Humidity conditions of brick enclosures heat-insulated by polystyrene foam from various manufacturers

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Abstract. The most appropriate way to select materials for a heat-insulating coating of an exterior wall depends on the opportunity to prevent water condensate to appear in this enclosure and, during the development of design and detail documentation, to prevent harmful effects on the building structures (damages of enclosing structures, improved heat conductivity of materials and heat leaks from premises resulting in reduced energy efficiency of buildings) during operation. The analytical study has been conducted for the most efficient grades of heat insulators made of polystyrene foam for the bearing layer of a wall made of silicate bricks. Two options for heat-insulating layer materials are investigated: A) polystyrene foam by Radoslav, Pereslavl-Zalessky, plate No. 18; B) polystyrene foam by BASF, model Styropor PS 15. Based on the characteristics of the heat insulators selected for the study, the calculation and analytical method was used to determine probability of water condensate to appear in the wall structure at the exterior temperatures of –9.9 °C to –27 °C. The findings showed that when any heat insulators selected for the study is used as a heat-insulating layer, the bearing structure excludes condensate formation and strength characteristics of the enclosure will not be reduced due to the brickwork freezing.

1 Introduction

Silicate brick walls are currently used for residential construction in most cases as a bearing layer of exterior enclosures due to excellent strength characteristics and comparatively low economic expenses required for erection. Polystyrene foam is usually used for the heat-insulating layer, which has a number advantages as compared to other materials, namely: high heat insulation performance, low cost, easy to install.

At the designing stage, only thermotechnical analysis is done to select an exterior enclosure in most cases, but a structure having high heat-protection properties may soak up moisture and get destroyed due to moisture condensate and wall freezing at negative ambient temperatures. One of the major problems in construction is improved humidity

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conditions in currently erected buildings and structures requiring more efficient heat protection [3-16].

The calculation and analytical method was used in this paper to find put the probability of condensate formation inside the wall enclosure made of a layer of silicate brickwork and a heat-insulation layer with several polystyrene foam options.

2 Materials and methods

All calculations in this paper are done for the city of Penza (according to SP 131.13330.2020 Construction Climatology and SP 50.13330.2012 Heat Protection of Buildings). A heat-insulating layer whose thickness is based on the heat protection requirements for civil buildings is adopted as per the specifications of manufacturers who produce these materials (the pitch of thicknesses of selected plates = 0.05 m).

As a specimen for calculations, a wall was selected whose layers consist of the following materials (from inside outwards):

Layer 1: Lime and sand plaster – δ₁=0.02 m; λ₁= 0.7 W/(m · °C); γ₁=1600 kg/m³; μ₁ = 0.12 mg/(m · h · Pa).

Layer 2: Brickwork of silicate ordinary whole bricks – δ₂=0.51 m; λ₂= 1.25 W/(m · °C); γ₂=2000 kg/m³; μ₂ = 0.09 mg/(m · h · Pa).

Layer 3: Heat insulation with polystyrene foam. Two calculation options are defined:

Option 1: polystyrene foam by Radoslav, Pereslavl Zalensky, plate 18 – δ₃=0.15 m; λ₃= 0.042 W/(m · °C); γ₃=18 kg/m³; μ₃ = 0.02 mg/(m · h · Pa).

Option 2: polystyrene foam by BASF, model Styropor PS 15 – δ₃=0.1 m; λ₃= 0.04 W/(m · °C); γ₃=15 kg/m³; μ₃ = 0.035 mg/(m · h · Pa).

Layer 4. Lime and sand plaster – δ₄=0.02 m; λ₄= 0.76 W/(m · °C); γ₄=1800 kg/m³; μ₄ = 0.09 mg/(m · h · Pa).


To determine a probability of moisture condensate inside the enclosure structure in winter period, it is required to find temperature distributions in the wall.

