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Saving the Architectural Appearance of the Historical Buildings due to Heat Insulation of their External Walls

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Abstract

The energy-efficient modernization of the historical buildings involves usually the warmth-insulation of their external walls. However the external mounting of the isolation materials leads to the loss of historical appearance of the buildings. The design of the construction of the inner warmth isolation for the external walls is of great importance to ensure keeping the optical appearance of the particular buildings and historical authenticity of the dwelling atmosphere in general.
The paper contains the recommendations for the selection of construction of the inner isolation of the external walls in the historical buildings for Saint-Petersburg. The conditions of internal insulation assigned for exterior walls of historical buildings in Saint-Petersburg have been analyzed. The required thickness of an insulation material based on extrusion-type polystyrene foam panels has been determined, and humidity regime of insulated and non-insulated exterior walls has been considered.

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

1. Introduction

Almost all the historical buildings need insulating in accordance with existing requirements for energy performance. As a rule, a specific power consumption of historical buildings which haven't been exposed to energy efficient upgrade exceeds the standard level to a significant extent. [1, 2]

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There are some examples of bad practice reconstruction of historical buildings abroad showing complete loss of a historical building image caused by thermal insulation. (Figure 1-3)

Fig. 1. Thermal insulation historical building, Ludwig Feuerbach-Strasse 75, 90489 Nuremberg Germany [3]

Fig. 2. Thermal insulation house in Stuttgart (Schreiberstraße 23), Germany [3]

Fig. 3. Thermal insulation historical building in Eisenach, Germany [3]

Reconstruction and restoration of historical buildings of Saint-Petersburg are implemented in strict adherence to the requirements stated in the law of Saint-Petersburg “On the boundaries of protection areas of objects of cultural heritage and on the conditions of using the land in the above boundaries and on the introduction of changes into the law of Saint-Petersburg “On the master plan of Saint-Petersburg and on the boundaries of the protection areas of cultural heritage in the region of Saint-Petersburg” and other regulations.

In the majority of cases regulations of protection assigned for historical buildings do not allow to make any changes in the front facades of the buildings, but courtyards can be changed. Having compared a number of commercial apartment buildings in Saint-Petersburg a significant difference between rich architectural decorations of front facades and contrast ‘poor’ courtyards’ facades can be distinguished. (Figure 4 a), b)) Therefore a typical insulation scheme for historical buildings can include both exterior insulation of courtyard facades and and interior insulation of front facades (Figure 5).

a)

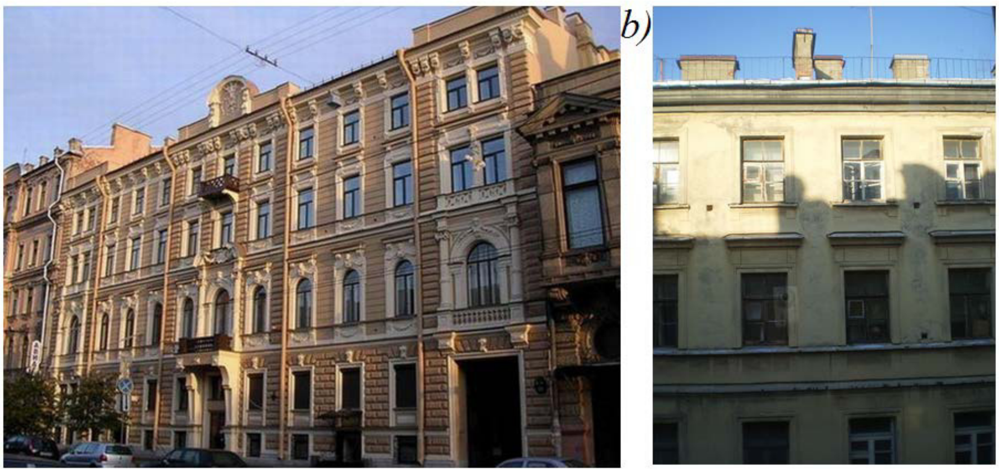

Fig. 4. Commercial apartment building of V. A. Abaz in Saint-Petersburg, Chaikovskogo street, 26.

