнения ограждающей конструкции зависит от трех основных параметров: температура и относительная влажность наружного воздуха за период с отрицательными среднемесячными температурами и продолжительность периода влагонакопления. На основании критического значения критерия *l,* была построена номограмма переувлажнения ограждающей конструкции, по которой можно принять решение о строительстве проектируемой стены здания. Приведен алгоритм построения и применения номограммы переувлажнения ограждающей конструкции. Показана эффективность предложенного метода в сравнении с классическим подходом путем расчета защиты от переувлажнения в городах Благовещенск и Ерофей Павлович.

Ключевые слова: защита от переувлажнения, условия эксплуатации, температура, относительная влажность, продолжительность влагонакопления

INTRODUCTION

When designing buildings and structures [1], engineers face various tasks: calculating the strength of reinforced concrete and metal structures, calculating the thickness of shells, determining the temperature influences on the building [2-7].

When calculating the protection of the building envelope against waterlogging, the Russian regulatory document Set of Rules 50.13330.2012 “Thermal protection of buildings” is used. The method of protection against waterlogging presented in the regulatory document appears to be quite effective, but at the same it is complicated for engineering use. Therefore, the research on the development of a new simplified method of protecting the building envelope from waterlogging is currently relevant [8].

In calculating building structures, it is important to take into account the physical characteristics of building materials: humidity, density, vapor permeability, etc. However, the choice of thermal conductivity value depends on the humidity conditions in residential premises and the humidity zone in which the building structure is placed. Therefore, there are 2 operating conditions: A and B.

Thermal conductivity values for some building materials have been given (Table 1).

Table 1. Thermal conductivity values for some building materials

Material	Thermal conductivity, $W/m\ ^{\circ}C$	
	A	B
Mineral wool slabs made of stone fiber	0.045	0.048
Gravel expanded clay	0.13	0.145
Gas and foam concrete on cement binder	0.38	0.43
Reinforced concrete	1.92	2.04
Cement-sand mortar	0.76	0.93
Plywood	0.15	0.18

To simplify calculations of protection against waterlogging, the waterlogging criterion found using the following formula was introduced:

$$l = \frac{R_n^{req}}{R_n}. \quad (1)$$

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

Using the waterlogging criterion, it is possible determine whether the structure will be waterlogged. However, the criterion is calculated for each city taking into account climatic conditions, which complicates the method of protection against waterlogging. In this regard, there is a need to develop alternative methods of studying the balance of moisture transfer in more simplified ways. This article develops a method of assessing the construction of a building envelope using a waterlogging nomogram.

