



Insulation of Building Envelope Complicated Node Points

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Abstract

The article describes typical structural parts of building insulation, which significantly affect reduced thermal resistance. It analyzes flaws in calculation and construction of the described elements and provides further development of engineering calculation methods of building envelope when studying their difficult elements. Real values of linear heat transmission of building envelope difficult node points are calculated in the paper. It has been found that theoretical and experimental research of temperature and humidity conditions of difficult for thermal modernization structures (balconies, beam joints, cornices, foundation zones, thermally conductive inclusions etc.) enables the development of practical recommendations for avoiding localized condensation, mould growth, frost cracks. It is recommended to provide insulation continuity when developing energy efficient structural designs of building insulation.

Keywords: energy efficiency, building envelope, linear thermal bridges, total thermal resistance.

1. Introduction

The main approach to determining directions and methods of ensuring energy efficiency of public buildings and its harmonization with the European standards involves increasing accuracy of thermally insulated building envelope. Improvement of calculation methods of thermal insulation efficiency through studying temperature conditions of difficult elements of building envelope is a topical issue in the field of energy efficiency.

This research focuses on using and improving existing methodologies and algorithms for studying buildings and their parts in order to estimate the scale and sources of thermal energy losses with account of climatic and natural conditions in the area. The aim of the research is to perform optimization of temperature and humidity regime of building envelope for minimizing thermal failures.

Thermophysical research on building envelope was covered in the research papers [1, 2, 10, 12], there also were foreign researchers [3-5]. Some of the issues were dealt with by the researchers in the papers [6-9] as well.

When considering and designing energy efficient building envelope, we should consider structural features of all the node points of external envelope. This affects thermal properties of the whole building insulating envelope in the first place.

In Ukraine state construction standards, the effects of structural node points complexity on thermal insulating properties can only be taken into consideration when linear and point coefficients of heat transmission are calculated. However, the method for calculating linear and point coefficients shown in the Ukraine state standard ISO 10211-1:2005 contains some differences compared to the original document EN ISO 10211 – Thermal bridges and is quite complicated. It cannot be applied with general approach to every structurally complicated node points of the building envelope. Each node point should be considered and designed separately.

According to this method, alternative expression of total coefficient of thermal link $L_{i,j}$, in which linear and point coefficients of thermal transmission ψ and χ are used, is calculated by the formula:

$$L_{i,j} = \sum_{n=1}^N \chi_{n(i,j)} + \sum_{m=1}^M \psi_{m(i,j)} \cdot l_m + \sum_{k=1}^K U_{k(i,j)} \cdot A_k, \quad (1)$$

where $\chi_{n(i,j)}$ is a point heat transmission in the n -th part of the building;

$\psi_{m(i,j)}$ – linear transmission in the m -th part of the room or building;

l_m – the length to which $\psi_{m(i,j)}$ value is used;

$U_{k(i,j)}$ – heat transmission coefficient of the k -th part of the building;

A_k – the area, over which the $U_{k(i,j)}$ value applies;

N – the number of point transmission coefficients;

M – the number of linear transmission coefficients;

K – the number of heat transmission coefficients.

The value of linear thermal bridges is calculated by the formula:

$$\psi = L_{2D} - \sum_{j=1}^{N_j} U_j \cdot l_j, \quad (2)$$

L_{2D} – thermal coupling coefficient of the two-dimensional calculation component, which separates the two environments under study;

U_j – thermal transmittance of the 1-D component, j , which separates the two environments under study;

l_j – the length over which the U_j value applies.

The value of point thermal bridges is calculated by the formula:

$$\chi = L_{3D} - \sum_{i=1}^{N_i} U_i \cdot A_i - \sum_{j=1}^{N_j} \psi_j \cdot l_j, \quad (3)$$

L_{3D} – thermal coupling coefficient of the three-dimensional calculation component, which separates the two environments under study;

U_i – the thermal transmittance of the 1-D component, i , which separates the two environments under study;

A_i – the area over which the U_i value applies;

ψ_j – linear heat transmittance;

l_j – the length over which ψ_j applies;

j – the number of two-dimensional components;

i – the number of one-dimensional components.