a) Front facade; b) Yard facade;

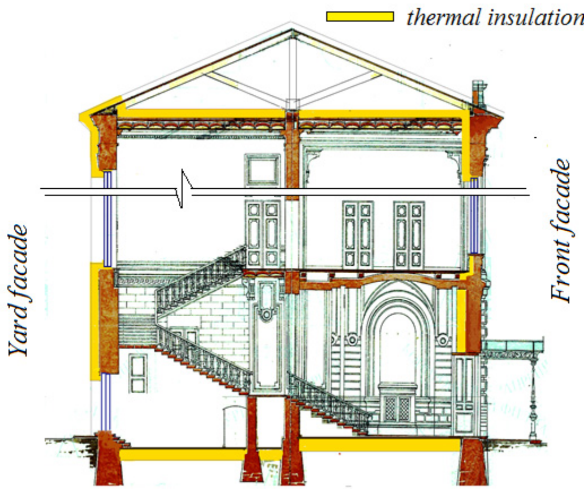

Fig. 5. Thermal insulation scheme for a historical building

2. Thermal insulation of historical buildings

An external placement of an insulation layer (Figure 2, 3) is more preferable to insulate facades of buildings while repair and reconstruction works. However, an internal placement of an insulation layer should be applied for front facades of historical buildings under protection which are normally rich in decorative elements.

An option of insulation material layout assigned for interior walls has the following advantages:

- thermal protection material is under favourable maintenance conditions and does not require additional protection from external impacts (variable temperature and humidity regime; possible capillary and diffusive moisture; wind impact; dead-weight loads);
- thermal protection works can be carried out in any season of a year, scaffold and wooden false work are not required;
- historical image of a building is remained.
- There the following disadvantages with regard to the rooms:
- decrease of a room area due to increase in thickness of walls;
- complex insulation arrangement in the area of heating devices as well as within the limits of a floor thickness;
- insulation arrangement is required to eliminate additional insulation drop-out at the places where overlapping slaps are supported by walls, and interior walls and partition-walls adjoin to exterior walls;
- it is require to protect insulation material and wall masonry from moisture by placing vapour seal covering from a room's side before insulation material is used;
- existing wall material (brick masonry), which accumulates heat in an efficient way, should be applied after insulation procedure in the area of low temperature that significantly reduces thermal inertia of an enclosure.

Moisture regime of an insulated wall is focused when arranging internal insulation. If internal insulation inside an enclosure is carried out in an improper way moisture can be accumulated and exterior wall gets wet entailing formation of mildew.

3. Survey of possibilities for internal insulation of historical buildings

Exterior walls of historical buildings of Saint-Petersburg have a variable thickness, and the higher the walls are the thinner they are. As a rule, thickness of a wall can change within the range from 4 bricks (1.15 m) at the bottom of the wall up to 2.5 bricks (0.72 m) at the top of the wall. Design conditions for Saint Petersburg calculated on the basis of the standard SNiP 23-02-2003 and are presented in Table 1.

Table 1. Design conditions for Saint Petersburg

City - Saint Petersburg	Symbol	Units	Value
Design ambient air temperature	t_{ext}	ºC	-26
Design interior temperature	t_{int}	ºC	-1.8
Duration of the heating season	z_{ht}	day	220
Design interior temperature	t_{int}	ºC	20
Operating conditions of walling	Type B (high humidity)		
Relative humidity inside the building	φ	%	55
Degree-day heating season	D_d	°C day	4796
Coefficient taking into account the dependence of the enclosing structure position in relation to ambient air			n = 1
Normalized temperature difference between the interior temperature and the temperature of enclosing structure inner surface	Δt_n	ºC	not more than 4
Heat transfer coefficient of the enclosing structure inner surface	α_{int}	W/m² °C	8.7
Heat transfer coefficient of the enclosing structure outer surface	α_{ext}	W/m² °C	23
Dew point interior temperature for the cold season	t_d	ºC	10.7
Normalized heat transfer resistance of enclosing structure	R_{req}	m² • C/W	3.0786
Required thermal resistance of enclosing structure according to hygiene requirements $R= n\ (t_{int} - t_{ext})/\ \alpha_{int}\ \Delta t_n$	R	m² • C/W	1.3218

