Analysis of Influence of Metal Elements of Window and Door Openings in Brick Walls on the Temperature of the Interior Plain of a Wall at the Place of Their Installation

Oleksandr Semko, Olena Filonenko, Oleg Yurin, Petro Sankov, and Nataliia Mahas

Abstract Renovation of buildings often requires the building of window and door openings in the exterior walls. The lintel over the slot is most often made of metal angles that are installed on the edges of the slot. The metal angles are connected by bandages or laths. Horizontal angle legs are connected by metal laths and are established at certain pitches. Metal structures, due to their high thermal conductivity, reduce heat transmission resistance in the place of their application. This leads to a decrease in the temperature of the slope surface on the interior side of the wall and the deterioration in the humidity conditions of this part of the wall. Condensate forms on the slope, if its temperature is below the dew point, in such cases wall material moistens, and mould and fungus form there. The article examines the influence on the slope temperature of the pitch and thickness of the metal laths connecting metal angles, the location of filling the slots with transom bars of windows and/or doors (near the inner and outer surfaces of the wall), the insulation of the slope on the outer side of the enclosure. The authors have proposed methods of avoiding moisture condensation on the slope on the inner side of the wall.

Keywords Heat flow · Insulation · Temperature fields · Window and door openings in brick walls

1 Introduction

Renovation of buildings often requires the building of window and door openings in the exterior walls. The lintel over the slot is most often made of metal angles that are installed on the edges of the slot. The metal angles are connected by bandages or laths. Horizontal angle legs are connected by metal laths and are established at

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certain pitches. Metal structures, due to their high thermal conductivity, reduce heat transmission resistance in the place of their application. This leads to a decrease in the temperature of the slope surface on the interior side of the wall and the deterioration in the humidity conditions of this part of the wall. Moisture accumulates in the enclosure and reduces its heat-insulation properties at the point of use of metal structures. The question of the influence of metal elements on humidity conditions was studied in Ref. [1]. Studies of the influence of heat-conducting inclusions on heat-protective qualities and moisture resistance of external enclosing structures are presented in Refs. [2–5]. Decreasing the temperature of the slope surface, located on the inner side of the room, may also lead to negative consequences. Condensate forms on the slope, if its temperature is below the dew point, in such cases wall material moistens, and mould and fungus form there. Therefore, the study of the influence of metal elements of transom bars on the temperature of the slope surface is relevant. The article examines the influence on the slope temperature of the pitch and thickness of the metal laths connecting metal angles, the location of filling the slots with transom bars of windows and/or doors (near the inner and outer surfaces of the wall), the insulation of the slope on the outer side of the enclosure [6–11]. The authors have proposed methods of avoiding moisture condensation on the slope on the inner side of the wall.

2 Selection of Bench-Mark Data and the Range of Variables for Performing Analysis

The studies were performed for the first temperature zone. The design room air temperature was taken as for a residential building $t_{ind} = 20$ °C, the calculated outside temperature was taken as $t_{out} = -22$ °C (1st temperature zone, [12]). The thickness of the brick wall was 0.25, 0.38, and 0.51 m. The wall was insulated on the outside with a layer of mineral wool with a density of 125 kg/m^3. The thickness of the layer of mineral wool was determined by thermotechnical calculation and was equal to 0.14 m at the 0.25 m thickness of the layer of brickwork, and it was equal to 0.13 m at the thickness of 0.38 and 0.51 m. 75 × 8 metal angles and 60 mm wide laths were used to arrange the slot. The thickness of the laths was taken from 4 to 10 mm, and the pitch of the slots was taken from 300 to 1500 mm.

The research was performed using calculations of temperature fields. The design model of the enclosing structure for the calculation of temperature fields is shown in Fig. 1 [13, 14].

Characteristics of the layers of the enclosing structure are given in Table 1. The numbering of the layers is done from the inner surface of the enclosing structure.

The thermal conductivity of the area, where the batten plate is located, was determined by the following formula:

$$\lambda = \frac{\lambda_{met} \cdot b_{met} + \lambda_{cem} \cdot b_{cem}}{b_{met} + b_{cem}} \tag{1}$$