2. Main body

For experimental research it was suggested to calculate linear and point coefficients of heat transmission for several types of structurally complicated node points models of external building envelope with thermally-conductive inclusions.

One of the types of constructional units under consideration were node points of one of the external walls of a real building made of light steel thin-walled structures in Poltava. Structural schemes of the node points are shown on figures 1-6, each of them includes the following materials:

1 – base reinforcement layer (CERESIT CT-190); glass-cloth sheet; quartz primer; decorative plaster (CERESIT CT-35); facade paint (CERESIT CT-42); total thickness of the layer is 10 mm; $\lambda(B)=0,27$ W/m·K;

2 – insulant (ТЕХНОФАС ЭФФЕКТ 1200×600×50 mm): 50 mm; $\rho=135$ kg/m³; $\lambda(B)=0,042$ W/m·K;

3 – polymer adhesive for thermal covering (CERESIT CT-190): 2 mm; $\lambda(B)=0,30$ W/m·K;

4 – OSB-3 board: 12 mm; $\lambda(B)=0,10$ W/m·K;

5 – metal frame (profile C152,4×50,8×1,5; $t=1,5$ mm);

6 – insulant (ТЕХНОБЛОК СТАНДАРТ 1200×600×50 mm): 150 mm; $\rho=45$ kg/m³; $\lambda(B)=0,043$ W/m·K;

7 – vapor barrier (JUTA R110);

8 – counter batten: double S profile $h=40$ mm, $t=0,7$ mm – for calculations we used insulator (ТЕХНОФАС ЭФФЕКТ 1200×600×50 mm): 40 mm; $\rho=135$ kg/m³; $\lambda(B)=0,042$ W/m·K;

9 – 2 layers of gypsum plasterboard: 12,5×2=25 mm; $\rho=800$ kg/m³; $\lambda(B)=0,21$ W/m·K.

The first node point for calculation was an **intermediate node point** (№1) (Fig. 1): thermal inclusion is a metal post – C-shaped profile sized 152,4x50,8x1,5 mm, with 1,5 mm thickness. Effective length of the experimental sample on the internal surface of the wall was taken as 1m. The width of the thermal inclusion was 50 mm.

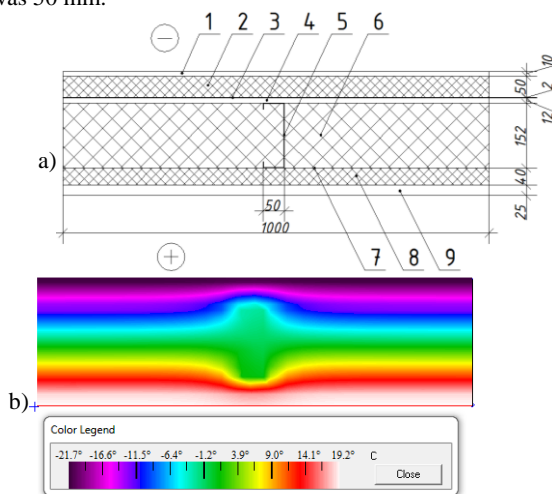


Fig. 1: Node point №1: a) structural scheme;b) node point thermal field. The second node point for calculation was a **coupled intermediate node point** (№2) (Fig. 2): its thermal inclusions are coupled metal posts – two C-shaped profiles with a size of

152,4x50,8x1,5 mm, thickness 1,0 mm, connected wall to wall with self-tapping screws.

Effective length of the experimental sample on the internal surface of the wall was equal to 1 m. The width of the thermal inclusion was 100 mm.