Requirement for design heat transfer resistance R_o, (m^2 • C/W) of enclosing structure, without heat transfer performance uniformity factor, is determined by the formula:

$R_o \geq R_{req},$

taking into account heat transfer performance uniformity factor *r*:

$R_o \cdot r \geq R_{req},$

$R_o = 1/\alpha_{int} + (R_1 + R_2 + ...+ R_n)+1/\alpha_{ext},$

The requirement for design temperature difference Δt_0 between the interior temperature and temperature of enclosing structure inner surface:

$\Delta t_0 \leq \Delta t_n$

$\Delta t_0 = n\ (t_{int} - t_{ext})/\ R_o \cdot \alpha_{int}$

The requirement for minimum temperature in all areas of inner surface of exterior walls τ_{int}, °C in relation to dew point interior temperature t_d (without condensate formation).

$\tau_{int} \geq t_d$
$\tau_{int} = t_{int} - [n(t_{int} - t_{ext})]/(R_o\alpha_{int})$
The calculation results for different thicknesses of brick walls are shown in Table 2.

Table 2. The results of normalized parameters calculation

	Thickness of the wall, in bricks				Normal value
	4	3.5	3	2.5	
Thermal resistance of enclosing structure "on coats", R_o $(m^2{*}°C)/W$	1.6399	1.4670	1.2818	1.1089	≥ 3.0786
Temperature of the inner surface, $\tau_{int,}$ ºC	16.78	16.40	15.87	15.23	≥ 10.7
Temperature difference Δt_0	3.22	3.60	4.13	4.77	≤ 4

Therefore, we can specify that insulation of walls is required on the basis of the estimation findings.
Let's consider the following construction [6, 7] as internal insulation given in the Figure 5.

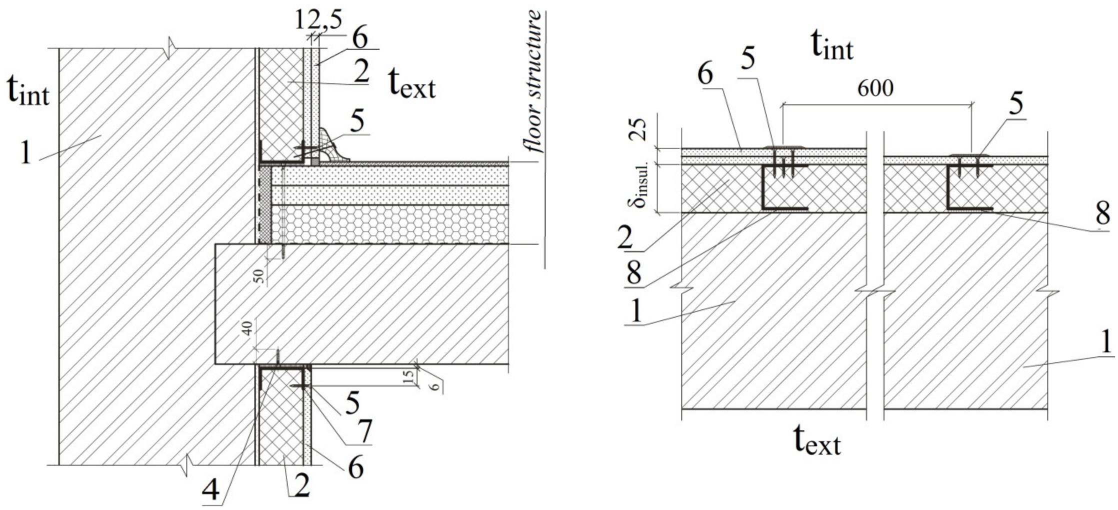

Fig. 5. Scheme of internal insulation of an exterior wall: 1 – existing exterior wall; 2 – thermal insulation based on extrusion-type polystyrene foam panels PENOPLEKS 35; 3 – smoothing plaster; 4 – concrete insert; 5 – screw; 6 – gypsum plasterboard; 7 – frame profile made of steel; 8 – sealing band

