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Determination of optimal variant for insulation of the attic floor of the educational building

Yurin Oleg[1], Zyhun Alina[2]*, Kliepko Anastasiia[3], Mahlinza Qiniso[4]

[1] National University «Yuri Kondratyuk Poltava Polytechnic» https://orcid.org/0000-0002-9290-9048
[2] National University «Yuri Kondratyuk Poltava Polytechnic» https://orcid.org/0000-0002-1743-2294
[3] National University «Yuri Kondratyuk Poltava Polytechnic» https://orcid.org/0000-0001-7200-1510
[4] National University «Yuri Kondratyuk Poltava Polytechnic» https://orcid.org/0000-0003-2132-5755
*Corresponding author E-mail: alinazygun@gmail.com

The analysis of heat-protective properties of the existing attic floor of the educational building of National University «Yuri Kondratyuk Poltava Polytechnic» showed their non-compliance with regulatory requirements. The required thickness of the insulation in the attic floor was determined without taking into account the heat-conducting inclusions. Overlapping areas with heat-conducting inclusions reduce the reduced heat transfer resistance. In the attic floor, these are the areas where the floor adjoins the inner and outer walls. It is possible to increase the reduced heat transfer resistance due to additional insulation of external and internal walls within the cold attic. The study determined the optimal length of additional insulation for eight different options. To determine the optimal value, options for additional insulation of external and internal walls within the attic with a simultaneous reduction in the thickness of the insulation on the attic floor were considered.

Keywords: heat-conducting inclusions, insulation of cold attic walls, optimal insulation option.

Визначення оптимального варіанту утеплення горищного перекриття навчального корпусу

Юрін О.І.[1], Зигун А.Ю.[2]*, Клєпко А В.[3], Кінісо Махлінза[4]

[1,2,3,4] Національний університет «Полтавська політехніка імені Юрія Кондратюка»
*Адреса для листування E-mail: alinazygun@gmail.com

Робота присвячена визначенню оптимального варіанту утеплення горищного перекриття навчального корпусу Національного університету «Полтавська політехніка імені Юрія Кондратюка». Аналіз теплозахисних властивостей існуючого горищного перекриття показав невідповідність їх нормативним вимогам. Була визначена необхідна товщина утеплювача у горищному перекритті без урахування теплопровідних включень. Але на теплозахисні властивості горищного перекриття значний вплив здійснюють ділянки перекриття з теплопровідними включеннями. Вони зменшують приведений опір теплопередачі. Такими ділянками у горищному перекритті є ділянки примикання перекриття до внутрішніх та зовнішніх стін. Збільшити приведений опір теплопередачі можливо за рахунок додаткового утеплення зовнішніх та внутрішніх стін у межах холодного горища. У роботі були розглянуті варіанти додаткового утеплення у межах холодного горища: зовнішньої стіни з зовнішньої сторони, зовнішньої стіни з внутрішньої сторони, зовнішньої стіни з внутрішньої та зовнішньої сторони, внутрішніх стін, зовнішньої стіни з зовнішньої сторони та внутрішніх стін, зовнішньої стіни з внутрішньої сторони та внутрішніх стін, зовнішньої стіни з обох сторін та внутрішніх стін, збільшення товщини утеплювача горищного перекриття. Були визначені оптимальні варіанти довжини додаткового утеплення ділянок з теплопровідними включеннями. За оптимальні приймалися такі довжини додаткового утеплення при яких подальше збільшення довжини утеплювача не дає істотного збільшення приведеного опору теплопередачі. Дослідження показали, що варіант підвищення товщини утеплювача на горищному перекритті до 400 мм дозволяє досягнути нормованого значення теплозахисту для горищного перекриття. Але даний варіант утеплення є економічно не доцільним так як потребує значного збільшення об’єму утеплювача. Для визначення економічно оптимального варіанта були розглянуті варіанти додаткового утеплення зовнішніх та внутрішніх стін у межах горища з одночасним зменшенням товщини утеплювача на горищному перекритті.

Ключові слова: теплопровідні включення, утеплення стін холодного горища, оптимальний варіант утеплення

Introduction

Ensuring the projected regulatory level of thermal protection of buildings is the main task of modern design and construction in Ukraine.

Heat losses through sections of walls of complex configuration are usually different from heat losses through sections accepted for thermal calculation. Areas of complex shape include nodal joints of walls with mezzanine floors, adjacency of window filling to the walls, corners of walls, etc. Such and similar nodes are «cold bridges», which significantly reduce the value of the reduced resistance to heat transfer of enclosing structures.

Additional insulation of the main field of enclosing structures is economically impractical, as it requires a significant increase in the volume of insulation. Therefore, it is necessary to find ways to insulate the nodes with heat-conducting inclusions that would bring the reduced resistance of heat transfer to the requirements of the norms.

Review of the research sources and publications

Research on building thermophysics devoted to the calculation of temperature fields of sections of external enclosing structures of complex configuration belong to such prominent scientists as K. Fokin [1], A. Lykov [2], V. Ilinskiy [3], M. Miheev [4], A. Shklover [5], A. Mogilat [6], as well as modern research H. Fareniuk [7], A. Prishchenko [8], M. Tymofieiev [9, 10], S. Fomin [11].