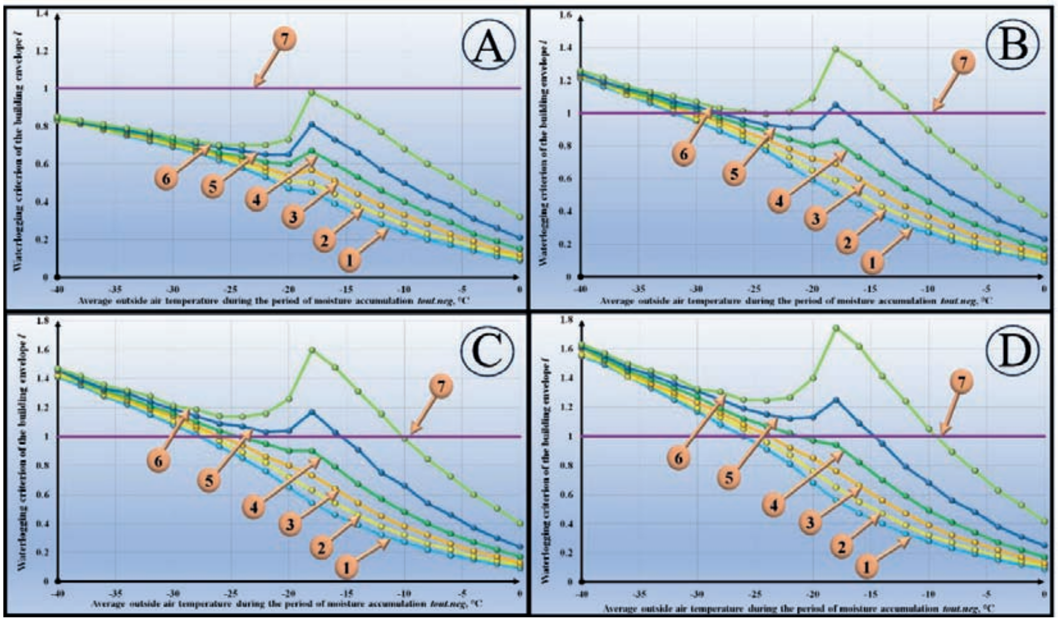
1. THE PROBLEM

To develop a method of calculating protection against waterlogging of external building envelopes using a waterlogging nomogram.

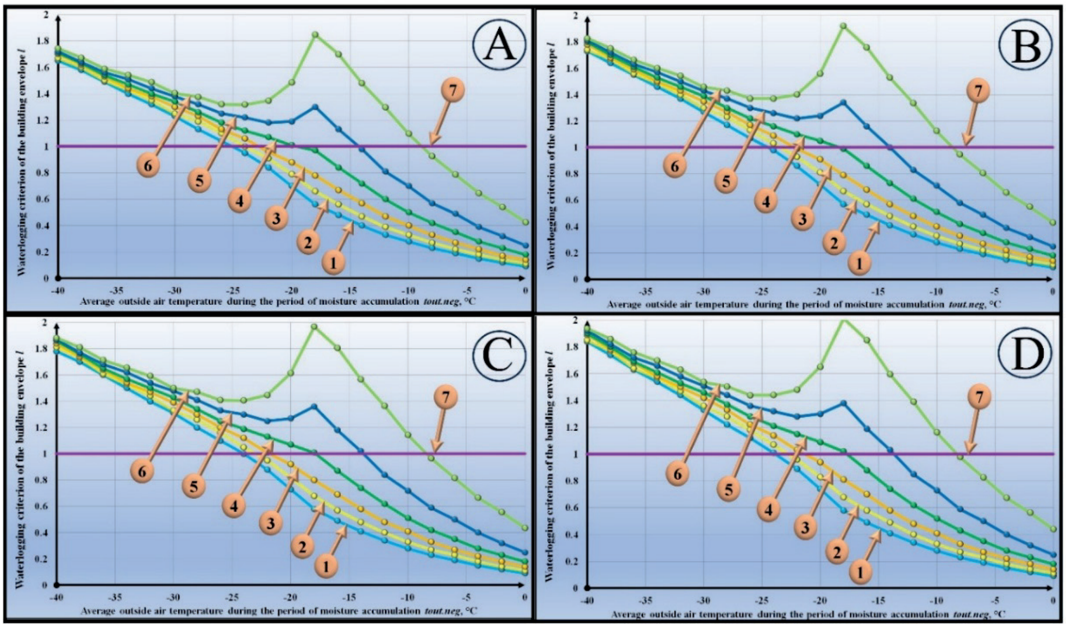
2. MATERIALS AND METHODS

2.1. Studying the value of the waterlogging criterion at different duration of the moisture accumulation period

Analyzing the obtained values of the criterion of waterlogging of the building envelope in different cities in Russia, it was found that the criterion l depends on climatic parameters. It was determined that the period of moisture accumulation does not exceed 8 months. Graphs of the dependence of the waterlogging criterion on the values of the average monthly negative outdoor air temperature at different durations of the period of moisture accumulation were obtained (Figure 1, Figure 2).