A distinctive feature of the construction is a specific vapor seal covering to be applied between gypsum plasterboards (it is not shown in the Figure 5). Such construction can actually prevent penetration of vaporous moisture from a room into an insulation material. For instance, water vapor permeability of a polyethylene seal with thickness of 0,16 mm can be applied as a vapor insulating seal amounting to 7.3 $m^2{\cdot}h{\cdot}Pa/mg$.

It is necessary to determine thickness of an insulation layer to be applied in a dwelling houses with exterior walls having thickness of 2.5 bricks (720 mm) and more, and also research possibility to make construction without vapor insulation.

Thermal, technical and humidity estimations have been carried out for an exterior wall construction with insulation and without in accordance with the requirements specified [8].

There are the following estimation results for an assumed exterior wall construction without insulation:

- the following requirement SNiP 23-02-2003 [8] based on standard temperature drop have been met; the drop between internal air temperature and external air temperature of an enclosure surface does not exceed 4 °C (Δt0=3.1 °C); there is no humidity condensation on the internal surface of exterior wall;
- water vapor permeability resistance (Rvp) of an enclosing structure (within the limits from internal surface for possible condensation) is higher than a standard water vapor permeability under a condition when moisture accumulation in an enclosing structure over a maintenance year (Rvp1req) is impossible:
- Rvp=4.170 m2·h·Pa/mg > Rvp1req=0.029 m2·h·Pa/mg;
- water vapor permeability resistance (Rvp) of an enclosing structure (within the limits from internal surface for possible condensation) is higher than a standard water vapor permeability under a condition when moisture in an enclosing structure is limited over a period with average negative monthly temperatures of external air (Rvp2req) [8]

R_{vp}=4.170 m^2·h·Pa/mg > R_{vp2}^{req}=0.149 m^2·h·Pa/mg.

The scheme of humidity regime of exterior wall of a building without insulation is given in the Figure 8. There are no crossing lines e (water vapor partial pressure line, Pa) and E (change of rich water vapor pressure line, Pa) with average monthly temperature of the coldest month equal to 7.8 °C below zero. It shows that there is no humidity condensation in the wall [9]. The wall has been drawn in the scale of resistances to water vapor permeability.