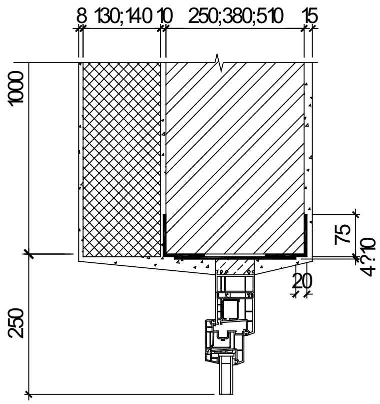

Fig. 1 The design model of the enclosing structure

Table 1 Characteristics of the layers of the enclosing structure

Name	Thickness, m	Thermal conductivity, W/(m · K)
Sand-lime mortar	0.015	0.81
Brick	0.25; 0.38; 0.51	0.81
Adhesive mixture	0.01	0.93
Insulation	0.13; 0.14	0.049
Finishing layer	0.008	0.93

where λ_{met}, λ_{cem}—thermal conductivity, W/(m · K), respectively, of the metal lath and cement-sand mortar $\lambda_{met} = 58$ W/(m · K); $\lambda_{cem} = 0.93$ W/(m · K), b_{met}, b_{cem}—width, m, respectively, of metal lath and cement-sand mortar between the laths.

The width of the cement-sand mortar between metal laths is determined by the formula:

$$b_{cem} = k - b_{met} \tag{2}$$

where k is the pitch of laths, m.

Thus, at the pitch of laths 0.3 m and at 0.06 m width of laths, the thermal conductivity of a place of the enclosure, where the batten plate is located, shall make:

$$\lambda = \frac{\lambda_{met} \cdot b_{met} + \lambda_{cem} \cdot b_{cem}}{b_{met} + b_{cem}} = \frac{58 \cdot 0{,}06 + 0{,}93 \cdot 0{,}24}{0{,}006 + 0{,}24} = 12,344\,\mathrm{W/(m \cdot K)} \tag{3}$$

$$b_{cem} = k - b_{met} = 0{,}3 - 0{,}06 = 0,24\,\mathrm{m} \tag{4}$$

3 Analysis of the Impact of the Pitch and Thickness of Metal Laths, Connecting Metal Angle, on the Temperature Along the Inner Surface of the Slope

Figures 2, 3 and 4 show the temperature fields of the calculated section of the wall with the thickness of 0.25 m at the thickness of batten plates from 2 to 10 mm (every 2 mm) and their pitches of 300 mm, 600 m and 900 mm respectively. For illustrative purposes, the temperature fields are shown only in the location of the reinforcing elements, not of the whole design model.

If the temperature of the slope surface, located on the inner side of the enclosure below the dew point decreases, condensate is formed on it, which moistens the enclosure near the condensation zone. Humidification of enclosure material reduces heat transmission resistance of this area, which, in turn, leads to an even greater decrease in the temperature of the slope surface. In addition, the inner finishing layer of enclosure structures may peel off on damp inner surfaces of enclosure structures, as well as there may occur the formation of mould and fungus, which worsens the sanitary and hygienic conditions, and in some cases leads to diseases.

At $t_{ind} = 20$ °C and $\varphi_{ind} = 55\%$, the dew point temperature will be $t_{dew} = 10.7$ °C.

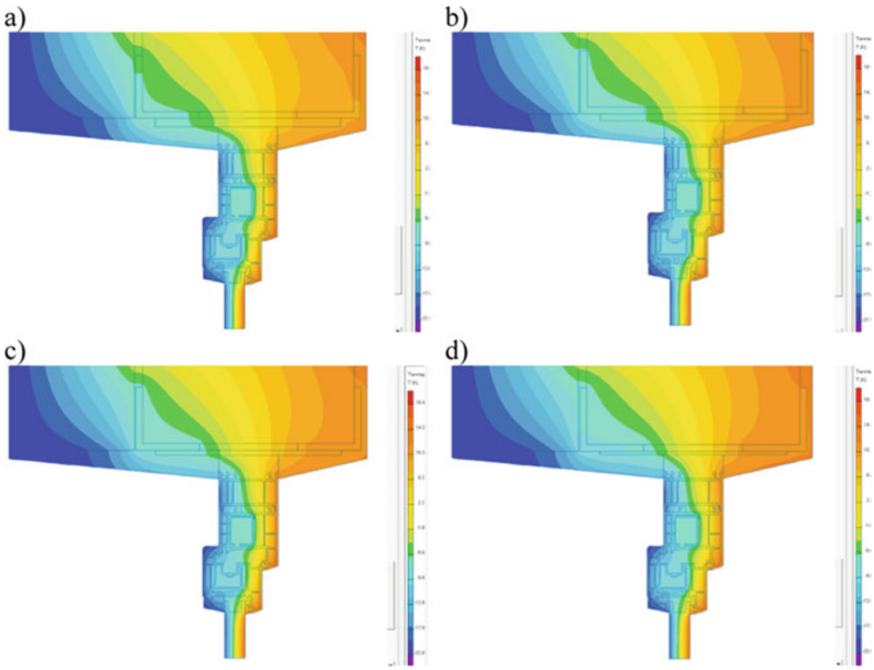

Fig. 2 Temperature fields of the wall with the thickness of 0.25 m, with a 300 mm pitch of batten plates and their thickness: **a** 10 mm; **b** 8 mm; **c** 6 mm; **d** 4 mm