The next experimental node point was a **corner node point** (№3) (fig. 3): thermal inclusions in it were three metal posts: three C-shaped profiles sized 152,4x50,8x1,5 mm, with 1,0 mm thickness, connected together by means of self-tapping screws according to the construction solution of the node point structure. Effective length of the experimental sample on the internal surface of the wall was equal to 1 m. The width of the thermal inclusion on the corner cannot be measured on the wall internal surfaces since all metal inclusions are in the geometric plane, which does not intersect the internal surface of the external wall. This node point has point thermally conductive inclusion.

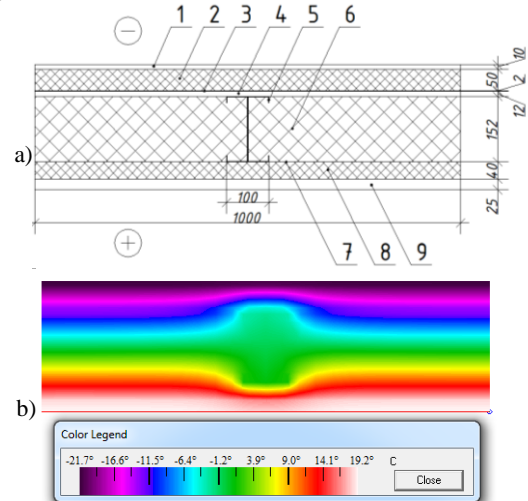
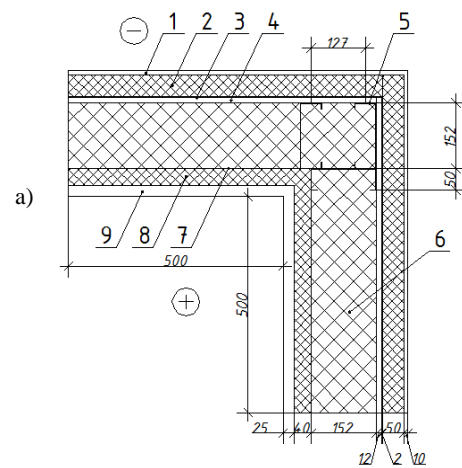


Fig. 2: Node point №2: a) structural scheme;b) node point thermal field.



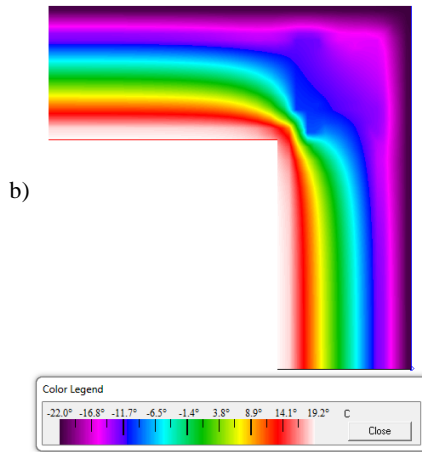


Fig. 3: Node point №3: a) structural scheme;b) node point thermal field

According to the method of point thermal transmittance coefficient of EN ISO 10211 – Thermal bridges, it is necessary to perform three-dimensional thermal model testing of such structural nodes. As visual software tools used for modelling the nodes did not have 3-D modelling options, such types of node points calculations were performed backward: with known values of thermal characteristics of building envelope homogeneous areas, the density of the heat flow rate was measured in the point of thermally-conductive inclusion.

At set heat flow rate density q_{com} W/m², which passes through the building envelope with thermally conductive inclusion, the average value of the heat flow density, which passes through the thermally conductive inclusion $\overline{q_{m6}}$ is calculated by the formula:

$$\overline{q_{m6}} = q_{3az} - (\overline{q_1} + \overline{q_2} + \dots + \overline{q_n}) \tag{4}$$

where $\overline{q_1}, \overline{q_2}, \dots, \overline{q_n}$ are average values of heat flow rate density in the 1st, 2nd, ..., nth thermally homogeneous areas of the node point, W/m². One of the experimental node points was the **node of internal and external walls connection (№4)** (fig. 4): there, thermal inclusions were three metal posts – two C-shaped profiles sized 152,4x50,8x1,5 mm, with 1,0 mm thickness and one C-shaped profile sized 102,2x50,8x1,5 mm, with 1,0 mm thickness, connected together by means of self-tapping screws according to the construction solution for the node. Effective length of the experimental sample on the internal surface of the wall was equal to 1 m. This node has point thermally conductive inclusion.