The rated plane temperature in the wall cross-section τₙ, °C, is calculated as follows:

\[
τ_n = t_{\text{int}} - (t_{\text{int}} - t_{\text{ext}}) \frac{n R_{\text{int}} + \Sigma R}{R_{\text{act}}} \tag{1}
\]

Based on the plane temperature in the wall cross-section, let us take the maximum water vapor pressure Eₙ, Pa, for each section based on the tables given in regulatory documents. Then let us find the distribution of partial pressures of water vapors by calculating eₙ, the actual water vapor pressure, Pa, for air as follows:

\[
e_n = e_{\text{int}} - (e_{\text{int}} - e_{\text{ext}}) \frac{n R_{\text{int}} + \Sigma R}{R_{\text{ext}}} \tag{2}
\]

\[
e_{\text{ext}}, e_{\text{int}} \text{ are actual water vapor pressure in internal and external air, Pa, calculated as follows:}
\]

\[
e_{\text{ext}} = \frac{q_{\text{ext}}}{100} E_{\text{ext}} \tag{3}
\]

\[
e_{\text{int}} = \frac{q_{\text{int}}}{100} E_{\text{int}} \tag{4}
\]

According to the regulatory documents, the internal air humidity is 60%. According to SP 131.13330.2020 Construction Climatology, let us find the average ambient air humidity for 15 hours per day of the coldest month, e.g., 80%.
For calculations let us select the external air temperature with a range of -9.9 °C (average temperature of the coldest month for Penza) to -27 °C (temperature of the coldest five days with probability of 0.92). The study in this range allows finding the air temperature inside the building in winter when condensate falls out during a long period of time inside the enclosing structure. Exterior air parameters are defined in SP 131.13330.2020 Construction Climatology.

Let us find the air temperature inside the building for calculations, e.g. 20 °C.

The section of the wall structure under study for the first option of heat insulation (thickness of 150 mm) is shown in Figure 1, and that for the second option (thickness of 100 mm) is shown in Figure 2.

**Fig. 1.** Wall section for insulation option 1: Layer 1. Lime and sand plaster; layer 2. Brickwork of silicate ordinary whole bricks; Layer 3. Insulation option 1 – polystyrene foam by Radoslav, Pereslavl-Zalessky, plate No. 18; layer 4. Lime and sand plaster.
3 Results and discussion

3.1 Option 1. polystyrene foam by Radoslav, Pereslavl-Zalessky, plate No. 18

Enclosure characteristics:
- Heat transfer resistance: $R_{o,act} = 3.5 \text{ (m}^2 \cdot \text{°C})/\text{W}$;
- Vapor permeability resistance: $R_{o,act} = 9.09 \text{ (m}^2 \cdot \text{h} \cdot \text{Pa})/\text{mg}$.

The below diagrams show humidity conditions for the enclosure structure (option 1) at exterior air temperatures of -9.9, -15, -20, -25, -27 °C.
Fig. 2. Wall section for insulation option 2: Layer 1. Lime and sand plaster; layer 2. Brickwork of silicate ordinary whole bricks; Layer 3. Insulation option 2 – polystyrene foam by BASF, model Styropor PS 15; Layer 4. Lime and sand plaster.

3 Results and discussion

3.1 Option 1. polystyrene foam by Radoslav, Pereslavl-Zalessky, plate No. 18

Enclosure characteristics:

- Heat transfer resistance: $R_{act} = 3.5 \text{ (m}^2 \cdot \text{°C})/\text{W}$;
- Vapor permeability resistance: $R_{ost} = 9.09 \text{ (m}^2 \cdot \text{h} \cdot \text{Pa})/\text{mg}$.

The below diagrams show humidity conditions for the enclosure structure (option 1) at exterior air temperatures of -9.9, -15, -20, -25, -27 °C.

Fig. 3. Humidity conditions for an enclosure (option 1) at exterior air temperatures of -9.9 °C

Fig. 4. Humidity conditions for an enclosure (option 1) at exterior air temperatures of -15 °C

Fig. 5. Humidity conditions for an enclosure (option 1) at exterior air temperatures of -20 °C

Fig. 6. Humidity conditions for an enclosure (option 1) at exterior air temperatures of -25 °C.
Humidity conditions for an enclosure (option 1) at exterior air temperatures of -27 °C.