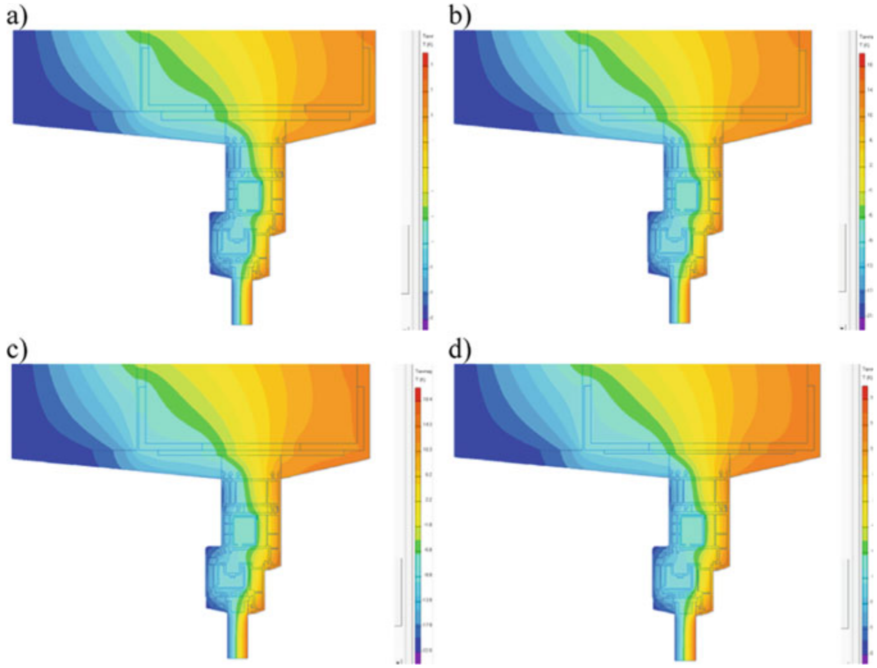

Fig. 3 Temperature fields of the wall with the thickness of 0.25 m, with a 600 mm pitch of batten plates and their thickness: **a** 10 mm; **b** 8 mm; **c** 6 mm; **d** 4 mm

Figure 5 shows temperature curves on the slope surface of the wall with the thickness of 0.25 m, at the thickness of batten plates from 2 to 10 mm, and at their 300 mm pitch.

Figure 6 shows temperature curves on the slope surface of the wall 0.25 m in thickness, at the thickness of batten plates from 2 to 10 mm and at their 600 mm pitch.

Figure 7 shows temperature curves on the slope surface of the wall 0.25 m in thickness, at the thickness of batten plates from 2 to 10 mm, and at their 900 mm pitch.

Temperature curves on the inner surface of the wall (Figs. 5, 6 and 7) start from the junction of the slope surface with the structure of the filling of the window aperture or doorway and end at the upper edge of the inner surface of the calculation area. The minimum temperature is observed at the beginning of the temperature curve at the junction of the slope surface with the slot filling structure.

The minimum slope surface temperature of the 0.25 m thick wall, with the thickness of batten plates from 4 to 10 mm and their pitch from 300 to 900 mm are given in Table 2.

Figure 8 shows graphs of the dependence of the minimum temperature on the inner surface of the enclosure from the pitch of the laths at different thicknesses, for a brick wall of 0.25 m thick.