Definition of unsolved aspects of the problem

A significant number of works by many authors are devoted to the study of heat-protective properties of sections of external walls of complex configuration [12, 13].

The option of increasing the heat-protective properties of the cold attic floor due to additional insulation of its external and internal walls was not considered. Research in this area is relevant.

Problem statement

The aim of the work is to increase the level of thermal protection of cold roof enclosing structures by improving the thermal solutions of attic floor units with heat-conducting inclusions.

Research objectives:

– perform an analysis of the heat-protective properties of the floor of the educational building of the National University «Yuri Kondratyuk Poltava Polytechnic»;

– perform an analysis of ways to improve the heat-protective properties of the attic floor with heat-conducting inclusions. Identify a cost-effective option.

Basic material and results

Thermally conductive inclusions reduce the reduced resistance to heat transfer of enclosing structures. In the construction of the attic floor, heat-conducting inclusions are the joints between the outer and inner walls with the floor structure.

To calculate the reduced heat transfer resistance of the attic floor, it is necessary to know the values of the linear heat transfer coefficients of these heat-conducting inclusions.

Determination of linear heat transfer coefficients is performed according to the method [14,15], which involves the calculation of temperature fields of these areas.

The cold attic of the educational building of the National University «Yuri Kondratyuk Poltava Polytechnic» was accepted for research. The performed researches of the value of heat protection of the existing external enclosing constructions of the educational building do not satisfy the norms. The facades of the educational building are shown in Figure 1 and 2.

Figure 1 – The main facade of the educational building

Figure 2 – Side facade of the educational building

Areas, where the linear heat transfer coefficients were determined, are:

1. Connection of the outer wall with the construction of the attic floor (node 1);
2. Connection of the inner wall with the construction of the attic floor (node 2).

ELCUT software is used for further calculations of two-dimensional temperature fields.

To increase the heat-protective properties of the outer wall, it was proposed to insulate it with a layer of mineral wool IZOVAT, density $\rho_0 = 135$ kg/m^3 and thickness 150 mm. Insulation must be performed on the outside after removing the finishing layer from the ceramic tile, cleaning and repairing the outer surface of the wall.

Determination of the linear heat transfer coefficient of the node №1.

The calculation scheme for determining the linear coefficient of the node №1 is shown in Figure 3.

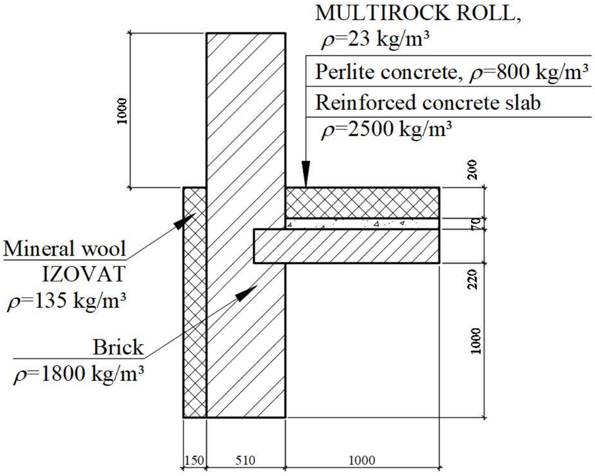

Figure 3 – Calculation scheme for determining the linear coefficient of the node №1

The calculation of the linear heat transfer coefficient is performed according to the formula:

$$k_1 = \sum L_i^{2D} - \sum_{i=1}^{j} U_i \cdot I_i =$$

=0.545+0.444–0,199·1–0,235·1=0,556 W/(m·K)

where L^{2D} – linear coefficient of thermal connection, W/K, respectively in the areas of the attic floor and the outer wall is determined by formulas:

$$L_{at}^{2D} = \frac{Q_{tot.at}}{t_{in} - t_{at}} = \frac{21.101}{21-(-17.7)} = 0.545 \text{ W/K}$$

$$L_{w}^{2D} = \frac{Q_{tot.w}}{t_{in} - t_{ex}} = \frac{19.104}{21-(-22)} = 0.444 \text{ W/K}$$

where $Q_{tot.at}$, $Q_{tot.w}$ – the heat flux passing through the attic floor and the outer wall, respectively, W, is determined on the basis of the results of the calculation of the two-dimensional temperature field (Figure 4);

$Q_{tot.at}$ = 21.101 W ;

$Q_{tot.w}$ = 19,104 W

where t_{in} – temperature, ºC, indoor air t_{in} =21 ºC

Since the difference between the outside air temperature and the attic temperature is 0.9 of the difference between the outside air temperature and the room temperature, the attic temperature is determined by the formula:

$t_{at} = 0.9\,(t_{ex} - t_{in}) + t_{in} =$

= 0.9 (–22 + 21) + 21 = – 17,7 ºC

U_1, U_2 – heat transfer coefficients of one-dimensional fragments, W/(m²·K), respectively, the floor and the outer wall separating the studied medium is determined by formulas:

$$U_1 = \frac{1}{R_{\Sigma.at}} = \frac{1}{5.024} = 0.199 \text{ W/(m}^2\text{·K)}$$

$$U_2 = \frac{1}{R_{\Sigma.w}} = \frac{1}{4.248} = 0.235 \text{ W/(m}^2\text{·K)}$$