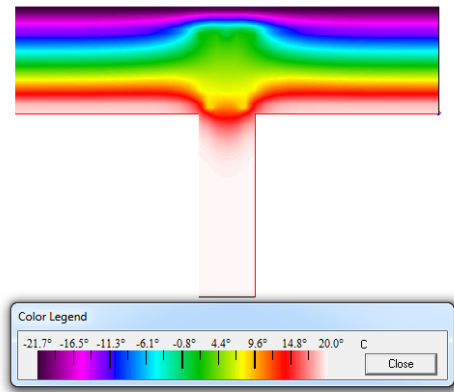
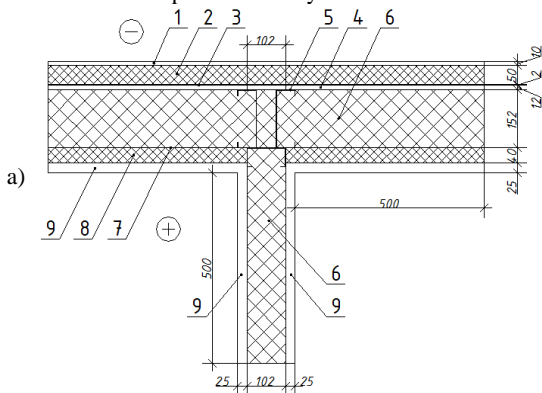


Fig. 4: Node point №4: a) structural scheme;b) node point thermal field.

Window node point (fig. 5) in the experimental study was divided into two separate nodes: the upper node, window header (**node point №5**) and the lower node – apron and side parts of a window or a door aperture (**node point №1**). Construction solution on the lower node point was similar to the intermediate one, so there were no separate calculations, and the research results were the same as for the intermediate node point. Reinforcement with light steel thin-walled profiles was made over apertures of doors and windows, so for such node points thermal inclusions were two C-shaped profiles sized 152,4x50,8x1,5 mm, with 1,0 mm thickness and two U-shaped profiles sized 152,4x50,8 mm, with 1,0 mm thickness, connected by means of self-tapping screws according to the construction solution for the node. Effective length of the experimental sample on the internal surface of the wall was equal to 1 m. The width of thermal inclusion was 154 mm.

Another node point was the node of the **floor slab connection with the external wall (№6)** (fig. 6): thermal inclusions in the node point were two U-shaped profiles sized 152,4x50,8 mm, with 1,0 mm thickness, connected by means of self-tapping screws according to the construction solution for the node. Effective length of the experimental sample on the internal surface of the wall was equal to 1 m. This node has point thermally conductive inclusion.

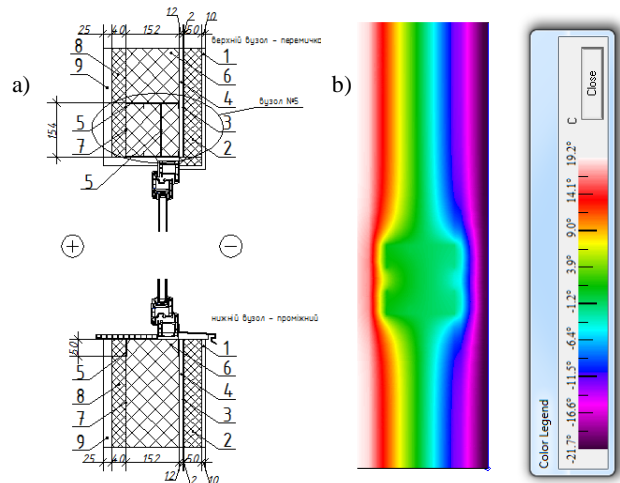


Fig. 5: Node point №5: a) structural scheme; b) node point thermal field.

