E3S Web of Conferences 563, 02022 (2024) https://doi.org/10.1051/e3sconf/202456302022
ICESTE 2024

Study on the heat and vapor transfer resistance of the basement's outer walls and calculation of moisture regime: A case study of Uzbekistan

Elmurad Tulakov[1], *Alijon* Kurbonov[1], *Dilovar* Inoyatov[1*], *Ikrom* Eshatov[1], *Sohiba* Abdullayeva[1]

[1]Samarkand State Architecture and Construction University named after Mirzo Ulugbek (SamSACU), Lolazor str. 70, 140143 Samarkand, Uzbekistan

Abstract. In the article, the type of effective thermal insulation materials used as a solution to increase the resistance to heat transfer of the outer walls of the basement of the buildings (residential and public) being built in the climatic conditions of Uzbekistan, the solution for determining its thickness, the resistance to vapor transmission of the outer walls of the basement, the appearance of moisture in the barrier structure, Experimental results are presented on the calculation of the moisture regime and its effect on the energy efficiency of the barrier structure. Experiments were conducted in the basement of a public building in use. It contains practical recommendations on the use of thermal insulation material.

1. Introduction

Today, the problem of saving heat (energy) lost from buildings remains an urgent issue. According to the data presented in [1], it is possible to see significant heat loss through the underground part of the buildings (external walls of the basement). As we know, most of the underground external barrier structures of buildings also perform load-bearing functions in buildings. Therefore, they are usually made of dense, strong, but heat-conducting materials. In such constructions, materials that perform both load-bearing and heat-insulating functions are used. With their help, it is almost impossible to fulfill the heat saving requirements imposed on the underground external barrier structures of some buildings. As the main way to solve this problem, the design of underground external barrier structures for various tasks, that is, the separation of load-bearing and thermal insulation layers, making them multi-layered and installing a thermal insulation layer, is being used in world practice. In this case, since the external walls of the basement are in direct contact with the ground layer, the type of thermal insulation materials that can be used in the underground part is important.

In addition to materials such as fibrolite, foam glass, mineral wool, foam plastics are also widely used in the design of multi-layered external barrier structures of buildings. Nowadays, various new synthetic and organic materials are recommended for use as thermal insulation material. It should be noted that earlier the quality of thermal insulation materials was assessed by their resistance to heat transfer, but now, great importance is attached to their ability to protect against radiation, durability, resistance to moisture and chemical effects, and fire safety. In addition, features such as vapor permeability, sound insulation, ease of use are also taken into consideration.

The physical and technical properties of thermal insulation materials have a great impact on the thermal and technical efficiency of the structure and its reliability during operation, as well as the amount of labor spent on assembly. They should be fire-safe, have a hygienic certificate, and should not emit toxic substances during operation and during fire.

Long-term durability, stability of thermophysical and physical-mechanical properties of heat-insulating materials are affected by factors in the operation of the structures where they are used. These factors include:

- variable heat-humidity regime of constructions;
- moisture absorption of thermal insulation material in the structure due to capillary moisture and diffusion;
- impact of wind force;
- mechanical load effects from own weight.

*Corresponding author: dilovar.sam@mail.ru

Taking these factors into account, the following basic requirements are set for thermal insulation materials used to increase the energy efficiency of buildings:

- when the heat insulation material is minimal in thickness of the construction, it should provide sufficient resistance to heat transfer;
- the vapor permeability of the material should be such that there is no possibility of moisture accumulation in the structure during operation;
- no heavy load from the thermal insulation layer on load-bearing structures;
- to be solid;
- to be resistant to freezing and high temperature;
- waterproof (hydrophobic) and water resistant;
- it should be resistant to biological effects and not emit toxic smoke when burned.

Heat insulation materials used in housing construction are divided into several types according to the structure, shape, type of main raw materials, density, uniformity, thermal conductivity and flammability [2,3,11].

When insulating the underground part of buildings, it is necessary to use heat-insulating materials not only with very low water absorption, but also resistant to high cold and aggressive effects [4, 12, 13, 14, 15].

Examples of such materials include basalt plates, foam glass (penosteklo), extruded polystyrene penoplex plates, etc., obtained mainly on the basis of organic substances. Table 1. lists the heat-technical indicators of some heat-insulating materials for comparison.