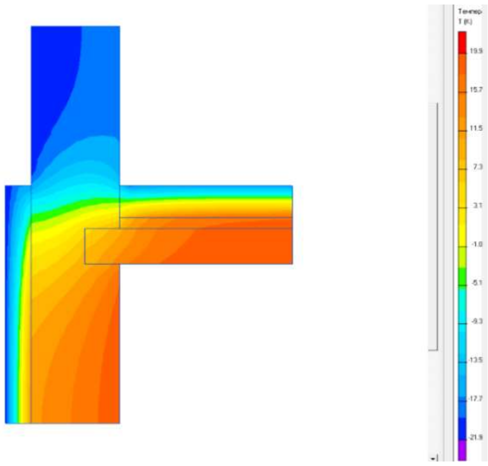

Figure 4 – Results of calculation of temperature field of node №1

where $R_{\Sigma.at}$; $R_{\Sigma.w}$ – heat transfer resistance of the thermally homogeneous part of the attic floor and the wall, respectively, (m²·K)/W, determined by formulas:

$$R_{\Sigma.at} = \frac{1}{\alpha_{in.at}} + \sum_{i=1}^{n} R_i + \frac{1}{\alpha_{ex.at}} =$$

$$= \frac{1}{\alpha_{in.at}} + \frac{\delta_1}{\lambda_{1cal}} + \frac{\delta_2}{\lambda_{2cal}} + \frac{\delta_3}{\lambda_{3cal}} + \frac{1}{\alpha_{ex.at}} =$$

$$= \frac{1}{8.7} + \frac{0.22}{2.04} + \frac{0.07}{0.33} + \frac{0.20}{0.044} + \frac{1}{12} =$$

=5.024 (m²·K)/W

$$R_{\Sigma.w} = \frac{1}{\alpha_{in.w}} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3} + \frac{\delta_4}{\lambda_4} + \frac{\delta_5}{\lambda_5} + \frac{1}{\alpha_{ex.w}} =$$

$$= \frac{1}{8.7} + \frac{0.02}{0.81} + \frac{0.51}{0.81} + \frac{0.01}{0.93} + \frac{0.15}{0.044} + \frac{0.014}{0.93} + \frac{1}{23} =$$

=4.248 (m²·K)/W

$\alpha_{in.at}$, $\alpha_{in.w}$ – heat transfer coefficients of internal surfaces, respectively, attic and wall, W/(m²·K), which are accepted in accordance with Annex B [14]:

$\alpha_{in.at}$ = 8.7 W/(m²·K); $\alpha_{in.w}$ = 8.7 W/(m²·K) ;

$\alpha_{ex.at}$, $\alpha_{ex.w}$ – heat transfer coefficients of external surfaces, respectively, attic and wall, W/(m²·K), which are accepted in accordance with Annex B [14]:

$\alpha_{ex.at}$ = 12 W/(m²·K); $\alpha_{ex.w}$ = 23 W/(m²·K) ;

l_1 , l_2 – lengths, respectively, of the attic and the wall, m, to which the values are applied U_1 and U_2

l_1 =1 m; l_2 =1 m

Determination of the linear heat transfer coefficient of the node №2.

The calculation scheme for determining the linear coefficient of the node №2 is shown in Figure 5.

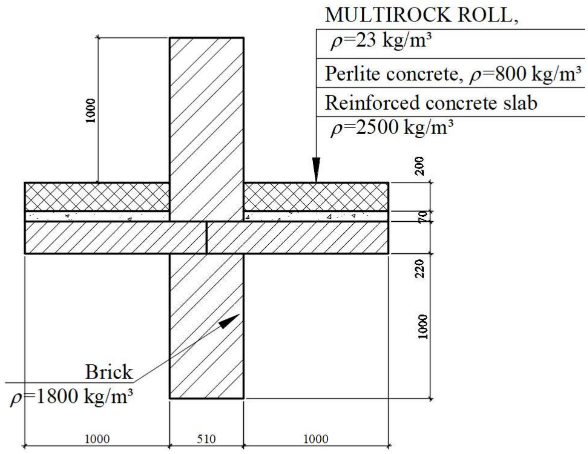

Figure 5 – Calculation scheme for determining the linear coefficient of the node №2

The calculation of the linear heat transfer coefficient is performed according to [15] according to the formula:

$$k_2 = \sum L_i^{2D} - \sum_{i=1}^{j} U_i \cdot l_i =$$
$$= 1.066 - 0{,}199 \cdot 2 = 0.668 \text{ W/(m·K)}$$

where L^{2D} – linear coefficient of thermal connection, W/K, on the site of the attic floor is determined by the formula:

$$L_{at}^{2D} = \frac{Q_{tot.at}}{t_{in} - t_{at}} = \frac{41.236}{21 - (-17.7)} = 1.066 \text{ W/K}$$

where $Q_{tot.at}$, $Q_{tot.w}$ – heat flow passing through the attic floor and the outer wall, W, determined on the basis of the results of the calculation of the two-dimensional temperature field (Figure 6);

$Q_{tot.at}$ = 41.236 W

where t_{in} – temperature, °C, indoor air indoor air t_{in} =21 °C.