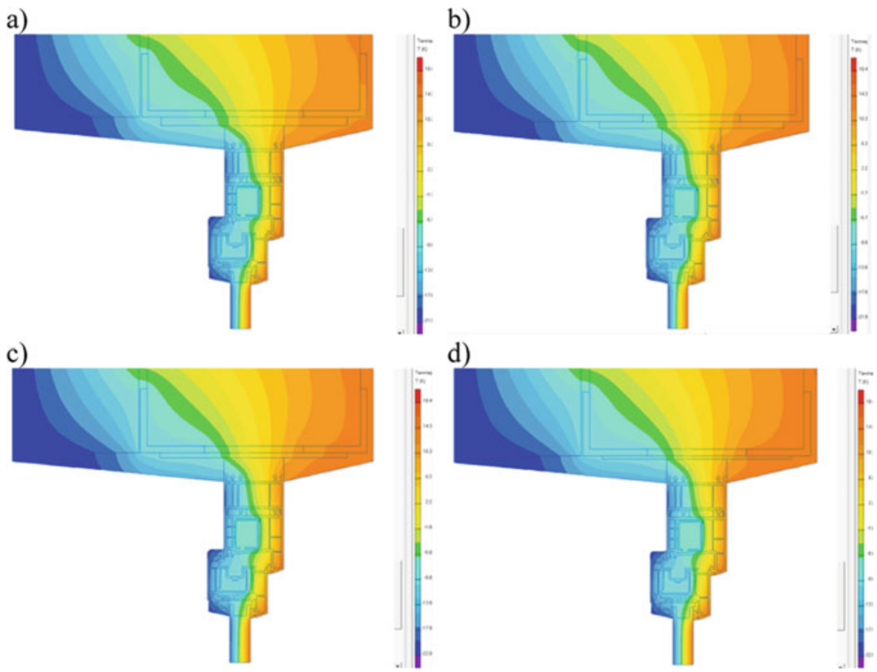

Fig. 4 Temperature fields of the wall with the thickness of 0.25 m, with a 900 mm pitch of batten plates and their thickness: **a** 10 mm; **b** 8 mm; **c** 6 mm; **d** 4 mm

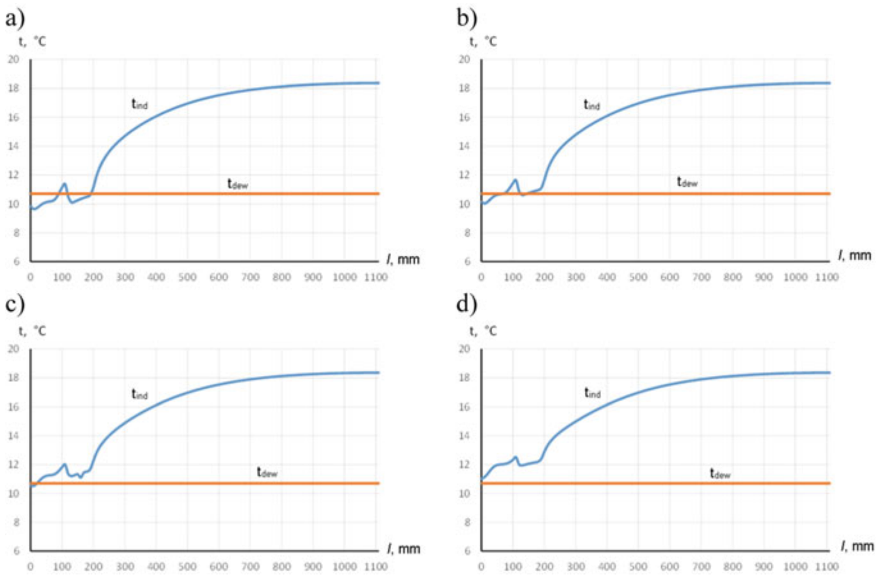

Fig. 5 Temperature curves on the slope surface of the wall 0.25 m in thickness, with a 300 mm batten plate pitch and at their thickness: **a** 10 mm; **b** 8 mm; **c** 6 mm; **d** 4 mm

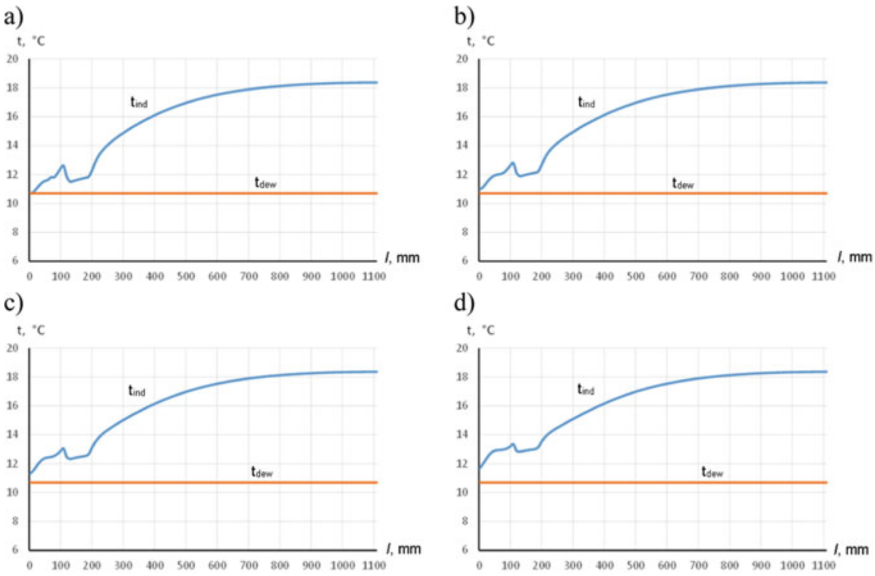

Fig. 6 Temperature curves on the slope surface of the wall 0.25 m in thickness, with a 600 mm batten plate pitch and at their thickness: **a** 10 mm; **b** 8 mm; **c** 6 mm; **d** 4 mm

