Humidity Conditions for Exterior Walls Insulation (Case Study of Residential Housing Development in Saint-Petersburg)

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Abstract

Residential housing in Saint-Petersburg built-up in 1960-1995 can be featured by poor thermal properties. New requirements assigned for energy efficiency of buildings called for insulation. Heat losses are primarily specified by thermal properties of building envelopes depending on what humidity conditions construction materials are exposed to. High humidity of exterior walls can result in diminution of thermal properties and increase in heat losses. Besides, excessive moistening of envelopes may lead to cladding peeling, their deterioration and service life reduction. When designing building envelopes a crucial issue arises – forecast of temperature and humidity conditions for buildings in service. The article deals with an option for exterior walls insulation in the case of buildings with protective finishing coating made of thin plaster. A structure for external walls insulation based on heat insulating slabs made of rock wool has been taken. A required thickness of an insulation material has been determined, and an analysis of humidity conditions for insulated and non-insulated exterior walls has been performed.

Keywords: heritage historical building, thermal insulation, energy efficiency, protection of historical buildings.

1. Introduction

A major issue for the city’s economy of Saint-Petersburg is its energy consumption. More than 50% of all the fuel and energy city resources are consumed to supply heat. Residential housing in Saint-Petersburg built-up in 1960-1995 can be featured by poor thermal properties. Heat losses are primarily specified by thermal properties of building envelopes [1-31].
Brick, large-panel and block constructions are widely-spread; living floor area of brick buildings amounts to 55132 K sq. m2 (46.1%), panel and block ones – 51211 K sq. m2 (42.8%) [1]. The major material used in large-panel buildings is light-weight aggregate concrete (density 900-1200 kg/m3) and autoclaved aerated concrete (600-700 kg/m3).

Estimated values of the resistance to heat transfer in regard to main series of panel buildings in Saint-Petersburg do not exceed 1 m2 /kW, that is three times less than it is required according to up-to-date heat protection standards [32], and actual values are 0.7-0.85 m2 /kW. It can be explained by high humidity of building envelopes.

With moisture content increase in buildings envelopes thermal conductivity coefficients of building materials increase as well, and this causes extra heat losses. For example, heat losses through brick walls under high-humidity conditions exceed normal standards for apartments located at corner of a building by 36%, and for apartments located inward a building – by 25%.

Saint-Petersburg can be distinguished by frequent climatic changes. Annual dynamics of external air temperature can be characterised by considerable fluctuations. A number of cases when the temperature of air passes over 0 °C per season reaches 9 to 10 with peak values from plus (5÷10) °C up to minus (20÷25) °C, and on average (5.9÷6.3) °C having intervals of 10-15 days and with a rate of change from 2 up to 10 °C per day [33].

Moistening of building constructions under climatic conditions of Saint-Petersburg may result in deterioration of buildings. Ice crystals formation on the surfaces of cracks, cavities and porous spaces in construction structures can cause deformations due to temperature and humidity changes and may lead to deterioration of buildings (Fig. 1).

![Fig.1. Exterior walls defects due to deformations caused by temperature and humidity changes a) brick walls, b) panel walls](image)

2. Insulation in mass residential housing

When it comes to reconstruction and repair works with the aim to insulate buildings facades outside location of insulation layers (Fig. 2, 3) are preferred. If materials are located on exterior walls surfaces there are more advantages as compared with location on interior surfaces:

- there are no ‘thermal bridges’ after insulation has been done;
- there is no need in insulation vapour barrier;
- location of a material with high heat accumulation performance at positive temperature, and this increases heat inertia of envelopes and contributes to improvement of thermal properties when there is unsteady heat transfer;
- a major material of a wall (brick or panel) is protected against alternate freezing and melting and other atmospheric effects;
- there is no decrease in housing area, there is no need to open floors and dissemble heating system, exterior look of a building may be improved.
There are some disadvantages as follows: there is a need in dependable protective insulation layers, costly framing scaffold and false work, and positive temperature and low humidity of external air are required as well to execute appropriate works.

When making thermotechnical calculations of exterior walls a number of factors is not quite often taken into account. They are thermal conductivity of building materials to moisture content ratio, influence on temperature fields of constructions in the area of fastening nods and others. In this regard local values of the resistance to heat transfer may differ from estimated values by 1.5-2 times.

An example of a dwelling panel hose after reconstruction in Saint-Petersburg (Torzhkovskaya str., 16) having exterior heat insulation with finishing coating is given in Fig. 2.

Let’s take a construction shown in Figure 3 as an example of exterior insulation [37]:

- an existing wall – a panel made of aggregate lightweight concrete ($\delta=0.4$ m; $p=1000$ kg/m$^3$; $\lambda=0.41$ W/m·°C; $\mu=0.14$ mg/m·h·Pa);
- insulated slabs made of rock wool FASAD BATTS ($\delta=0.12$ m; $p=145$ kg/m$^3$; $\lambda=0.042$ W/m·°C; $\mu=0.3$ mg/m·h·Pa);
- decorative plaster ($\delta=0.01$ m; $p=1000$ kg/m$^3$; $\lambda=0.87$ W/m·°C; $\mu=0.05$ mg/m·h·Pa).