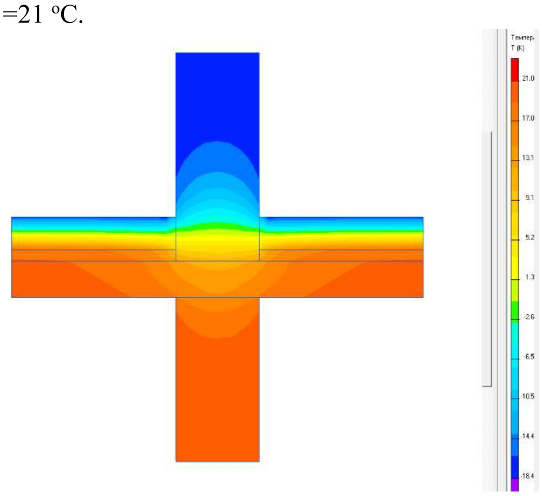

Figure 6 – Results of calculation of temperature field of node №2

Since the difference between the outside air temperature and the attic temperature is 0.9 of the difference between the outside air temperature and the room temperature, the attic temperature is determined by the formula:

$$t_{at} = 0.9\,(t_{ex} - t_{in}) + t_{in} =$$
$$= 0.9\,(-22 + 21) + 21 = -17.7 \text{ °C}$$

U_1 – heat transfer coefficient of one-dimensional fragment, W/(m²·K), the overlap separating the studied medium is determined by the formula:

$$U_1 = \frac{1}{R_{\Sigma.at}} = \frac{1}{5.024} = 0.199 \text{ W/(m}^2\text{·K)}$$

where $R_{\Sigma.at}$ – heat transfer resistance of the thermally homogeneous part of the attic floor, (m²·K)/W, determined by the formula:

$$R_{\Sigma.at} = \frac{1}{\alpha_{in.at}} + \sum_{i=1}^{n} R_i + \frac{1}{\alpha_{ex.at}} =$$
$$= \frac{1}{\alpha_{in.at}} + \frac{\delta_1}{\lambda_{1p}} + \frac{\delta_2}{\lambda_{2p}} + \frac{\delta_3}{\lambda_{3p}} + \frac{1}{\alpha_{ex.at}} =$$
$$= \frac{1}{8.7} + \frac{0.22}{2.04} + \frac{0.07}{0.33} + \frac{0.20}{0.044} + \frac{1}{23} =$$
$$=5.024 \text{ (m}^2\text{·K)/W}$$

l_1 – the length of the attic floor, m, to which the value is applied U_1, l_1 =1 m

Determination of the reduced heat transfer resistance of the attic floor structure

The configuration of the design area for determining the reduced resistance to heat transfer to the attic floor is shown in Figure 7.

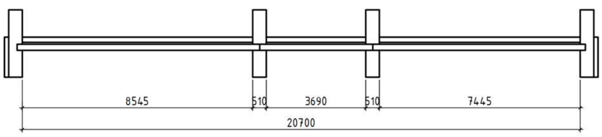

Figure 7 – Configuration of the calculation scheme for determining the reduced heat transfer resistance of the attic floor

The width of the calculated section is assumed to be 1 m.

The reduced heat transfer resistance of the attic floor is determined by the formula:

$$R_{\Sigma 1} = \frac{F_{\Sigma}}{\sum_{i=1}^{n} \frac{Fi}{R_{\Sigma i}} + \sum_{j=1}^{m} k_j L_j + \sum_{k=1}^{k} \varphi_k N_k} =$$

$$= \frac{F_{\Sigma}}{\frac{Fi}{R_{\Sigma}} + k_1 L_1 \times 2 + k_2 L_2 \times 2} =$$

$$= \frac{20{,}7}{\frac{19{,}68}{5{,}024} + 0{,}556 \times 1 \times 2 + 0{,}668 \times 1 \times 2} =$$

$$= 3.253\ (\mathrm{m^2 \cdot K})/\mathrm{W}$$

where F_{Σ} – area of the enclosing structure, m^2, determined by the formula

F_{Σ} =20.7 × 1 = 20.7 m^2 ;

R_{Σ} – heat transfer resistance of thermally homogeneous part of the structure, (m^2·K)/W, determined by the formula:

$$R_{\Sigma} = \frac{1}{\alpha_{in}} + \sum_{i=1}^{n} R_i + \frac{1}{\alpha_{ex}} =$$

$$= \frac{1}{\alpha_{in}} + \frac{\delta_1}{\lambda_{1p}} + \frac{\delta_2}{\lambda_{2p}} + \frac{\delta_3}{\lambda_{3p}} + \frac{1}{\alpha_{ex}} =$$

$$= \frac{1}{8.7} + \frac{0.22}{2.04} + \frac{0.07}{0.33} + \frac{0.20}{0.044} + \frac{1}{23} =$$

$$=5.024\ (\mathrm{m^2 \cdot K})/\mathrm{W}$$

F_1 – the area of the thermally homogeneous part of the enclosing structure, m^2, determined by the formula

F_1 = (8.545 + 3.69 + 7.445) × 1 = 19.68 m^2 ;

k_1 , k_2 – linear heat transfer coefficients, W/(m^2·K), respectively in the place of adjacency of the overlap structure to the outer and inner walls

k_1 = 0.55 W/(m^2·K) ; k_2 = 0.668 W/(m^2·K) ;

L_1 , L_2 – linear size (projection) of linear heat-conducting inclusions, m;

L_1 = 1 m, L_2 = 1 m.