Table 1. Comparison of heat-technical indicators of insulation materials

S/n	Heat-technical indicators of heat-insulating materials	Styrofoam (penosteklo)	Extruded expanded polystyrene PENOPLEKS® GEO	Basalt slab
1	-coefficient of thermal conductivity λ_o, t/(m·°C)	0,07-0,11	0,03-0,032	0,035-0,041
	-the density γ_o, *kg/m*^{3}	100-400	29-33	35-200
	-relative heat capacity c_o, *kdj/(kg·°C)*	0,84	0,84	1,45
2	coefficient of thermal conductivity, λ, *vt/(m·°C)*	0,04-0,08	0,032	0.035- 0.039
3	Vapor absorption μ, *мg/(м·ch·Pa)*	0,03-0,02	0,005	0,3
4	Water absorption, %.	<1%	Zero	1-2
5	Compressive strength, MPa.	0,7-4 (70-400 t/m^2)	0,30 (30t/m^2)	0.01 (10t/m^2)
6	Refractoriness	Non-flammable	G1	Non-flammable
7	Effect of weather conditions during installation	It is necessary to take into account the influence of weather conditions during installation	Can be installed in all weather conditions	It is necessary to take into account the influence of weather conditions during installation
8	The presence of a G-shaped edge on all sides	A G-shaped edge is not present on all sides	It allows to fasten the plates without forming existing cold bridges	A G-shaped edge is not present on all sides
9	Ecological purity	It is developed using advanced freon-free technologies	It is developed using advanced freon-free technologies	It is developed using advanced freon-free technologies
10	In what form it is produced	Blocks, slabs, crushed stone and granular	Plate	Block, plate and roll
11	Durability	Unbounded	More than 50 years. Test report of NIISF RAASN No. 132-1 dated 29.10.2001	More than 50 years.

It can be seen from Table 1 that PENOPLEKS®GEO thermal insulation boards are the best solution for thermal insulation of basement walls.

Taking this into account, we will consider the calculation method of increasing the heat transfer resistance of the outer walls of the basement using these heat insulation plates. For this, it is necessary to choose a thermal insulation board with sufficient thickness to ensure its resistance to heat transfer, taking the thickness of the basement wall as 0.4 m.

2. Materials and Methods

The overall resistance of the outer wall of the basement to heat transfer, providing the condition $R_o = R_o^{mp}$, if the barrier structure is a homogeneous one-layer, based on the formula 4 given in [5], if the barrier structure is a homogeneous multi-layer, taking into account clause 2.6 of [5], it is determined as follows:

$$R_0 = \frac{1}{\alpha_в} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_n}{\lambda_n} + \frac{1}{\alpha_н}\ m^2 \cdot {}^{\circ}C / vt; \quad (1)$$

where $\alpha_в$ is the heat transfer coefficient of the inner surface of the barrier structure, taken from table 5 of [5];

δ - the thickness of the barrier structure layer, m;

λ - thermal conductivity coefficient of the material of the barrier construction layer, taken from Appendix 1 of [5];

$\alpha_н$ - heat transfer coefficient of the outer surface of the barrier structure, taken from table 6 of [5];

$R_o = R_o^{mp}$ in the condition R_o^{mp} is the required resistance of the heat transfer resistance of the barrier structure, its value is taken from table 2b of [5] for the external walls of the buildings in accordance with the degree-day indicators (D_d) of the heating season.

The value of the degree-day indicator (D_d) of the heating season is determined based on the formula (1) of the current normative document [5].

Taking into account the above, for the part of the basement walls located above the ground level and below the ground level, the thickness of the thermal insulation plates (layer) is calculated as follows.

The thickness of the heat insulation layer for the part of the basement walls located above the ground level is accepted as the thickness of the heat insulation layer of the external walls and is determined using the following formula:

$$\delta_{is.i} = \left(R_o^{mp} - 0{,}16 - \frac{\delta_i}{\lambda_i} - \frac{\delta}{\lambda} \right) \cdot \lambda_{is.i}; \quad (2)$$

Here $0{,}16 = \frac{1}{\alpha_в} + \frac{1}{\alpha_н}$.

Since the part of the basement wall located below the ground level is in direct contact with the soil and not with the external environment, the value of in this case is different. Instead, it will be necessary to take into account the thermal conductivity or heat absorption coefficient of the soil. In this case, based on the indicators given in Table 1 of [5], it is necessary to determine the thickness of the thermal insulation layer for basement walls by the following formula:

$$\delta_{is.i} = \left(R_o^{mp} - \frac{1}{\alpha_в} - \frac{\delta}{\lambda} - K \right) \cdot \lambda_{is.i} \quad (3)$$

Here $\lambda_{uc.u}$ - thermal conductivity coefficient of heat insulation layer material, $vt / \left(m \cdot {}^{\circ}C\right)$;

K-the coefficient taking into account the heat transfer resistance of the external environment (soil layer) (K=0.5-1.05), this coefficient is calculated according to the value obtained from Table 1 of [6], depending on the type of soil, volume weight and moisture content.