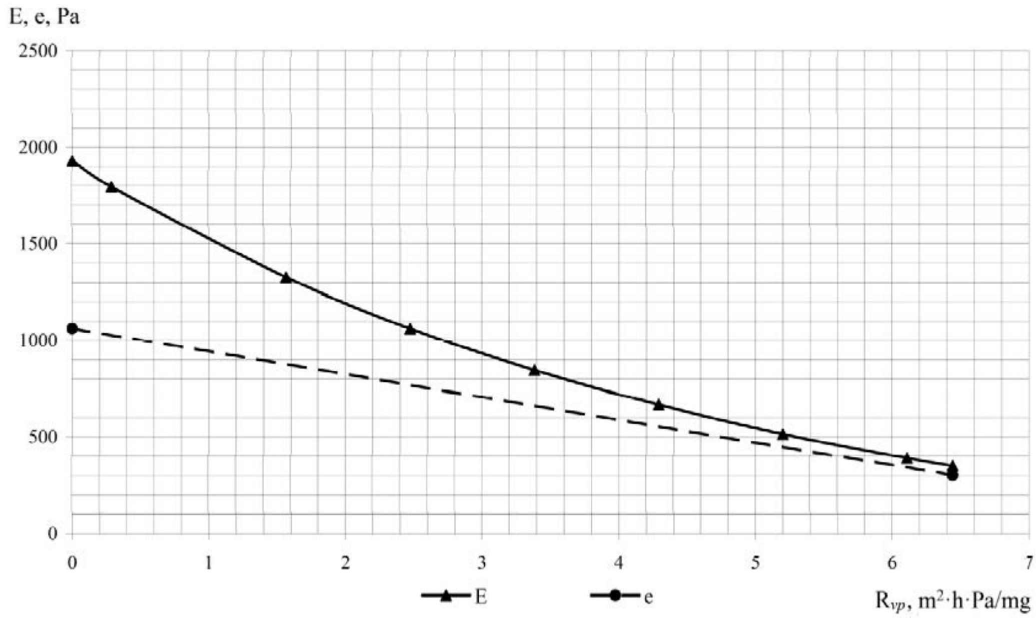

Fig. 6. The scheme of humidity regime of an exterior wall without insulation with average monthly temperature of the coldest month equal to 7.8 °C below zero (from the left top the right – from an interior wall to an exterior one)

4. Estimation results for an assumed exterior wall construction with insulation and without water vapor barrier

A required thickness of an additional internal layer of thermal insulation with the thermal and technical uniformity factor r=0.9 – δ=80 mm has been determined based on the conditions to ensure the required level of thermal protecting for dwelling buildings (R_{req}=3.08 $m^2 \cdot °C/W$). An additional increase of thermal resistance is ΔR=2.7 $m^2 \cdot °C/W$. Resistance to heat transfer of the construction amounted to R_0=3.22 $m^2 \cdot °C/W$.

Vapor permeability resistance of an enclosing structure (within the limits from internal surface for possible condensation) is higher than a standard water vapor permeability under a condition when moisture accumulation in an enclosing structure over a maintenance year is impossible - R_{vp}=4.623 $m^2 \cdot h \cdot Pa/mg > R_{vp1}^{req}$=1.66 $m^2 \cdot h \cdot Pa/mg$.

Water vapor permeability resistance (R_{vp}) of an enclosing structure (within the limits from internal surface for possible condensation) is higher than a standard water vapor permeability under a condition when moisture in an enclosing structure is limited over a period with average negative monthly temperatures of external air R_{vp}=4.623 $m^2 \cdot h \cdot Pa/mg > R_{vp2}^{req}$=2.652 $m^2 \cdot h \cdot Pa/mg$.

The scheme of humidity regime of exterior wall with insulation and without water vapor insulation is presented in the Figure 7. The line, which connects points of partial pressure values of water vapor on internal (e_{int}, Pa) and external surfaces (e_{ext}, Pa), crosses the line of rich water vapor line. Tangent lines to the line E are drawn to make condensation area out of points e_{int} and e_{ext}. 'Condensation area' which is between tangent points is 35 mm in thickness – within the bounds of internal plaster of existing wall construction. The major amount of condensation can be formed in the plane where thermal insulation layer adjusts to the wall, and the line has a dramatic drop.

It should be noted that estimations are made without account for thermal transmittance impacts, joint areas at link beams and jumps and etc. Other certain estimations should be carried out to achieve actual design solutions with appropriate nods.