Determine the difference between the values $R_{\Sigma 1}$ and R_{Σ} according to the formula:

$$n = \frac{R_{\Sigma 1}}{R_{\Sigma}} 100 - 100 = \frac{3.253}{5.064} 100 - 100 = 35.8\%$$

Sincen $R_{\Sigma 1}$ =3.253 (m^2·K)/W < $R_{q/min}$=4.95 (m^2·K)/W then the heat-protective properties of the attic floor of the educational building are not sufficient.

Not taking into account heat-conducting inclusions leads to an overestimation of the actual heat transfer resistance of the attic floor of the educational building by 35.8%.

To bring the heat-protective properties of the attic floor of the educational building to the regulatory requirements, eight constructive options for insulation were considered.

Option 1. Insulation of the outer wall on its outer surface above the level of the top of the attic floor insulation.

Raising the insulation above the level of the top of the attic floor insulation was assumed to be a multiple of 200 mm. Determination of the reduced heat transfer resistance of the attic floor was performed on the basis of calculations of the temperature fields of node 1 and node 2. The temperature field of node 2 is constant.

The calculation results of the reduced resistance of heat transfer of the attic floor are shown in table 1.

Table 1 – Calculation results of the reduced heat transfer resistance of the attic floor

Increasing the length of the insulation, mm	k_1, W/(m·K)	k_2 , W/(m·K)	$R_{\Sigma пр}$, m^2·K/W	$R_{q.min}$, m^2·K/W
0	0,556	0,668	3,253	4,95
200	0,508		3,302	
400	0,487		3,325	
600	0,477		3,335	
800	0,473		3,339	
1000	0,472		3,341	
1200	0,471		3,342	
1400	0,470		3,343	
1600	0,470		3,343	

Figure 8 shows a graph of the dependence of the reduced resistance to heat transfer of the attic floor on the increase in the length of the insulation.

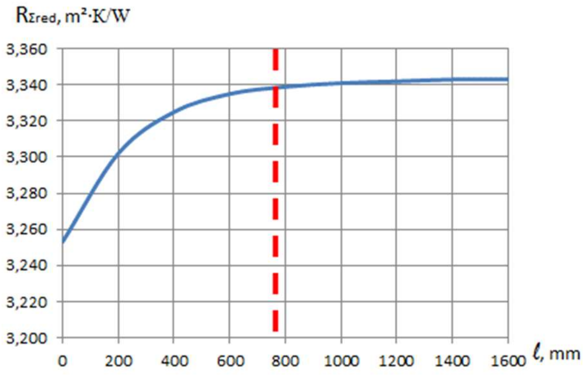

Figure 8 – The graph of the dependence of the reduced resistance of heat transfer of the attic floor on the increase in the length of the insulation.

Result for option 1.

1. Additional insulation of the outer surface of the outer wall of the cold attic does not allow to achieve the normalized value of thermal protection for the attic floor.

2. The optimal increase in the length of the insulation is 800 mm. A further increase in the length of the insulation does not significantly increase the reduced heat transfer resistance.

Option 2. Insulation of the outer wall on its inner surface above the level of the top of the attic floor insulation.

Raising the insulation above the level of the top of the attic floor insulation was taken as a multiple of 200 mm. The determination of the reduced heat transfer resistance of the attic floor was performed on the basis of calculations of the temperature fields of node 1 and node 2. The temperature field of node 2 is constant.

The calculation results of the reduced resistance of heat transfer of the attic floor are shown in table 2.

Table 2 – Calculation results of the reduced heat transfer resistance of the attic floor

Increasing the length of the insulation, mm	k_1, W/(m · K)	k_2, W/(m · K)	$R_{\Sigma пр}$, $m^2 \cdot K/W$	$R_{q.min}$, $m^2 \cdot K/W$
0	0,556	0,668	3,253	4,95
200	0,495		3,316	
400	0,483		3,329	
600	0,482		3,330	
800	0,483		3,329	
1000	0,483		3,329	
1200	0,483		3,329	
1400	0,484		3,328	
1600	0,484		3,328	

Figure 9 shows a graph of the dependence of the reduced resistance to heat transfer of the attic floor on the increase in the length of the insulation.

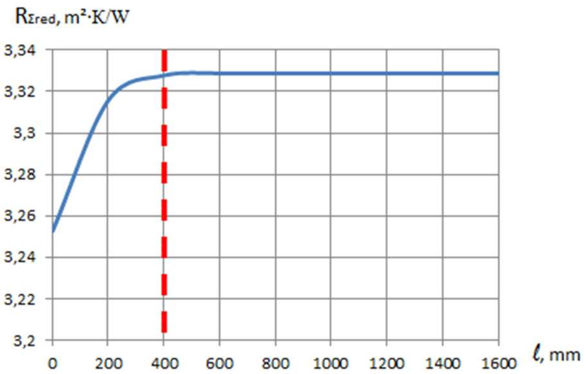

Figure 9 – The graph of the dependence of the reduced resistance of heat transfer of the attic floor on the increase in the length of the insulation

Result for option 2.