As can be seen from the formula (3), the thickness of the thermal insulation layer for the part of the basement walls located below the ground level is determined depending on the thermal resistance of the barrier structure, its material, the external environment, i.e., the type of soil layer, its volume weight, humidity, and the type of thermal insulation layer material.

2.1. Method for determining the total resistance of the outer wall of the basement to heat transfer

Based on formulas 1-2-3, we determine the total resistance to heat transfer of the outer wall of the basement of a one-story public building. The thickness of the basement wall is 0.4 m.we perform accounting work for the case when the thermal insulation plate is laid from the inside. The calculation scheme of the wall construction is presented in Fig. 1.

Calculations are performed in the following order:

Place of construction - Samarkand region, Toyloq district;

The function of the building is a public building;

- the calculation temperature of the indoor air of the room, $t_в = 18°C$ is taken from Appendix 1 of [5];
- the relative humidity of the indoor air of the room is taken as $\varphi = 57\%$ according to the note in Table 4 of [5];

From Table 4 of [7], the value of the average temperature $t_{om.nep}$ and the duration of these periods $Z_{om.nep}$ for the periods when the outdoor air temperature of the city of Samarkand is $t \leq 8°C$ and $t \leq 12°C$, respectively we will record information about:

Average temperature $t_{om.nep} = +3,3°C$, for periods with $t \leq 8°C$, duration 133 days;

For periods with $t \leq 12°C$, the average temperature $t_{om.nep} = +4,8°C$, duration is 172 days.

- on the basis of these values, we can determine the value of the average temperature $t_{om.nep}$ and the duration of these periods $Z_{om.nep}$ for periods with $t \leq 10°C$:

$$t_{om.nep} = \frac{3,3+4,8}{2} = 4,05°C \text{ and } Z_{om.nep} = \frac{133+172}{2} = 152,5 \approx 153 days.$$

- humidity mode of the room is moderate.

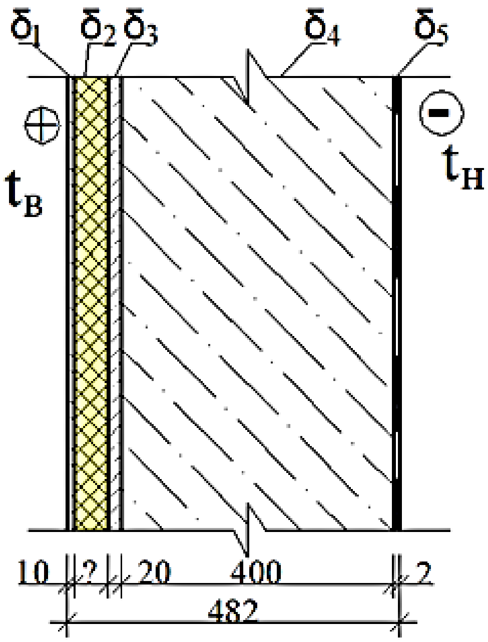

Fig. 1. Calculation scheme of the wall construction: δ_1 - thickness of plasterboard layer; λ_1 - thermal conductivity coefficient of plasterboard material; δ_2 - thickness of PENOPLEKS®GEO thermal insulation board layer; λ_2 - Heat transfer coefficient of PENOPLEKS®GEO heat insulation board; δ_3 - thickness of plaster layer; λ_3 - thermal conductivity coefficient of plaster layer material; δ_4 - thickness of the basement wall made of monolithic concrete; λ_4 - thermal conductivity coefficient of the wall material; δ_5 - thickness of the waterproofing layer

Using formula 1 of [5], we determine the degree-day index of the heating season for the city of Samarkand:

$$D_d = (t_в - t_{om.nep}) \cdot Z_{om.nep} = (18 - 4,05) \cdot 153 = 2135 \text{ degree-days.}$$

Based on the degree-day indicator D_d, we take the value of the required resistance to heat transfer R_o^{mp} for the outer wall of the basement from table 2b of [5]:

$$R_o^{mp} = 2,0 (m^2 \cdot °C) / vt.$$

Taking this value into account, we determine the thickness of the thermal insulation layer for the part above the ground level using formula (2):

$$\delta_{is.i}^{y.s.yu} = \left(R_o^{mp} - 0{,}16 - \frac{\delta_1}{\lambda_1} - \frac{\delta_2}{\lambda_2} - \frac{\delta_3}{\lambda_3} \right) \cdot \lambda_{is.i} = \left(2 - 0{,}16 - \frac{0{,}01}{0{,}19} - \frac{0{,}02}{0{,}76} - \frac{0{,}40}{2{,}04} \right) \cdot 0{,}032 =$$
$$= (2 - 0{,}16 - 0{,}05 - 0{,}03 - 0{,}2) \cdot 0{,}032 = 1{,}56 \cdot 0{,}032 = 0{,}049m$$

Therefore, the minimum thickness of the thermal insulation board (PENOPLEKSR GEO) is 49 mm for the part located above the ground level.