For this option of wall insulation, condensation formation and freezing may occur when the air temperature remains below -15 °C for a long time in the plane of cross-section 1. If the temperature goes down further, the freezing zone of the structure will extend inwards the wall enclosure, which may result in destruction of the heat-insulating layer and decreased heat transfer resistance.

The zone between the insulation layer and the outer plaster will freeze at the exterior air temperature of -25 °C and less, which will unlikely result in lamination of the outer layer. This may cause complications in detecting a failure of the heat-insulating layer. The bearing layer of the enclosure lies beyond the zone of condensate formation and freezing, which means that the enclosure strength will not be impaired.

3.2 Option 2. Polystyrene foam by BASF, model Styropor PS 15

Enclosure characteristics:
- Heat transfer resistance: $R_{0}^{\text{act}} = 3.11 \text{ (m}^2 \cdot \text{°C)/W}$;
- Vapor permeability resistance: $R_{0}^{\text{vap}} = 8.95 \text{ (m}^2 \cdot \text{h} \cdot \text{Pa})/\text{mg}$

The below diagrams show humidity conditions for the enclosure structure (option 2) at exterior air temperatures of -9.9, -15, -20, -25, -27 °C.

Humidity regime of the enclosing structure (option 1) at outdoor temperature -27 °C

Humidity regime of the enclosing structure (option 2) at outdoor temperature -9.9 °C
For this option of wall insulation, condensation formation and freezing may occur when the air temperature remains below -15 °С for a long time in the plane of cross-section I. If the temperature goes down further, the freezing zone of the structure will extend inwards the wall enclosure, which may result in destruction of the heat-insulating layer and decreased heat transfer resistance.

The zone between the insulation layer and the outer plaster will freeze at the exterior air temperature of -25 °С and less, which will unlikely result in lamination of the outer layer. This may cause complications in detecting a failure of the heat-insulating layer. The bearing layer of the enclosure lies beyond the zone of condensate formation and freezing, which means that the enclosure strength will not be impaired.

3.2 Option 2. Polystyrene foam by BASF, model Styropor PS 15

Enclosure characteristics:
- Heat transfer resistance: R_о = 3.11 (m²·°С)/W;
- Vapor permeability resistance: R_о = 8.95 (m²·h·Pa)/mg

The below diagrams show humidity conditions for the enclosure structure (option 2) at exterior air temperatures of -9.9, -15, -20, -25, -27 °С.

**Fig. 9.** Humidity conditions for an enclosure (option 2) at exterior air temperatures of -15 °С.

**Fig. 10.** Humidity conditions for an enclosure (option 2) at exterior air temperatures of -17 °С.

**Fig. 11.** Humidity conditions for an enclosure (option 2) at exterior air temperatures of -20 °С.
The calculation shows that moisture condensation in the wall starts at -17 °С in the wall cross-section plane J, which is between the heat-insulating layer and the cement-sand layer. As the exterior air temperature goes down, the condensate formation (freezing) zone greatly increases.

For the exterior air temperature of -20 °С, moisture is condensed in the wall cross-section plane I. If the temperature falls further, the condensate will not fall out in other planes.

The bearing layer of the enclosing structure lies beyond freezing zone.

### 4 Conclusion

To conclude, it should be noted that the wall structure insulated by Radoslav polystyrene foam (option 1) has lower performance in terms of humidity conditions than option 2; the probability of freezing is observed as low as at -15 °С; the condensate formation zone goes in 4 cross-sections at the rated temperature of -27 °С.
An enclosure insulated by polystyrene foam by BASF Styropor PS 15 (option 2) has higher performance in terms of humidity conditions: condensate forms at much lower temperatures (-18 °C and -17 °C); the condensate fallout zone is observed at the boundaries of the heat-insulating layer rather than in its body, and occurs in the third and second cross-sections, which significantly reduces the probability of insulating material damages.

For two calculation options, the condensate formation zone is not observed in the bearing layer of the enclosure structure, which means that the wall strength will not be subject to destruction by freezing and further brickwork damage.

References

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