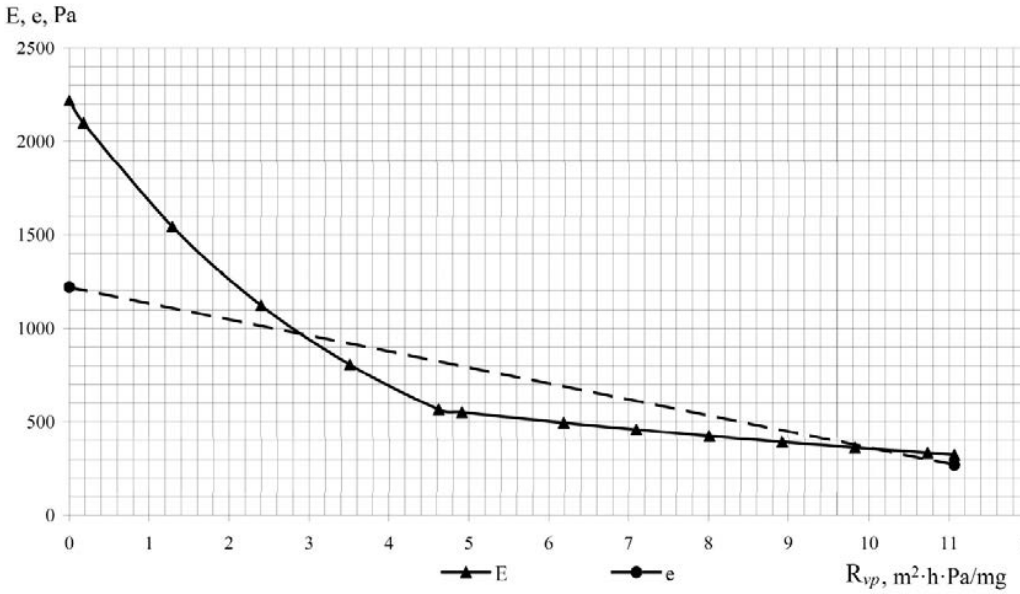

Fig. 7. The scheme of humidity regime of an exterior wall with insulation having no water vapor barrier with average monthly temperature of the coldest month equal to 7.8 °C below zero (from the left top the right – from an interior wall to an exterior one)

5. Estimation results for an assumed exterior wall construction with insulation and with water vapor barrier

A water vapor seal is taken to avoid water vapor humidity permeability from the rooms into the exterior wall construction between gypsum plasterboards. It has been specified that only materials with water vapor permeability resistance not less than 12 $m^2 \cdot h \cdot Pa/mg$ must be applied as water-vapor insulation layer. The scheme of humidity regime of an exterior wall with insulation and water vapor insulation are shown in the Figure 8. In this case There is no water vapor condensation in the wall.

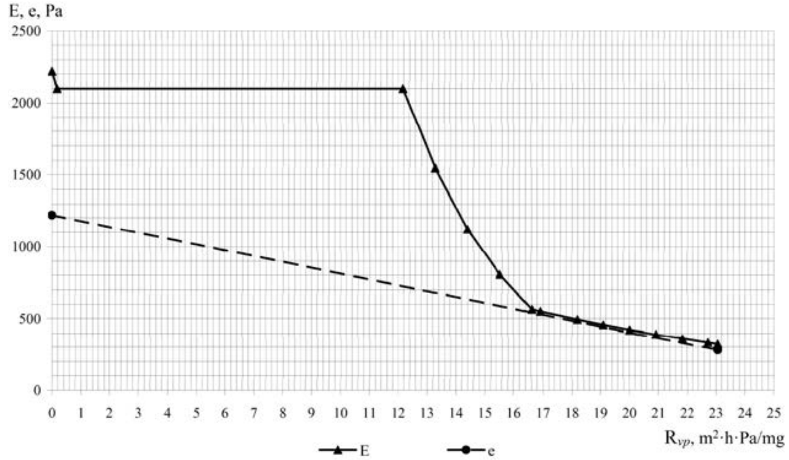

Fig. 8. The scheme of humidity regime of an exterior wall with insulation having water vapor barrier with average monthly temperature of the coldest month equal to 7.8 °C below zero (from the left top the right – from an interior wall to an exterior one)

6. Conclusions

The conditions of internal insulation assigned for exterior walls of historical buildings in Saint-Petersburg have been analyzed. The required thickness of an insulation material based on extrusion-type polystyrene foam panels has been determined, and humidity regime of insulated and non-insulated exterior walls has been analyzed.

The following aspects should be taken into consideration when working on enclosing structures design: required level of thermal protection should be achieved, and exterior walls should be protected from humidity condensation.

Estimation of humidity regime for masonry wall with internal insulation based on based on extrusion-type polystyrene foam panels PENOPLEKS 35 without water vapor barrier has proven that there can be a possible drop-out of condensation at the join of insulation material and internal plaster of an exterior wall.

Water vapor barriers using materials with water vapor permeability resistance not less than 12 $m^2 \cdot h \cdot Pa/mg$ should be considered when making internal insulation for exterior brick walls.

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