We determine the thickness of the thermal insulation layer for the part of the basement wall located below the ground level using formula (3).

$$\delta_{is.i}^{yer.s.p} = \left(R_o^{mp} - \frac{1}{\alpha_в} - \frac{\delta_1}{\lambda_1} - \frac{\delta_2}{\lambda_2} - \frac{\delta_3}{\lambda_3} - K \right) \cdot \lambda_{is.i} = \left(2 - \frac{1}{8{,}7} - \frac{0{,}01}{0{,}19} - \frac{0{,}02}{0{,}76} - \frac{0{,}40}{2{,}04} - 0{,}7 \right) \cdot 0{,}032 =$$
$$= 1{,}113 \cdot 0{,}032 = 0{,}029m$$

The minimum thickness of the thermal insulation board (PENOPLEKSR GEO) for the part of the basement wall located below the ground level is 29 mm. Taking into account the available thicknesses of heat insulation plates, we accept 0.05 m for the plinth part, and 0.03 m for the part located below the ground level.

Putting the determined values into the formula (1), we determine the total resistance of the wall to heat transfer:

<u>For the Sokol part:</u>

$$R_o = \frac{1}{\alpha_i} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3} + \frac{\delta_4}{\lambda_4} + \frac{1}{\alpha_t} = \frac{1}{8{,}7} + \frac{0{,}01}{0{,}19} + \frac{0{,}05}{0{,}032} + \frac{0{,}02}{0{,}76} + \frac{0{,}4}{1{,}74} + \frac{1}{23} =$$
$$= 0{,}115 + 0{,}053 + 1{,}56 + 0{,}026 + 0{,}23 + 0{,}043 = 2{,}03m^2 \cdot {}^\circ C / vt.$$

For the part below ground level:

$$R_o = \frac{1}{\alpha_i} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3} + \frac{\delta_4}{\lambda_4} + \frac{1}{\alpha_t} = \frac{1}{8{,}7} + \frac{0{,}01}{0{,}19} + \frac{0{,}03}{0{,}032} + \frac{0{,}02}{0{,}76} + \frac{0{,}4}{1{,}74} + 0{,}7 =$$
$$= 0{,}115 + 0{,}053 + 0{,}938 + 0{,}026 + 0{,}23 + 0{,}7 = 2{,}06m^2 \cdot {}^\circ C / vt.$$

For both cases, the condition $R_o = R_o^{mp}$ is fulfilled. So, the external wall of the basement has sufficient resistance to heat transfer.

3. Results and Discussion

Taking into account that the basement walls are made of dense materials and are in direct contact with moisture and aggressive influences, the use of PENOPLEKS®GEO heat insulation board as a heat insulation material is an optimal solution.

When calculating the thickness of the thermal insulation layer of the basement walls, it is appropriate to use formula (2) for the part of the plinth located above the ground level, and formula (3) for the part located below the ground level.

Taking into account that the outer walls of the basement differ from the outer walls of buildings during operation, it is necessary to calculate the moisture regime, regardless of whether the thermal insulation boards are placed from the inside or outside.

Based on the conclusion given above, we will calculate the moisture regime of the barrier construction for the case where the thermal insulation layer is placed from the inside of the barrier structure. For this, the following circumstances should be taken into account.

It is known that the characteristics of resistance to heat transfer of underground external barrier structures of buildings directly depend on their moisture condition. Because, when the moisture in the construction material increases, its thermal conductivity also increases. High humidity reduces the long-term durability of the structure and negatively affects the sanitary-hygienic condition of the room.

The reasons for the appearance of moisture in the underground external barrier structures of buildings:

- technological, soil, atmospheric moisture, operational moisture, sorption moisture, condensation moisture, water vapor diffusion, [8, 9].

During the cold season, the interior of the building is usually warm. Therefore, the partial pressure of water vapor in the indoor air is high, and the temperature of the outdoor air is low, so the partial pressure of water vapor in it is also lower. In such cases, due to the difference in partial pressures, a flow of water vapor from the inner surface of the external barrier structure to the outer surface appears. This is called water vapor diffusion.