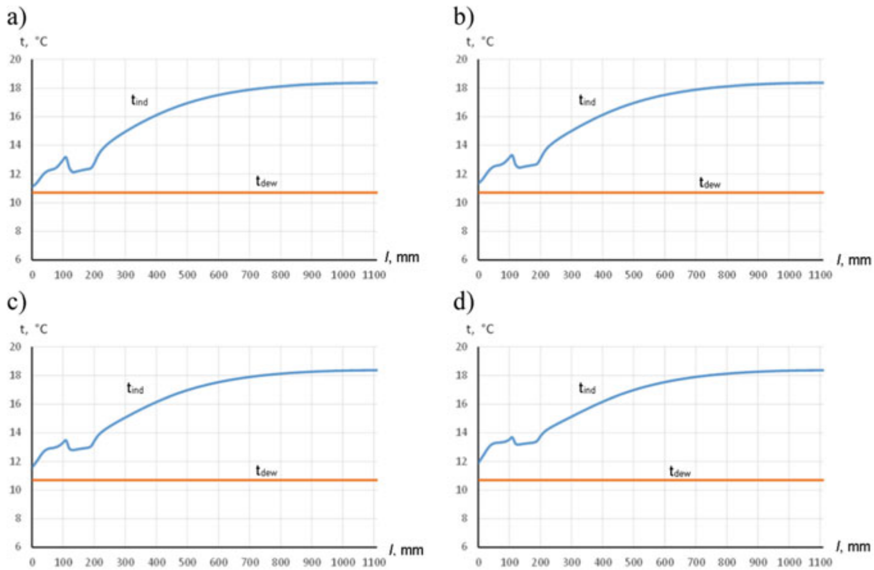

Fig. 7 Temperature curves on the slope surface of the wall 0.25 m in thickness, with a 900 mm batten plate pitch and at their thickness: **a** 10 mm; **b** 8 mm; **c** 6 mm; **d** 4 mm

Table 2 The minimum slope surface temperature of the 0.25 m thick wall

The pitch of the laths	Minimum slope surface temperature, °C at the thickness of the batten plate			
	10	8	6	4
300	9.6	10	10.5	11
600	10.7	11	11.3	11.6
900	11.1	11.3	11.6	11.9

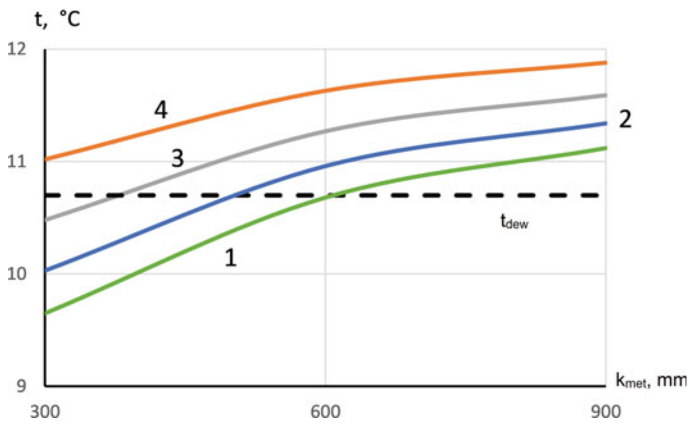

Fig. 8 Graphs of the dependence of the minimum temperature on the inner surface of the slope of the 0.25 m thick wall thickness on the pitch of the laths at their thickness: 1. 10 mm, 2. 8 mm, 3. 6 mm, 4. 4 mm

As can be seen from the graphs, the minimum temperature on the inner slope surface of the wall is higher than the dew point at:

- the lath thickness of 10 mm and their pitches more than 600 mm;
- the lath thickness of 8 mm and their pitches more than 500 mm;
- the lath thickness of 6 mm and their pitches more than 370 mm;
- the lath thickness of 4 mm and their pitches more than 300 mm.

Similar studies were performed for 0.38 and 0.51 m thick walls. For these wall thicknesses, the thickness of the insulation was specified, as well as the thermal conductivity of the area, where the batten plate is located.

The minimum slope surface temperature of the 0.38 m thick wall, with the thickness of the batten plates from 4 to 10 mm and their pitch from 300 to 1200 mm are given in Table 3.