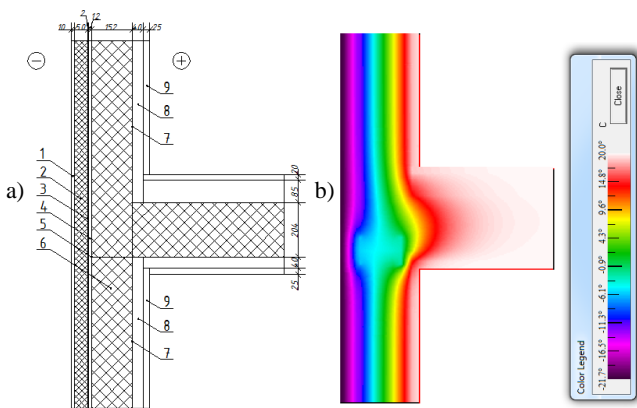


Fig. 6: Node point №6: a) structural scheme; b) node point thermal field.

The received values of the linear thermal transmittance of the wall node points with light steel thin-walled structures are shown in table 1.

Table 1: Values of the linear thermal transmittance of the wall node points with light steel thin-walled structures

| Node point № | №1 | №2 | №3 | №4 | №5 | №6 |
|---------------------------------|-------|-------|-------|-------|-------|-------|
| $\Psi (\lambda), W/(m \cdot K)$ | 0,016 | 0,033 | 0,057 | 0,035 | 0,057 | 0,018 |

Probabilistic analysis of the main thermal properties of light steel thin-walled constructions with changes in physical characteristics were also conducted in the research papers [11, 13, 14].

This paper also handles a **parapet of the built-up roof node point** (fig. 7). The structure consists of:

- 1 – brick wall;
- 2 – adhesive layer for adhesion of insulation panels to the base and for surface smoothing;
- 3 – thermal insulation layer (mineral wool);
- 4 – reinforcement fiberglass mesh;
- 5 – multilayer bonding plaster;
- 6 – reinforced concrete floor slab;
- 7 – roll vapor barrier;
- 8 – thermal insulation layer (mineral wool), 250 mm;
- 9 – two layers of roofing felt;
- 10 – thermal insulation layer (mineral wool), 100 mm;
- 11 – sheet steel;
- 12 – treated board.

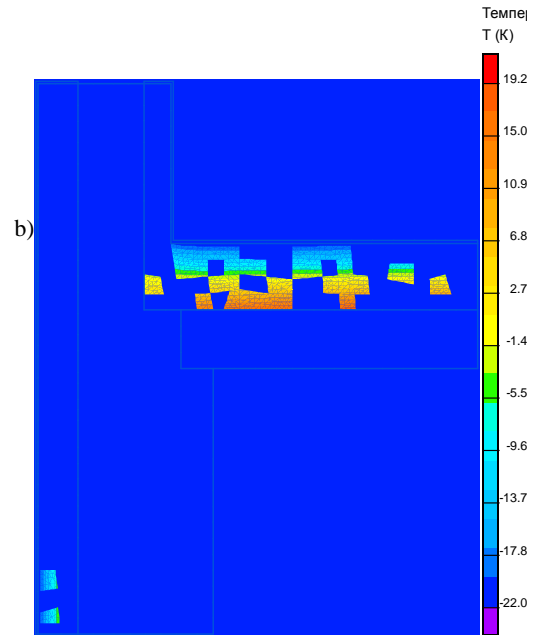
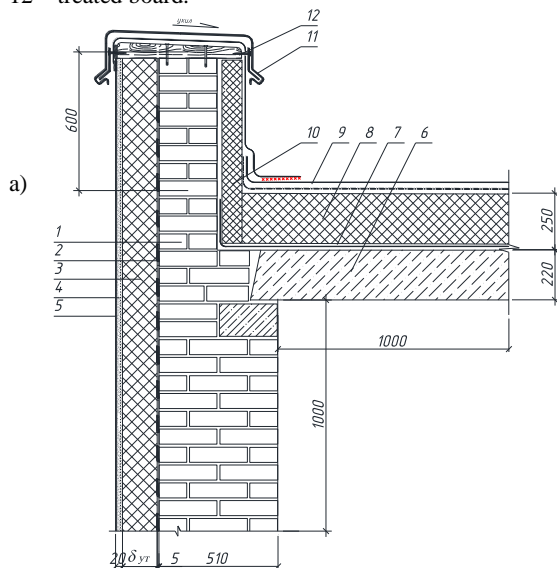