Water vapor - As the temperature drops from the inside to the outside as the room flows through the external barrier structure to the outside environment, water vapor condenses in some building materials, making it humid. In multi-layer external barrier constructions, such a dangerous section - if the thermal insulation material is installed from the

inside of the wall, the thermal insulation is formed at the junction of the colder, denser layer in the outer zone of the layer.
The vapor transmission resistance of a single layer in a single-layer, homogeneous structure or a multi-layer barrier structure is determined by the formula (35) in [5]:

$$R_{П} = \frac{\delta}{\mu}\ (m^2 \cdot s \cdot Pa / mg) \tag{4}$$

The value of the vapor permeability coefficient μ of the material depends on the amount of moisture in it. As humidity increases, μ also increases. The overall resistance to vapor transmission of the barrier structure is determined as follows:
for single layer construction

$$R_{0П} = R_{В.П} + \frac{\delta}{\mu} + R_{Н.П}\ (m^2 \cdot s \cdot Pa / mg) \tag{5}$$

for multi-layer construction

$$R_{0П} = R_{В.П} + \frac{\delta_1}{\mu_1} + \frac{\delta_2}{\mu_2} + \cdots + \frac{\delta_n}{\mu_n} + R_{Н.П}\ (m^2 \cdot s \cdot Pa / mg) \tag{6}$$

where $R_{В.П}$ and $R_{Н.П}$ are the moisture exchange resistance of the internal and external surfaces of the structure $R_{В.П} = 0,2\ (m^2 \cdot s \cdot Pa / mg)$, $R_{Н.П} = 0,1\ (m^2 \cdot s \cdot Pa / mg)$ [8].
In order to ensure normal moisture conditions in external barrier constructions, the vapor resistance of the part between the inner surface of the barrier structure and the section where condensation is likely to occur, $R_{В.П}$ must not be less than the required value of resistance to vapor transmission $R_{П}^{ТР}$ i.e.

$$R_{П.B} > R_{П}^{ТР} \tag{7}$$

The value of $R_{П}^{ТР}$ must be determined for two cases:

a) from the formula (28) in [10], based on the condition of preventing moisture accumulation during the year-round operation of the barrier structure:

b) from the formula (29) in [5] based on the condition of limiting the amount of moisture accumulated in the barrier structure during the period when the outside air temperature is lower than the average monthly temperature:

When checking the fulfillment of condition (7), the larger of the two values determined by formulas (28) and (29) in [5] is taken as the value of . Then it is possible to guarantee that the moisture condition of the construction being designed will not deteriorate during the operation period.
For the conditions of stationary water vapor diffusion, the grapho-analytical method is used to calculate the moisture condition of multi-layer external barrier structures and to determine the formation of condensation moisture inside the external barrier structures [8].
Taking into account the above, let's check the moisture regime of the barrier structure for the case where the thermal insulation layer is installed from the inside of the outer wall of the basement.

3.1. Determination of the boundary of the condensation zone by grapho-analytical method

Determining the boundary of the condensation zone by the grapho-analytical method for the case where the 50 mm PENOPLEKS® GEO thermal insulation board is installed on the basement wall from the inside.
When insulating the walls of the basement, it is necessary to take into account the contact of the part above and below the ground level with the external environment. It is known that the plinth part of the basement walls is more in contact with the external environment and the negative effects on it (outdoor air, moisture, aggressive environment, rain and snow water) are observed more often. Therefore, we will check the moisture regime for the plinth part of the outer wall of the basement.
First, based on the calculation scheme of the basement wall presented in Figure 2, we will determine the total resistance of the basement wall to heat transfer.

$$R_o = \frac{1}{\alpha_i} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3} + \frac{\delta_4}{\lambda_4} + \frac{1}{\alpha_t} = \frac{1}{8,7} + \frac{0,01}{0,19} + \frac{0,05}{0,032} + \frac{0,02}{0,76} + \frac{0,4}{1,74} + \frac{1}{23} =$$
$$= 0,115 + 0,053 + 1,56 + 0,03 + 0,23 + 0,04 = 2,03 m^2 \cdot °C / vt.$$

Taking into account the value of the total heat transfer resistance of the barrier structure, we determine the vapor transmission resistance of the wall layers based on the formula (6). To perform the calculation, we first determine the coefficients of thermal conductivity λ and vapor absorption μ of the materials of the barrier construction layers from Figure 2 and Appendix 1 in [5]:

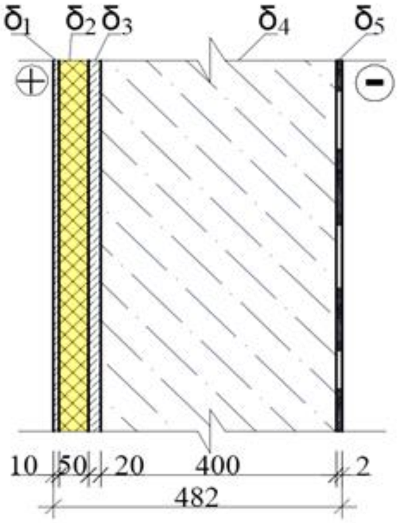

Fig. 2. Calculation scheme of the wall construction

- $\delta_1 = 0,01m,$ thickness of plasterboard layer with volume weight goes =800 kg/m^3;
- $\lambda_1 = 0,19 vt / (m \cdot °C);$
- $\mu_1 = 0,075 mg / (m \cdot s \cdot Pa);$
- $\delta_2 = 0,05m$ thickness of the PENOPLEKS® GEO layer with volume weight γ_o=35 kg/m^3;
- $\lambda_2 = 0,032 vt / (m \cdot °C);$
- $\mu_2 = 0,018 mg / (m \cdot s \cdot Pa);$
- $\delta_3 =$ thickness of the layer of lime-sand mixture with a volumetric weight of 0.02 m = 1600 kg/m^3;
- $\lambda_3 = 0,76 vt / (m \cdot °C);$
- $\mu_3 = 0,12 mg / (m \cdot s \cdot Pa);$
- δ_4 - 0.4 m concrete wall made of natural stone and small pebbles with a volume weight of 2400 kg/m^3;
- $\lambda_4 = 1,74 vt / (m \cdot °C);$
- $\mu_4 = 0,03 mg / (m \cdot s \cdot Pa);$
- δ_5=0.002 m thickness of bituminous waterproofing layer with volume weight γ_o = 1400 kg/m^3;
- $\lambda_5 = 0,27 vt / (m \cdot °C);$
- $\mu_5 = 0,008 mg / (m \cdot s \cdot Pa).$

We determine the vapor transmission resistance of wall layers:
- vapor transmission resistance of the first layer

$$R_{1.\Pi} = \frac{\delta_1}{\mu_1} = \frac{0,01}{0,075} = 0,13 \frac{m^2 \cdot s \cdot Pa}{mg}$$

- vapor transmission resistance of the second layer

$$R_{2.\Pi} = \frac{\delta_2}{\mu_2} = \frac{0,05}{0,018} = 2,78 \frac{m^2 \cdot s \cdot Pa}{mg}$$

- vapor transmission resistance of the third layer

$$R_{3.\Pi} = \frac{\delta_3}{\mu_3} = \frac{0,02}{0,12} = 0,17 \frac{m^2 \cdot s \cdot Pa}{mg}$$

- vapor transmission resistance of the fourth layer

$$R_{4.\Pi} = \frac{\delta_4}{\mu_4} = \frac{0,4}{0,03} = 13,33 \frac{m^2 \cdot s \cdot Pa}{mg}$$

- vapor transmission resistance of the fifth layer

$$R_{5.\Pi} = \frac{\delta_5}{\mu_5} = \frac{0,002}{0,008} = 0,25 \frac{m^2 \cdot s \cdot Pa}{mg}$$

$$R_{0.\Pi} = R_{1.\Pi} + R_{2.\Pi} + R_{3.\Pi} + R_{4.\Pi} + R_{5.\Pi} = 0,13 + 2,78 + 0,17 + 13,33 + 0,25 = 16,7 \frac{m^2 \cdot s \cdot Pa}{mg}$$

We will draw the wall scheme on the scale of the values of vapor transmission resistance of the wall layers (Fig. 2).
3. We determine the temperature at the boundary of the wall layers using the formula (2.67) in [10]:

$$\tau_x = t_i - \frac{(t_i - t_t) \cdot n}{R_o} \left(R_B + \sum_i^n R_X \right)$$

$$\tau_i = 18 - \frac{(18+16)}{2} \cdot 0,115 = 18 - 1,955 = 16,05°C;$$

$$\tau_1 = 18 - \frac{(18+16)}{2} \cdot (0,015 + 0,053) = 18 - 2,86 = 15,14°C;$$

$$\tau_2 = 18 - \frac{(18+16)}{2} \cdot (0,115 + 0,053 + 1,56) = 18 - 29,38 = -11,38°C;$$

$$\tau_3 = 18 - \frac{(18+16)}{2} \cdot (0,115 + 0,053 + 1,56 + 0,03) = 18 - 29,89 = -12,89°C;$$

$$\tau_4 = 18 - \frac{(18+16)}{2} \cdot (0,115 + 0,053 + 1,56 + 0,03 + 0,2) = 18 - 33,29 = -15,3°C;$$

$$\tau_t = 18 - \frac{(18+16)}{2} \cdot (0,115 + 0,053 + 1,56 + 0,03 + 0,2 + 0,007) = 18 - 33,41 = -15,41°C;$$