Notes: Symbol legend:
- $\delta$ – thickness in regard to a material’s layer of an envelope, m;
- $\rho$ – density in regard to a material’s layer of an envelope, kg/m$^3$;
- a coefficient of vapour permeability in regard to material’s layer of an envelope, mg/m·h·Pa.
Fig. 3. Structure of an exterior wall insulated from outside using a protective decorative coating made of thin plaster
1 – an existing wall; 2 – an adhesive compound to glue an insulated slab; 3 – decorative plaster; 4 – reinforcing mesh; 5 – a wall dowel; 6 – insulated slabs made of rock wool FASAD BATTS

Insulated slabs FASAD BATTS are rigid and solid ones based on synthetically binding agent resistant to deformations. They are produced out of rock wool based on geological materials related to gabbro-basalt group. A required thickness of an extra external layer has been determined on the grounds of a heat protection standard required for dwelling houses (the required standard value of the thermal resistance to heat transfer is $R_{req}=3.08 \text{m}^2\cdot\text{K}/\text{W}$ [32]) with the coefficient of thermotechnical uniformity $r=0.8$ [38].

3. Inspection of humidity conditions for an exterior wall in the case of outside insulation using a protective decorative coating made of thin plaster

The following method has been applied to test the structure for condensation inside the exterior wall with insulation and without one [38]:
- the resistance to vapour permeability of the wall is determined (we do not consider the resistance moisture exchange in the area of external and internal surfaces)

$$R_{vp} = \sum_{i=1}^{n} \frac{\delta_i \mu_i}{L_i} \text{m}^2\cdot\text{h} \cdot \text{Pa/mg},$$

Where $\delta_i$ is the thickness of a layer ‘$i$’ of an envelope, m; $\mu_i$ – the coefficient of vapour permeability in regard to material’s layer ‘$i$’ of an envelope, mg/m·h·Pa;
- the partial pressure of water vapour inside ($e_{int}, \text{Pa}$) and outside ($e_{ext}, \text{Pa}$) a wall is computed

$$e_{int} = \left(\varphi_{int} / 100\right) \cdot E_{int}, \text{Pa};$$

$$e_{ext} = \left(\varphi_{ext} / 100\right) \cdot E_{ext}, \text{Pa},$$

where $\varphi_{int}, \varphi_{ext}$ is a relative humidity of external and internal air, respectively, $\%$; $E_{int}, E_{ext}$ – partial pressure of saturated water vapour, Pa, at the internal temperature $t_{int}, \degree\text{C}$, and external temperature $t_{ext}, \degree\text{C}$;
- distribution of the temperatures $t_1$, °C in the exterior wall and values of the partial pressure of saturated water vapour $E_1$, Pa are determined;
- the charts for partial pressure of saturated water vapour $E_1$ and partial pressure of water vapour $e_1$ are plotted. If the curve, which connects points of the partial pressure of water vapour inside and outside $e_i$ intersects the curve of the saturated water vapour $E_1$, then there will be water vapour condensation. A tangent line is drawn to the line $E$ to obtain a condensation area made out of the points $e_{\text{int}}$ and $e_{\text{ext}}$.

The calculation results made to determine humidity conditions for the exterior wall without insulation are given in Fig. 4. The wall is drawn on a scale of the resistance to vapour permeability. Intersection of the lines $e_1$ and $E_1$ at an estimated temperature of the external air equal to 26 °C above zero exhibits that the moisture condensates in this case. The moisture condensation in the wall starts at the temperature of the external air equal to 13.5 °C. There is no moisture condensation at the average monthly temperature of the coldest month 7.8°C below zero.

The calculation results made for an assumed structure of the exterior wall (Fig. 3) with insulation.

The humidity conditions for the insulated exterior wall with a protective decorative layer made of thin plaster is given in Fig. 5. The water vapour condensation in the wall starts at the average monthly temperature of the coldest month 7.8°C below zero. Condensation is arranged within the protective decorative layer made of thin plaster. The major amount of condensation is formed where the protective decorative layer adjoins insulation.

![Fig. 4. Humidity conditions for the exterior wall without insulation (from the left to the right – from the surface of the internal wall to the external one) ](image-url)

1 – at the average monthly temperature of the coldest month equal to 7.8 °C below zero; 2 – at the estimated temperature of the external air equal to 26 °C below zero
Fig. 5. Humidity conditions for the exterior wall with insulation (from the left to the right – from the surface of the internal wall to the external one)
1 – at the average monthly temperature of the coldest month equal to 7.8 °C below zero; 2 – at the estimated temperature of the external air equal to 26 °C below zero

It is necessary to ensure the resistance to vapour permeability of the wall with the protective decorative layer no more than 0.032 m²·h·Pa/mg to prevent condensation of the water vapour.

Following the sorption lines made for water vapour absorbed by the materials of the exterior walls layers, the distribution for the bulk humidity is drawn, w, %, along the section of the exterior wall (Fig. 6). When insulating the mass humidity of the panel (made of lightweight aggregate concrete) decreases significantly, and this ensures improvement of thermothechnical properties of the panel made of lightweight aggregate concrete.

Fig. 6. Distribution for the bulk humidity no along the section of the exterior wall at the average monthly temperature of the coldest month equal to 7.8 °C below zero. 1 – an insulated panel; 2 – a panel
Summary

1. An analysis of humidity conditions for the exterior wall insulated from outside with the protective decorative layer made of thin plaster in the case of mass residential housing development in Saint-Petersburg has been performed.

2. At the stage when envelopes are designed the requirements for heat resistance standards as well as for prevention of moisture condensation in exterior walls should be considered.

3. When insulating existing buildings the humidity conditions for exterior walls with significant reduction of the moisture in the exterior wall, starting from internal surface up to the additional protective insulation layer, can change.

4. A possible area of water vapour condensation shifts to the plane where the protective decorative layer made of thin plaster adjoins insulation.

5. It is necessary to ensure the resistance to vapour permeability of the wall with the protective decorative layer no more than 0.032 m$^2$·h·Pa/mg to prevent condensation of the water vapour.

References