Fig. 7: parapet of the built-up roof node point: a) structural scheme; b) node point thermal field

Calculation example. The brick wall thickness is 510 mm, the external wall insulator thickness is 150 mm, built-up roof thickness is 250 mm, the parapet is 100 mm, thermal transmittance of insulation is 0,04 W/(m · K).

Linear thermal transmittance is calculated by the formula (2);

$$\psi_1 = L^{2D} - \sum_{i=1}^j U_j \cdot l_j = 0,618 - (0,2184 \times 1 + 0,1521 \times 1) = 0,248 W/(m \cdot K),$$

where L^{2D} is thermal coupling linear coefficient, W/K, calculated by the formula

$$L^{2D} = \frac{Q_{com}}{t_b - t_3} = \frac{25,966}{20 - (-22)} = 0,618 W/K,$$

where Q_{com} is the heat flow, which passes through the calculation area of the building envelope with thermally conductive inclusion, m, W, calculated based on the results of two-dimensional thermal field calculation (fig. 7b);

$$Q_{com} = 25,966 W,$$

t_b, t_3 – temperature, °C, of the internal and external air accordingly.

The calculation is carried out for a residential house located in the Ist temperature zone as specified in Ukraine state construction standards B.2.6-31:2016 Thermal insulation of buildings, $t_b = 20$ °C;

$$t_3 = -22$$
 °C;

U_j is the thermal transmittance coefficient of a one-dimensional part, W/(m² · K), which divides two environments under study, by the formula:

$$U_1 = \frac{1}{R_{\Sigma 1}} = \frac{1}{4,579} = 0,2184 W/(m^2 \cdot K),$$

where $R_{\Sigma 1}$ is thermal resistance of thermally homogeneous part of the external wall structure, m² · K/W, calculated by the formula:

$$R_{\Sigma 1} = \frac{1}{\alpha_b} + \sum_{i=1}^n R_i + \frac{1}{\alpha_3} = \frac{1}{\alpha_b} + \frac{\delta_1}{\lambda_{1p}} + \frac{\delta_2}{\lambda_{2p}} + \frac{\delta_3}{\lambda_{3p}} + \frac{\delta_4}{\lambda_{4p}} + \frac{\delta_5}{\lambda_{5p}} + \frac{1}{\alpha_3} = \frac{1}{8,7} + \frac{0,02}{0,81} + \frac{0,51}{0,81} + \frac{0,005}{0,93} + \frac{0,15}{0,04} + \frac{0,01}{0,93} + \frac{1}{23} = 4,579 m^2 \cdot K/W,$$

where $\delta_1, \delta_2, \delta_3, \delta_4, \delta_5$ is the thickness of plaster, brick, adhesive mixture, insulator and decorative plaster accordingly, m;

$\lambda_{1p}, \lambda_{2p}, \lambda_{3p}, \lambda_{4p}, \lambda_{5p}$ is thermal transmittance of plaster, brick, adhesive mixture, insulator and decorative plaster accordingly, W/(m · K);

α_B , α_3 is the coefficient of internal and external surfaces heat transfer of the building envelope, $W/(m^2 \cdot K)$, the values of which are used as specified in state construction standards B.2.6-31:2016;

$\alpha_B = 8,7 W/(m^2 \cdot K)$; $\alpha_3 = 23 W/(m^2 \cdot K)$;

l_1 is the length, m, over which the U_1 value applies.