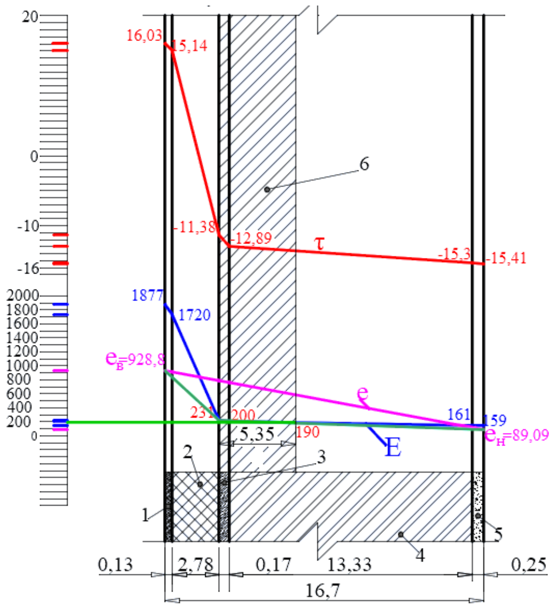

Fig. 3. The diagram for determining the boundary of the condensation zone when the thermal insulation board is installed on the basement wall from the inside: 1-plasterboard coating; 2 – thermal insulation plate; 3-cement-sand mixture; 4-monolithic concrete wall; 5-waterproofing layer; 6-condensation zone.

We determine the values of the maximum partial pressure (of saturated steam) corresponding to the ambient temperature from table 2.13-2.14 presented in [10]:

$$E_и = 1877Pa; \ E_1 = 1720Pa; \ E_2 = 231Pa; \ E_3 = 200Pa; \ E_4 = 161Pa; \ E_н = 159Pa;$$

Based on the current normative document [7], when the relative humidity of the room air is φ=45% and the relative humidity of the outdoor air is φ=59%, we determine the value of the partial pressure of water vapor in the considered environment based on the formula (30) given in [8]:

$$e_i = 2064 \cdot 0,57 = 1176,5Pa;$$

$$e_t = 151 \cdot 0,59 = 89,09Pa;$$

The amount of water vapor collected in the condensation zone:

$$\text{P}_1 = \frac{e_i - \text{E}_з}{R^{\Pi}_{ут} + R^{\Pi}_{шт}} = \frac{1176,5 - 231}{2,78 + 0,17} = \frac{945,5}{2,94} = 321,6mg / \left(m^2 \cdot s \cdot Pa\right);$$

The amount of water vapor leaving the left side of the condensation zone:

$$\text{P}_2 = \frac{\text{E}_2 - e_т}{R^{\Pi}_к + R^{\Pi}_к} = \frac{190 - 89,09}{16,7} = \frac{100,91}{16,7} = 6,04mg / \left(m^2 \cdot s \cdot Pa\right);$$

Amount of water vapor condensing on the wall:

$$\text{P} = P_1 - P_2 = 321,6 - 6,04 = \frac{315,6mg}{m^2 \cdot s \cdot Pa};$$

The amount of condensation that moistens the wall in a month:

$$\text{P}_w = \frac{\text{P} \cdot 24 \cdot 30}{1000} = \frac{0,316 \cdot 24 \cdot 30}{1000} = 0,23kg / m^2;$$

We determine the rate of moisture loss in summer with the following initial air parameters: t_t = 26 °C; $\varphi_в$=75%; $e_t = 3363 \cdot 0,25 = 841Pa$;

Temperature in the plane of gluing the heat insulation board to the basement wall:

$$R_o = \frac{1}{\alpha_i} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} = \frac{1}{8,7} + \frac{0,01}{0,19} + \frac{0,05}{0,032} = 0,115 + 0,053 + 1,56 = 1,73m^2 \cdot °C / vt.$$

$$\tau_1 = 18 - \frac{(18-16)}{2} \cdot (1,73) = 18 + 6,93 = 24,93°C;$$

This temperature corresponds to the following value of the maximum partial pressure of water vapor $E_{k.z}$=3156 Pa;
The other surface of the condensation zone is located at the following distance from the inner surface of the thermal insulation plate: δ = 3.65·0.03+0.02 = 0,13 m; here 0.03 $mg / \left(m^2 \cdot s \cdot Pa\right)$ – vapor absorption coefficient of concrete wall.