1 Additional insulation of the inner surface of the outer wall of the cold attic does not allow to achieve the normalized value of thermal protection for the attic floor.

2. The optimal increase in the length of the insulation is 400 mm.

Option 3. Insulation of the inner wall above the level of the top of the attic floor insulation.

Raising the insulation above the level of the top of the attic floor insulation was taken as a multiple of 200 mm. Determination of the reduced heat transfer resistance of the attic floor was performed on the basis of calculations of the temperature fields of node 1 and node 2. The temperature field of node 1 is constant.

The calculation results of the reduced resistance of heat transfer of the attic floor are shown in table 3.

Table 3 – Calculation results of the reduced heat transfer resistance of the attic floor

Increasing the length of the insulation, mm	k_1, W/(m · K)	k_2, W/(m · K)	$R_{\Sigma пр}$, $m^2 \cdot K/W$	$R_{q.min}$, $m^2 \cdot K/W$
0	0,556	0,668	3,253	4,95
200		0,492	3,443	
400		0,403	3,549	
600		0,350	3,613	
800		0,321	3,650	
1000		0,303	3,674	
1200		0,292	3,688	
1400		0,285	3,698	
1600		0,273	3,713	

Figure 10 shows a graph of the dependence of the reduced resistance to heat transfer of the attic floor on the increase in the length of the insulation.

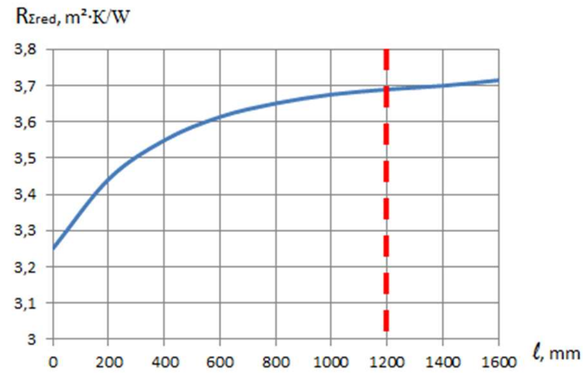

Figure 10 – The graph of the dependence of the reduced resistance of heat transfer of the attic floor on the increase in the length of the insulation

Result for option 3.

1. Additional insulation of the inner walls of the cold attic does not allow to achieve the normalized value of thermal protection for the attic floor.

2. The optimal increase in the length of the insulation is 1200 mm.

Option 4. Insulation of the outer wall on the outer and inner surface above the level of the top of the attic floor insulation.

Raising the insulation above the level of the top of the attic floor insulation was taken as a multiple of 200 mm. The determination of the reduced heat transfer resistance of the attic floor was performed on the basis of calculations of the temperature fields of node 1 and node 2. The temperature field of node 2 is constant.

The calculation results of the reduced resistance of heat transfer of the attic floor are shown in table 4

Table 4 – Calculation results of the reduced heat transfer resistance of the attic floor

Increasing the length of the insulation, mm	k_1, W/(m · K)	k_2, W/(m · K)	$R_{\Sigma пр}$, $m^2 \cdot K/W$	$R_{q.min}$, $m^2 \cdot K/W$
0	0,556	0,668	3,253	4,95
200	0,452		3,363	
400	0,378		3,445	
600	0,348		3,480	
800	0,329		3,503	
1000	0,317		3,516	
1200	0,310		3,525	
1400	0,305		3,531	
1600	0,294		3,545	

Figure 11 shows a graph of the dependence of the reduced resistance to heat transfer of the attic floor on the increase in the length of the insulation.

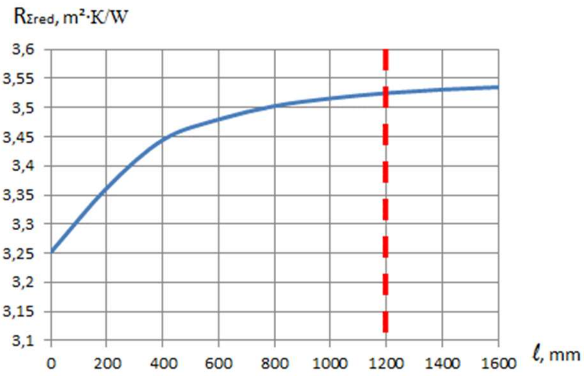

Figure 11 – The graph of the dependence of the reduced resistance of heat transfer of the attic floor on the increase in the length of the insulation

Result for option 4.

1. Additional insulation of the inner and outer surface of the outer wall of the cold attic does not allow to achieve the normalized value of thermal protection for the attic floor.

2. The optimal increase in the length of the insulation is 1200 mm.

Option 5. Insulation of the outer wall on the outside and the inner wall above the level of the top of the attic floor insulation.

Raising the insulation above the level of the top of the attic floor insulation was assumed to be a multiple of 200 mm.

The values of the linear heat transfer coefficient k_1 will be the same as in option 1, and the coefficient k_2 as in option 3.

The calculation results of the reduced resistance of heat transfer of the attic floor are shown in table 5.