Figure 9 shows graphs of the dependence of the minimum temperature on the inner surface of the enclosure on the lath pitch at their different thicknesses, for a brick wall of 0.38 m in thickness.

Table 3 The minimum slope surface temperature of the 0.38 m thick wall

The pitch of the laths	Minimum slope surface temperature, °C at the thickness of the batten plate			
	10	8	6	4
300	8.8	9.1	9.4	9.9
600	9.6	9.9	10.1	10.5
900	10	10.2	10.4	10.7
1200	10.2	10.4	10.6	10.8

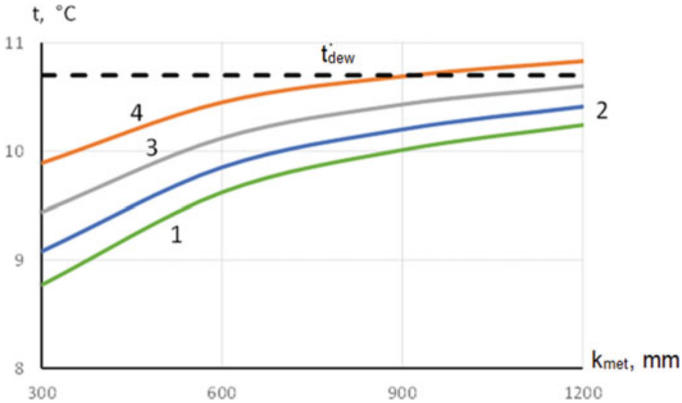

Fig. 9 Graphs of the dependence of the minimum temperature on the inner slope surface of the wall 0.38 m in thickness on the lath pitch at their thickness: 1. 10 mm, 2. 8 mm, 3. 6 mm, 4. 4 mm

As can be seen from the graphs, the minimum temperature on the inner surface of the enclosure is higher than the dew point temperature only when the thickness of the laths is 4 mm and their pitch is more than 900 mm. At other thicknesses of batten plates, the minimum slope surface temperature will be lower than a dew point at the lath pitch up to 1200 mm. In all cases, the minimum surface temperature increases with increasing the lath pitch. It is inexpedient to increase the lath pitch by more than 1200 mm, as an increase in the minimum temperature will be insignificant.

The minimum slope surface temperature of the wall 0.51 m in thickness, at the thickness of batten plates from 2 to 10 mm, and their pitch from 300 to 1500 mm is given in Table 4.

Figure 10 shows graphs of the dependence of the minimum temperature on the inner surface of the enclosure on the lath pitch at their different thicknesses, for a brick wall with the thickness of 0.51 m.

As can be seen from the graphs, the minimum temperature on the inner surface of the enclosure is lower than the dew point temperature in all cases. It is inexpedient to increase the lath pitch by more than 1500 mm for constructive reasons.

Table 4 The minimum slope surface temperature of the 0.51 m thick wall

The pitch of the laths	Minimum slope surface temperature, °C at the thickness of the batten plate				
	10	8	6	4	2
300	8.2	8.5	8.8	9.3	9.9
600	9	9.2	9.5	9.9	10.3
900	9.4	9.6	9.8	10.1	10.4
1200	9.6	9.8	10	10.3	10.5
1500	9.8	10	10.1	10.4	10.6

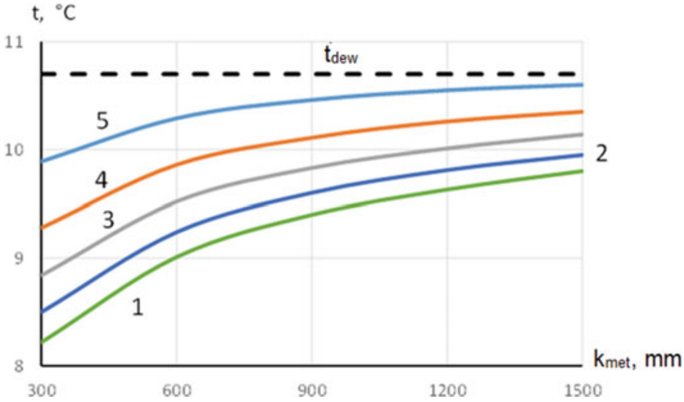

Fig. 10 Graphs of the dependence of the minimum temperature on the inner slope surface of the wall 0.51 m in thickness on the lath pitch at their thickness: 1. 10 mm, 2. 8 mm, 3. 6 mm, 4. 4 mm, 5. 2 mm

4 Analysis of Possible Ways to Increase the Minimum Temperature of the Slope Surface

The lowest temperature on the slope surface is observed at the wall thickness of 0.51 m with the use of batten plates 10 mm in thickness and their pitch of 300 mm. Therefore, in subsequent studies, we have considered this option.