<u>Figure 1.</u> Dependence of the waterlogging criterion on the outside air temperature and the duration of the moisture accumulation period for 1, 2, 3 and 4 months of moisture accumulation (A – 1 month; B – 2 months; C – 3 months; D – 4 months; the relative humidity of the outside air during the period with negative average monthly temperatures: 1 – $\varphi_{out.neg} = 70\ \%$; 2 – $\varphi_{out.neg} = 75\ \%$; 3 – $\varphi_{out.neg} = 80\ \%$; 4 – $\varphi_{out.neg} = 85\ \%$; 5 – $\varphi_{out.neg} = 90\ \%$; 6 – $\varphi_{out.neg} = 95\ \%$; 7 – $l = 1$)



<u>Figure 2.</u> Dependence of the waterlogging criterion on the outside air temperature and the duration of the moisture accumulation period for 5, 6, 7 and 8 months of moisture accumulation (A – 5 months; B – 6 months; C – 7 months; D – 8 months; the relative humidity of the outside air during the period with negative average monthly temperatures: 1 – $\varphi_{out.neg} = 70\ \%$; 2 – $\varphi_{out.neg} = 75\ \%$; 3 – $\varphi_{out.neg} = 80\ \%$; 4 – $\varphi_{out.neg} = 85\ \%$; 5 – $\varphi_{out.neg} = 90\ \%$; 6 – $\varphi_{out.neg} = 95\ \%$; 7 – $l = 1$)

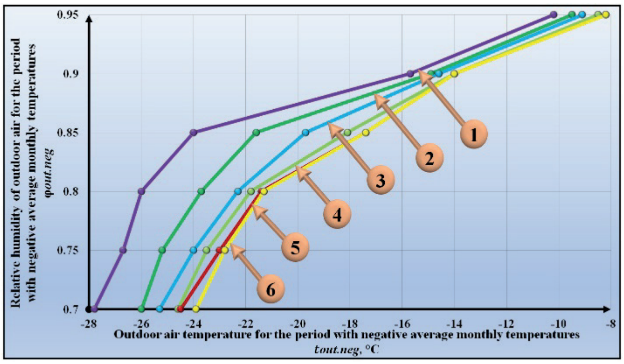
2.2. Construction of a nomogram of waterlogging of the building envelope

While analyzing the obtained graphical dependencies (Figure 1, Figure 2), it was found that waterlogging is influenced by 3 main factors: the temperature of the outside air during the period of moisture accumulation, the relative humidity of the outside air during the period with negative average monthly temperatures, and the duration of the period of moisture accumulation. By varying the values of the main factors, it is possible to construct a dependence graph when the criterion of waterlogging of the building envelope is equal to one. The values of the outside air temperature are plotted on the abscissa axis, the relative air humidity values are marked on the ordinate axis, and dependence lines that depend on the duration of the period of moisture accumulation are obtained. Due to the fact that there are operating conditions A and B, two waterlogging nomograms are obtained (Figure 3, Figure 4).

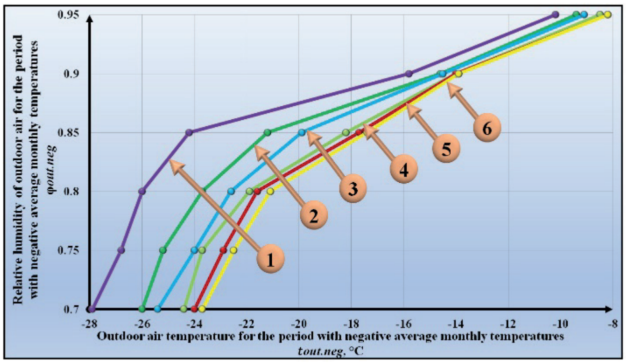
2.3. Algorithm for constructing and using a nomogram of waterlogging of building envelopes

To construct a nomogram of waterlogging of a building envelope based on the method of protection against waterlogging the following measures are taken:

1. The required design is selected;
2. The operating conditions of the building envelope are determined;
3. The value of the relative humidity of the outside air is set in increments of 5% and the duration of moisture accumulation;
4. The range of outdoor air temperature values during the period of moisture accumulation varies in increments of 1 °C;
5. The criterion of waterlogging of the building envelope is calculated;
6. The criterion values *l*=1 are selected, and the corresponding values of the outside air temperature, relative humidity of the outside air and the period of moisture accumulation are recorded;