Table 5 – Calculation results of the reduced heat transfer resistance of the attic floor

Increasing the length of the insulation, mm	k_1, W/(m · K)	k_2, W/(m · K)	$R_{\Sigma пр}$, $m^2 \cdot K/W$	$R_{q.min}$, $m^2 \cdot K/W$
0	0,556	0,668	3,253	4,95
200	0,508	0,492	3,498	
400	0,487	0,403	3,633	
600	0,477	0,350	3,716	
800	0,473	0,321	3,760	
1000	0,472	0,303	3,786	
1200	0,471	0,292	3,803	
1400	0,470	0,285	3,814	
1600	0,470	0,273	3,831	

Figure 12 shows a graph of the dependence of the reduced resistance to heat transfer of the attic floor on the increase in the length of the insulation.

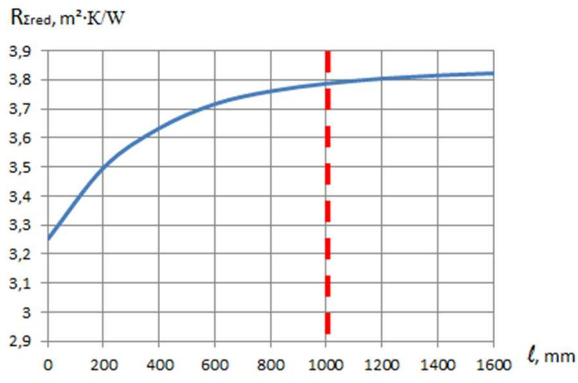

Figure 12 – The graph of the dependence of the reduced resistance of heat transfer of the attic floor on the increase in the length of the insulation

Result for option 5.

1. Additional insulation of the inner walls of the cold attic does not allow to achieve the normalized value of thermal protection for the attic floor.

2. The optimal increase in the length of the insulation is 1000 mm.

Option 6. Insulation of the outer wall from the inside and the inner wall above the level of the top of the attic floor insulation.

Raising the insulation above the level of the top of the attic floor insulation was assumed to be a multiple of 200 mm.

The values of the linear heat transfer coefficient k_1 will be the same as in option 2, and the coefficient k_2 as in option 3.

The calculation results of the reduced resistance of heat transfer of the attic floor are shown in table 6.

Table 6 – Calculation results of the reduced heat transfer resistance of the attic floor

Increasing the length of the insulation, mm	k_1, W/(m · K)	k_2, W/(m · K)	$R_{\Sigma пр}$, m^2 · K/W	$R_{q.min}$, m^2 · K/W
0	0,556	0,668	3,253	4,95
200	0,495	0,492	3,514	
400	0,483	0,403	3,638	
600	0,482	0,350	3,709	
800	0,483	0,321	3,746	
1000	0,483	0,303	3,771	
1200	0,483	0,292	3,786	
1400	0,484	0,285	3,795	
1600	0,484	0,273	3,811	

Figure 13 shows a graph of the dependence of the reduced resistance to heat transfer of the attic floor on the increase in the length of the insulation.

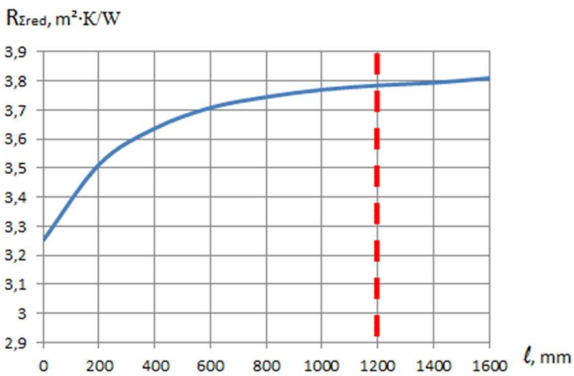

Figure 13 – The graph of the dependence of the reduced resistance of heat transfer of the attic floor on the increase in the length of the insulation

Result for option 6.

1. Additional insulation of the inner walls of the cold attic does not allow to achieve the normalized value of thermal protection for the attic floor.
2. Insulation of more than 1200 mm is inefficient.

Option 7. Insulation of the outer wall on the inside and outside and the inner wall above the level of the top of the attic floor insulation.

Insulation was taken from the same insulation as on the main wall. The thickness of the insulation was assumed to be the same (150 mm). Raising the insulation above the level of the top of the attic floor insulation was assumed to be a multiple of 200 mm.

The values of the linear heat transfer coefficient k_1 will be the same as in option 4, and the coefficient k_2 as in option 3.

The calculation results of the reduced resistance of heat transfer of the attic floor are shown in table 7.

Table 7 – Calculation results of the reduced heat transfer resistance of the attic floor

Increasing the length of the insulation, mm	k_1, W/(m · K)	k_2, W/(m · K)	$R_{\Sigma пр}$, m^2 · K/W	$R_{q.min}$, m^2 · K/W
0	0,556	0,668	3,253	4,95
200	0,452	0,492	3,566	
400	0,378	0,403	3,778	
600	0,348	0,350	3,896	
800	0,329	0,321	3,968	
1000	0,317	0,303	4,014	
1200	0,310	0,292	4,042	
1400	0,305	0,285	4,061	
1600	0,294	0,273	4,098	

Figure 14 shows a graph of the dependence of the reduced resistance to heat transfer of the attic floor on the increase in the length of the insulation.