Based on the formula (2.3), we determine the thermal resistance of the condensation zone:

$$R_К = \frac{\delta}{\lambda} = \frac{0,02}{0,76} + \frac{0,11}{2,04} = 0,084 \ (m^2 \cdot °C / vt)$$

The temperature tx of this surface is as follows:

$$\tau_{k.z.i} = 18 - \frac{(18-16)}{2} \cdot (0,115 + 0,053 + 1,56 + 0,03 + 0,084) = 18 + 7,37 = 25,37°C;$$

This temperature corresponds to the following value of the maximum partial pressure of water vapor $E_{k.z}$=3238 Pa;
17. $E_{k.z}$=3238 Pa> $e_i = 1176,5Pa$ since, construction occurs in both directions;
We determine the amount of moisture leaving the room:

$$\text{P}_1 = \frac{3238 - 1176,5}{2,78 + 0,17} = \frac{2061,5}{2,94} = 701,2mg / \left(m^2 \cdot s \cdot Pa\right) = 0,701g / \left(m^2 \cdot s \cdot Pa\right);$$

We determine the amount of moisture leaving the outside of the wall:

$$\text{P}_2 = \frac{3238 - 841}{16,7} = \frac{100,91}{16,7} = 144mg / \left(m^2 \cdot s \cdot Pa\right) = 0,144g / \left(m^2 \cdot s \cdot Pa\right);$$

where $\text{P} = \text{P}_1 + \text{P}_2 = 0,701 + 0,144 = 0,845g / \left(m^2 \cdot s \cdot Pa\right);$

The amount of condensation moisture leaving the wall in a month:

$$\mathrm{P_{к}} = \frac{P \cdot 24 \cdot 30}{1000} = \frac{0{,}845 \cdot 24 \cdot 30}{1000} = 0{,}61 kg / m^2;$$

$$\mathrm{P_{к}} = 0{,}61 kg / m^2 \succ \mathrm{P_{w}} = 0{,}23 kg / m^2.$$

As a result, it is ensured that the condensing moisture formed in the base part of the basement wall dries up during the summer.

4. Conclusion

From the calculations and the graph presented in Figure 3, it can be seen that when a layer of heat insulation is placed on the base part of the basement wall from the inside, condensation moisture appears in the body of the barrier structure in the winter season. This has a negative impact on the operational characteristics of the barrier structure and the comfort level of the room. In addition, it has been determined that the moisture that appears in the body of the barrier structure can dry up in the summer season. However, in winter, there is a possibility of moisture accumulation in the body of the barrier structure. Therefore, when insulating the exterior walls of the basement, it can be seen that it is more effective to put the insulation layer on the outside as much as possible. It is also necessary to calculate the part of the outer wall of the basement below the ground level in the same order.

References

1. A.S. Kurbanov, Study of heat (energy) loss from underground parts of buildings, its effect on energy efficiency of buildings. *Memory and construction problems* 159-162 (2022)
2. A.G. Komar, Building materials and products. Visshaya Shcola, Moscow (1988)
3. A. Hamidov, H. Alimov et al., Technology of construction materials, products and metals. NMPI, Namangan (2010)
4. N. Konovalova, P. Pankov, E. Rush, N. Avseenko, D. Bespolitov, Environmentally Friendly Road-Building Thermal Insulating Materials Based on Zeolite-Containing Rocks. Sustainable Energy Systems: Innovative Perspectives. *Lecture Notes in Civil Engineering* **141**, Springer, Cham (2021)
5. QMQ 2.01.04-18. Construction heat engineering. (2018)
6. GOST ISO 13370-2016. The national standard of the Russian Federation. The method of calculating heat transfer through the soil. Data entered 2017-07-01 GOST ISO 13370-2016.
7. S.V. Korniyenko, Improving methods of temperature and humidity calculation in enclosing structures. *Alphabuild* **13**, 1-16 (2020)
8. G. Shukurov, Architectural physics. *SamDU*, Samarkand (2022)
9. E.S. Tulakov, M.M. Mahmudov, Architecture of industrial and civil buildings. *Construction physics*, Samarkand (2022)
10. Z. Sirozhiddinov et al., Probabilistic approach to the calculation of ground and foundations by limit states. *Journal of Advanced Studies of Engineering Science* **2**(1), 47-55 (2023)
11. Sh. Mamatkulova, D.T. Inoyatov, Consideration of seismic impact in calculations of free-standing compounds during emergency soaking of loess soils. *Ta'lim fidoyilari* **13**, 90-95 (2022)
12. D. T. Inoyatov, E. S. Tulakov, Theoretical Solutions for Calculating the Height of the Capillary Rise of Water in the Foundation of a Building. *International Journal of Trend in Scientific Research and Development (IJTSRD*) **3**(2), 15-20 (2022)
13. E. S. Tulakov, D.T. Inoyatov, A.S. Kurbonov, Waterproofing and calculation of the thickness of the insulation of the basement wall of a low-rise energy-efficient house in accordance with domestic and foreign standards and norms. *International Journal of Scientific and Technology Research* **8**(11), 3311-3314 (2019)
14. E.S. Tulakov, D. Inoyatov, A.S. Kurbonov, Calculation of the insolation of buildings and its thickness by the facing wall of buildings. *Problems of architecture and construction* **4**, 29-32 (2020)