<u>Figure 3.</u> Nomogram of waterlogging of the building envelope for operating conditions A (duration of moisture accumulation period: 1 – three months; 2 – four months; 3 – five months; 4 – six months; 5 – seven months; 6 – eight months)



<u>Figure 4.</u> Nomogram of waterlogging of the building envelope for operating conditions B (duration of moisture accumulation period: 1 – three months; 2 – four months; 3 – five months; 4 – six months; 5 – seven months; 6 – eight months)

7. After finding all the points at which *l*=1, the values of the average outdoor air temperature for the period of moisture accumulation at the corresponding relative humidity and the period of moisture accumulation are reduced to a waterlogging nomogram, which enables us to arrive at decision on the possibility of the building envelope construction.

For structures under different operating conditions, different waterlogging nomograms are constructed.

To calculate the protection of the building envelope from waterlogging using the

waterlogging nomogram, the following steps are taken:
1. A nomogram that corresponds to the calculated building envelope taking into account operating conditions is selected.
2. The abscissa axis marks the outside air temperature for the period of moisture accumulation in accordance with the city in which the calculation is performed.
3. A vertical straight line is drawn from the found outside air temperature point until it intersects with the line of the desired moisture accumulation period.
4. A horizontal line is drawn from the found point until it intersects with the ordinate axis, thereby determining the critical value of the relative humidity of the outside air.
5. The value of the relative humidity of the outside air is determined from the ratio of the average partial pressure of water vapor of the outside air during the period with negative average monthly temperatures to the pressure of saturated water vapor in the plane of greatest moisture for the period of moisture accumulation, and then a horizontal straight line is drawn.
6. If the horizontal straight line of the critical humidity value is higher than the horizontal line of the relative humidity of the outside air, the structure has passed the waterlogging protection test successfully.
7. If the horizontal line of the critical humidity value is lower than the horizontal line of the relative humidity of the outside air, the structure fails to pass protection test against waterlogging.

3. RESULTS AND DISCUSSION

A calculation of protection of the building envelopes from waterlogging located in Blagoveshchensk and Yerofey Pavlovich has been conducted.
For a structure designed in Blagoveshchensk, the criterion of waterlogging of the building envelope is calculated using formula (1):

$$l = \frac{\mathrm{R}_n^{req}}{\mathrm{R}_n} = \frac{0.96}{1.655} = 0.58.$$

The value of the waterlogging criterion according to the calculation is less than one, therefore, the building structure in Blagoveshchensk has passed the test against waterlogging successfully.
Let us carry out calculations of protection of the building structure against waterlogging using the waterlogging nomogram. In Blagoveshchensk, the structure is operated under conditions B, and the main climatic parameters are: outside air temperature during the period with negative average monthly temperatures is -15.3 °C, the duration of moisture accumulation is 5 months. Relative humidity is determined by the formula:

$$\varphi_{out.neg} = \frac{e_{out.neg}}{E_0}. \tag{2}$$

where $e_{out.neg}$ – average partial pressure of water vapor of the outside air during periods with negative average monthly temperatures, Pa; E_0 – pressure of saturated water vapor in the plane of greatest moisture for the period of moisture accumulation, Pa.
Taking into account formula (2) we obtain:

$$\varphi_{out.neg} = \frac{e_{out.neg}}{E_0} = \frac{148}{192} = 0.77\ .$$

We plot the obtained values of the outdoor air temperature for the period with negative temperatures per month and the relative humidity of the outdoor air on the nomogram (Figure 5).
The critical humidity horizontal line is higher than the horizontal line of relative humidity of the outside air, so the structure passes the test against waterlogging successfully.
Let us calculate the value of the waterlogging criterion for a building structure in such city as Yerofey Pavlovich using formula (1):

$$l = \frac{R_n^{req}}{R_n} = \frac{2.8}{1.655} = 1.69.$$

It was found that the waterlogging criterion was greater than one, therefore, the building envelope Yerofey Pavlovich fails the waterlogging test.