To increase the temperature of the slope surface above the dew point, some methods, described in Ref. [1], were considered, namely:

- displacement of the slot filling with transom bars of windows (doors) to the inner surface of the wall;
- displacement of the slot filling with transom bars of windows (doors) to the outer surface of the wall;
- insulation of the slope on the outside from the slot filling with a layer of insulation 10 mm thick.

Figure 11 shows design models and their temperature fields when shifting the slot filling with transom bars of windows (doors) to the inner surface of the wall (a, b), when shifting the slot filling with transom bars of windows (doors) to the outer surface of the bricklayer of the wall (c, d), when insulating the slope on the outside from the slot filling with a layer of 10 mm thick insulation (e, f).

Graphs of temperature distribution on the slope surface are shown in Fig. 12 when shifting the slot filling with transom bars of windows (doors) to the inner surface of the wall (a), when shifting the slot filling with transom bars of windows (doors) to the outer surface of the bricklayer of the wall (b), when insulating the slope on the outside from the slot filling with a layer of 10 mm thick insulation (c).

When shifting the slot filling with transom bars of windows (doors) to the inner surface of the wall, the minimum slope temperature is $\tau_{ind.min} = 1.4$ °C, which is 9.4 below the dew point.

When shifting the slot filling with transom bars of windows (doors) to the outer surface of the bricklayer of the wall, the minimum slope temperature will be $\tau_{ind.min} = 12$ °C, which is 1.3 °C above the dew point.

When insulating the slope on the outside from the slot filling with a layer of 10 mm thick insulation, the minimum slope temperature will be $\tau_{ind.min} = 11.7$ °C, which is 1 °C above the dew point.

5 Conclusions

The performed research allows us to draw the following conclusions:

1. When increasing the pitch of batten plates, the minimum temperature on the inner slope surface of the wall increases too.
2. As the thickness of the batten plates decreases, the minimum temperature on the inner slope surface of the wall increases.
3. When increasing the wall thickness, the minimum temperature on the inner slope surface of the wall decreases.

When the thickness of the brick part of the wall is 0.25 m, the minimum temperature on the inner slope surface of the wall will be higher than the dew point at:

(a) 10 mm thickness of the batten plates and their step more than 600 mm;
(b) 8 mm thickness of the batten plates and their step more than 500 mm;
(c) 6 mm thickness of the batten plates and their step more than 370 mm;

4. When the thickness of the brick part of the wall is 0.38 m, the minimum temperature on the inner slope surface of the wall will be higher than the dew point temperature only when the thickness of the batten plates is 4 mm, and their step is more than 900 mm.