$l_1 = 1 m$.

$U_2 = \frac{1}{R_{\Sigma cci}} = \frac{1}{6,575} = 0,1521 W/(m^2 \cdot K)$,

where $R_{\Sigma cci}$ is thermal resistance of thermally homogeneous part of the built-up roof structure, $m^2 \cdot K/W$, calculated by the formula:

$$R_{\Sigma cci} = \frac{1}{\alpha_B} + \sum_{i=1}^n R_i + \frac{1}{\alpha_3} = \frac{1}{\alpha_B} + \frac{\delta_1}{\lambda_{1p}} + \frac{\delta_2}{\lambda_{2p}} + \frac{\delta_3}{\lambda_{3p}} + \frac{1}{\alpha_3} =$$

$$= \frac{1}{8,7} + \frac{0,22}{2,04} + \frac{0,25}{0,04} + \frac{0,01}{0,17} + \frac{1}{23} = 6,575 m^2 \cdot K/W,$$

where δ_1 , δ_2 , δ_3 is the thickness of reinforced concrete slab, insulator and roofing felt accordingly, m;

λ_{1p} , λ_{2p} , λ_{3p} is thermal transmittance reinforced concrete slab, insulator and roofing felt accordingly, $W/(m \cdot K)$;

α_B , α_3 is the coefficient of internal and external surfaces heat transfer of the building envelope, $W/(m^2 \cdot K)$, $\alpha_B = 8,7 W/(m^2 \cdot K)$; $\alpha_3 = 23 W/(m^2 \cdot K)$;

l_2 is the length, m, over which the U_2 value applies.

$l_2 = 1 m$.

For the build-up roof parapet node point we calculated linear thermal transmittance according to parameters of thermal insulation layer. The results are shown in Table 2.

Table 2: Values of linear thermal transmittance of the build-up roof parapet node point

| Effective thermal transmittance, $W/(m \cdot K)$ | Thickness of thermal insulation layer of the external wall insulator, δ_{ins} | | |
|--|--|--------|--------|
| | 120 mm | 150 mm | 180 mm |
| 0,035 | 0,245 | 0,241 | 0,237 |
| 0,040 | 0,252 | 0,248 | 0,243 |
| 0,045 | 0,259 | 0,254 | 0,249 |

Theoretical and experimental research on temperature and humidity conditions of structures that are difficult for thermal modernization (balconies, beam joints, cornices, foundation zones, thermally conductive inclusions etc.) will allow to develop practical recommendations for avoiding localized condensation, mould growth, frost cracks.

Research results (methods of energy efficient solutions for thermal building envelope difficult elements, their new construction solutions, innovational methods for enhancing energy efficiency of the buildings) will decrease the dependence of Ukraine on the countries-providers of fuel and energy resources and reduce the energy intensity of national products by means of energy economy. The term of Ukraine economic crisis recovery largely depends on energy efficiency.

3. Conclusions

The conducted research enables us to come to the following conclusions:

- 1) typical structural components of building envelope thermal insulation which significantly affect total thermal resistance have been identified;
- 2) the analysis of calculation and construction flaws of the mentioned elements has been conducted;
- 3) further development of engineering methods of building envelope calculation when studying their difficult parts has been specified;
- 4) real values of linear thermal transmittance coefficients for difficult structural node points of external envelopes have been obtained.

It is recommended to provide insulation continuity when developing energy efficient construction solutions of building envelope insulation. Social and economic effect can be significant and according to preliminary estimates energy consumption of buildings will be reduced 10 to 50 %; the switch to optimal energy consumption models will ensure a higher level of life quality with minimization of thermal failures.

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