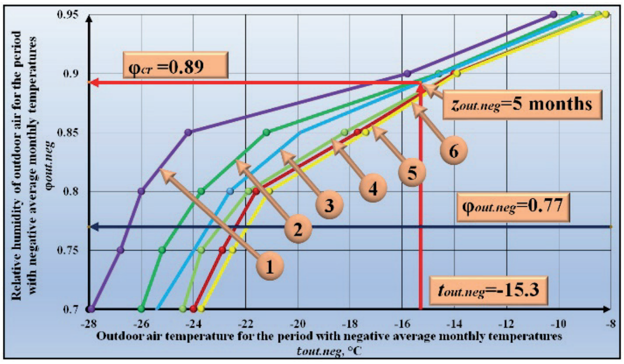


Figure 5. Nomogram of critical ratios of temperature and relative humidity of outdoor air and the duration of the period of moisture accumulation, used to make a decision on the construction of the enclosing structure of a building wall in Blagoveshchensk (duration of the period of moisture accumulation: 1 – three months; 2 – four months; 3 – five months; 4 – six months; 5 – seven months; 6 – eight months)

Let us consider a possibility to construct a building structure in Yerofey Pavlovich using a new method such as the waterlogging nomogram. The enclosing structure is located in the second humidity zone (normal), which corresponds to operating conditions B. Basic climatic parameters: outside air temperature is -17.4, the duration of moisture accumulation is 7 months. Relative air humidity is calculated using formula (2):

$$\varphi_{out.neg} = \frac{e_{out.neg}}{E_0} = \frac{173}{183} = 0.945$$

The values of outside air temperature and relative humidity are plotted on the waterlogging nomogram (Figure 6).

The horizontal line of critical humidity is lower than the horizontal line with the value of relative air humidity, therefore, it is impossible to design a building envelope in such city as Yerofey Pavlovich, since it fails the test against waterlogging.

The proposed method, namely, a nomogram of waterlogging of the enclosing structure has a number of advantages compared to the classical method of protection against waterlogging. The main advantage compared to the classical approach is that no calculations are required.

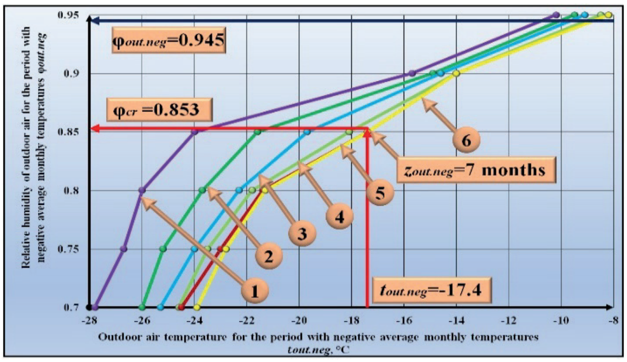


Figure 6. Nomogram of critical ratios of temperature and relative humidity of outdoor air and the duration of the period of moisture accumulation, used to make a decision on the construction of the enclosing structure of the building wall in Yerofey Pavlovich (duration of the period of moisture accumulation: 1 – three months; 2 – four months; 3 – five months; 4 – six months; 5 – seven months; 6 – eight months)

Also, this method can be applied by manufacturers of building materials who develop facade solutions. For each solution, the manufacturer can develop a series of waterlogging nomograms, with the help of which engineers can decide on the construction of the chosen building structure. This method will accelerate the process of designing buildings and structures and will facilitate decisions about constructing in a more convenient and visual form.

4. CONCLUSIONS

In the current work, a new effective method of determining the protection of a building envelope from waterlogging has been developed as a waterlogging nomogram constructed using the following main climatic characteristics: temperature and relative humidity of the outside air, and the period of moisture accumulation. An algorithm of constructing and using a nomogram of waterlogging of a building envelope for various operating conditions has been presented. Classic method of protection against waterlogging and a new method of determining waterlogging of a building structure using a nomogram have been compared. The new method may be used by engineers when calculating and assessing the protection of a building envelope against waterlogging.

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