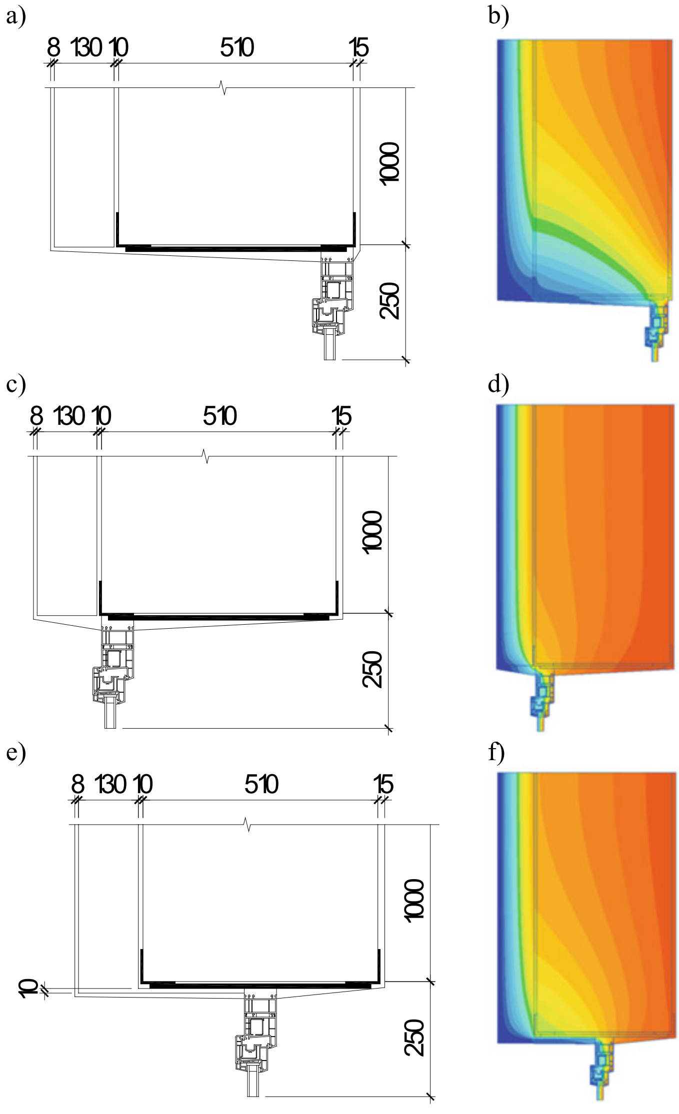

Fig. 11 Design models and their temperature fields when shifting the slot filling with transom bars of windows (doors) to the internal surface of a wall (**a**, **b**), when shifting the slot filling with transom bars of windows (doors) to the external surface of a bricklayer of a wall (**c**, **d**), when insulating the slope on the outside from the slot filling with a layer of 10 mm thick insulation (**e**, **f**)

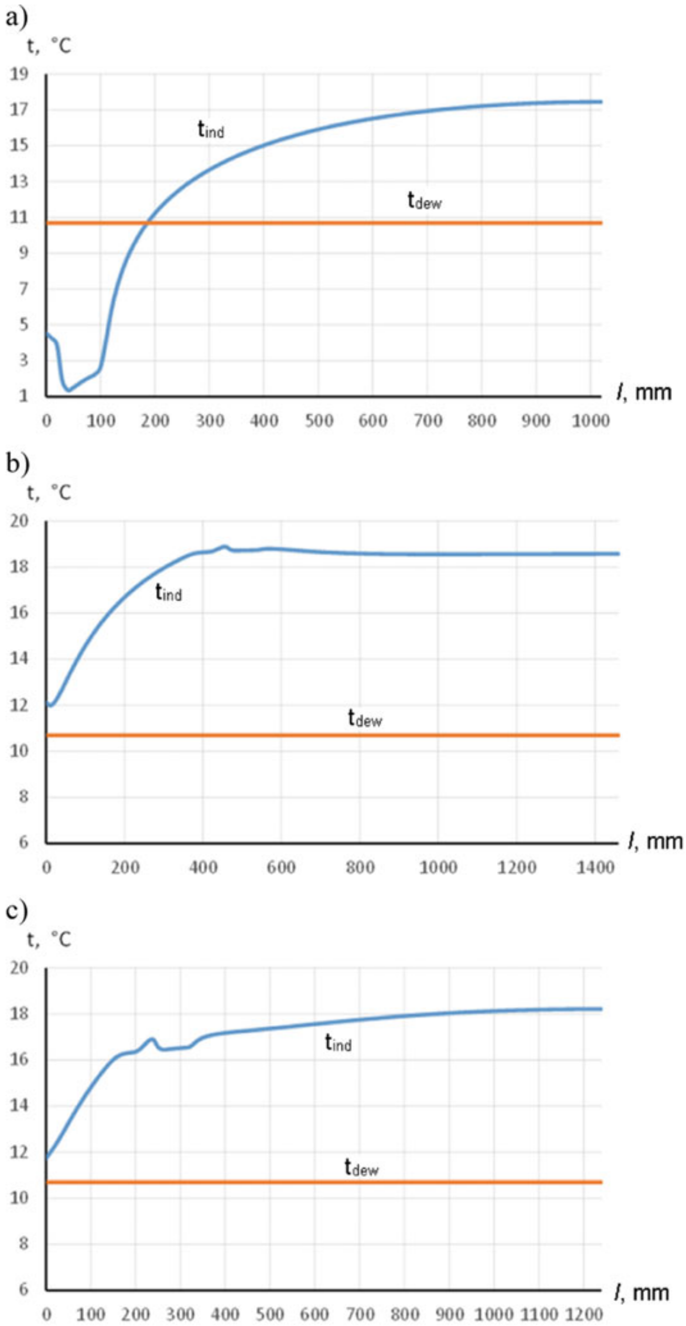

Fig. 12 Graphs of temperature distribution on the slope surface when shifting the slot filling with transom bars of windows (doors) to the inner surface of the wall (**a**), when shifting the slot filling with transom bars of windows (doors) to the outer surface of the bricklayer of the wall (**b**), when insulating the slope on the outside from the slot filling with a layer of 10 mm thick insulation (**c**)

5. When the thickness of the brick part of the wall is 0,51 m, the minimum temperature on an internal slope surface of the wall will be lower than the temperature of a dew point at all considered variants.
6. When shifting the slot filling with transom bars of windows (doors) to the inner surface of the wall the temperature of the inner surface of the wall will reduce significantly.

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