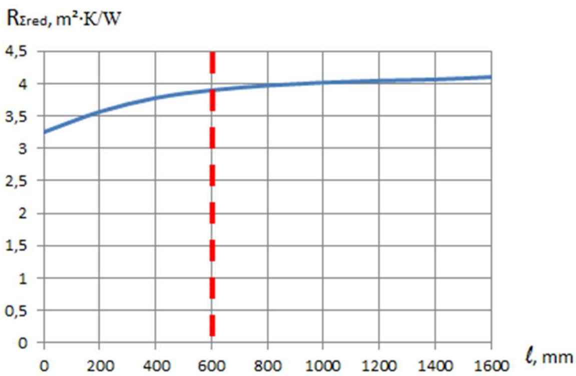

Figure 14 – The graph of the dependence of the reduced resistance of heat transfer of the attic floor on the increase in the length of the insulation

Result for option 7.

1. Additional insulation of the inner walls of the cold attic does not allow to achieve the normalized value of thermal protection for the attic floor.
2. Insulation of more than 600 mm is inefficient.

Option 8. Increasing the thickness of the attic floor insulation.

The increase in the thickness of the attic floor insulation was taken as a multiple of 20 mm.

The calculation results of the reduced resistance of heat transfer of the attic floor are shown in table 8.

Table 8 – Calculation results of the reduced heat transfer resistance of the attic floor

Increasing the length of the insulation, mm	k_1, $W/(m \cdot K)$	k_2, $W/(m \cdot K)$	$R_{\Sigma пр}$, $m^2 \cdot K/W$	$R_{q.min}$, $m^2 \cdot K/W$
0	0,556	0,668	3,253	4,95
20	0,553	0.649	3.452	
40	0,549	0.630	3.648	
60	0,546	0.613	3.834	
80	0,543	0.597	4.014	
100	0,541	0.580	4.191	
120	0,539	0,566	4.359	
140	0,538	0,551	4.523	
160	0,535	0,537	4.687	
180	0,534	0,525	4.840	
200	0,533	0,511	4.994	

Figure 15 shows a graph of the dependence of the reduced resistance to heat transfer of the attic floor on the increase in the length of the insulation.

Result for option 8.

Increasing the thickness of the insulation on the attic floor by 200 mm (up to 400 mm) allows to achieve the normalized value of thermal protection for the attic floor.

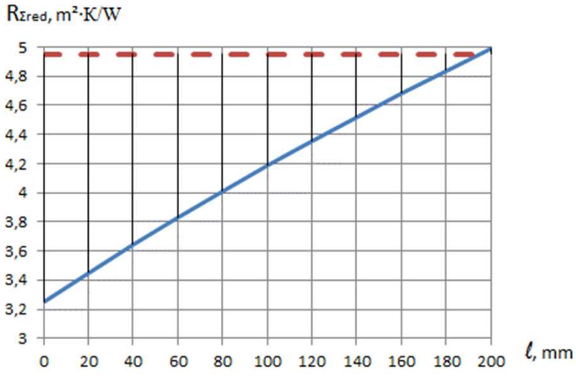

Figure 15 – The graph of the dependence of the reduced resistance of heat transfer of the attic floor on the increase in the length of the insulation

But this option of insulation is economically impractical as it requires a significant increase in the volume of insulation. It is more preferable to use the optimal options for additional insulation of external and internal walls within the mountain while reducing the thickness of the insulation on the attic floor. In this case, the reduced resistance to heat transfer of the attic transmission should be the closest in terms of the normal value.

The research results are shown in Table 9.

As can be seen from Table 9, the smallest volume of insulation equal to 7.09 m^3 per meter of running floor structure is achieved by increasing by 1 m the height of insulation of the outer wall on its outer surface and insulation of internal capital walls by 1.2 m from the level of insulation attic floor.

Table 9 – The cost of additional insulation of the cold attic (per 1 m of attic width), ensuring compliance with thermal protection

Variant	Additional insulation, m^3				Total amount of additional insulation
	Outer surface of the external walls	Inner surface of the external walls	Interior walls	Attic floor	
1	0,186			7,478	7,664
2		0,06		7,872	7,932
3			0,624	6,691	7,315
4	0,312	0,312		6,691	7,315
5	**0,264**		**0,528**	**6,298**	**7,09**
6		0,318	0,636	6,691	7,645
7	0,204	0,084	0,648	6,298	7,334
8				7,872	7,872

Conclusions

1. The value of thermal protection of the existing external enclosing structures of the educational building does not meet the standards.

2. Not taking into account heat-conducting inclusions leads to an overestimation of the actual resistance to heat transfer of the attic floor of the educational building by 35.8%.

3. The smallest amount of insulation of the cold attic of the educational building is 7.09 m^3 per 1 meter of the attic length. This amount of insulation is achieved when the thickness of the insulation on the attic floor is 320 mm, the height of the insulation of the outer wall along the outer surface is increased by 1 m and the surfaces of the internal capital walls are warmed to a height of 1.2 m from the bottom of the insulation of the attic floor.

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