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RECOMMENDATIONS FOR RESTORATION OF HISTORICAL TRANSPARENT COATINGS IN PUSHKIN MUSEUM

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ABSTRACT

Due to the intensification of historical buildings restoration works that are cultural monuments and related to architectural monuments, numerous questions arise about the possibility of increasing the efficiency of translucent structures, including their energy efficiency, using modern innovative technologies. The cost of competent reconstruction of windows and lanterns with the preservation of historical elements is much higher than the cost of standard modern structures, as a result of which there are numerous examples of barbaric illegal replacement of historical windows with modern ones. This not only spoils the appearance of buildings, but also contradicts federal laws (with all the ensuing consequences).

Earlier, NIISF RAASN carried out multifactorial field studies of historical translucent coverings of a cultural monument of federal significance – the main building of the Pushkin Museum, on the basis of which their inconsistency with modern requirements for such structures was established. According to the technical assignment and the project for the reconstruction of the building, 13 options were proposed for the possible restoration of these coatings. To assess the proposed options, a comprehensive computer simulation and corresponding calculations were carried out in accordance with the certified software package "WINDOW TECT".

On the basis of the conducted examinations and computer calculations, optimal solutions were proposed for the restoration of historical translucent coatings of the main building of the Pushkin Museum, providing for the preservation of the original elements of metal structures and ensuring an increase in the thermal characteristics of the lantern and side lamp.

Keywords: restoration of old buildings, historical translucent coatings, computer modelling, resistance to heat transfer, condensation, lantern, sidelight, recommendations, translucent structures, energy efficiency, micro-climate parameters, museum exhibition premises

1. INTRODUCTION

Recently, work on the preservation of buildings related to the historical and cultural heritage has intensified – practically throughout the Russian Federation and, to a greater extent, in a number of other countries. (In Moscow in 2019 alone, more than 170 historical buildings were restored, and in 2020 even more activity is planned in this direction.) However, the number of unsuccessful decisions, scandals and even court proceedings related to with the restoration of historical buildings, including those with light-transparent structures.

As already noted [1], most of the problems with the unjustified replacement of historical translucent structures of old buildings are observed in St. Petersburg and Moscow. This is absolutely understandable because in these cities is the largest number of surviving buildings belonging to the "objects of cultural and historical heritage" and, accordingly, increased budgets.

However, examples of the barbaric attitude to the "historical heritage" are not only in Moscow [2–5] and St. Petersburg [6–8], but also in Ryazan [9], Omsk [10], Nizhny Novgorod [11], Pereslavl-Zalessky [12] and in many other cities and towns of the immense Russian Federation.

We cannot say that everyone agrees with this practice. For example, there are known court decisions on the restoration of historical windows [11, 13, 14], and a ban on the installation of grilles and air conditioners disfiguring the facades of old buildings [15], and cases of the creation of special commissions designed to monitor the competent restoration of light transmission – transparent structures [16, 17], and thousands of fines for disfiguring building facades [14, 18]. True, there exist some "funny" initiatives. Thus, the new governor of St. Petersburg A.D. Beglov suggested simply paint the illegally installed white PVC-profile windows in a "historical" colour and thus cheaply "fix" these violations [19].

In fairness, it is worth noting successful reconstructions of historical light-transparent structures [20, 21], but, unfortunately, there are not very many of them. The relevance of the topic of preserving the identity of old buildings in cities is also emphasized by the publication in 2019 of the book [22], prepared with the participation of the well-known window companies VEKA and SIEGENIA. Of course, due to the main professional and commercial interest of these companies, the book focuses on the use of modern windows made of PVC profiles, and this is still not a "clean" restoration, but rather "reconstruction" or, fashionable today, "renovation". Nevertheless, the book [22] is certainly interesting and useful.

Specialists in the field of scientific restoration are trying to restore the damaged elements of historical buildings. This is not always possible – many windows are practically lost (wooden ones have rotted, and metal ones have rusted). In this case, they try to replace the frames with exact replicas made of similar materials. Unfortunately, PVC window profiles did not exist until the middle of the 20th century.

Disputes about the possibility of using different methods for the preservation of historical buildings have been going on for a long time – the supporters of different approaches are almost equally divided. Quite interesting considerations on this matter are published in the article [23].

At the same time, increasing the energy efficiency of translucent structures made of metal at the beginning of the 20th century and requiring the preservation of the main elements for the protection of a cultural monument, up to modern requirements using modern technologies is a unique task that has no analogues in practice.

2. METHOD OF INVESTIGATION

As a result of the conducted surveys of historical translucent coatings [24], it became obvious that they do not meet modern requirements either in terms of heat transfer resistance or other indicators. While preserving most of the metal frames (which is a requirement of the Law on the Protection of Cultural Heritage Monuments and the Customer's assignment [25]), it was necessary to carry out large-scale computer calculations to determine the optimal parameters for the restoration of coatings.

In accordance with the reconstruction plan of the Pushkin's Museum is supposed – while maintaining the main historical structures (the author is the outstanding engineer V.G. Shukhov) – to isolate the under-roof space from the exhibition premises and install energy-saving double-glazed windows instead of glass on the window lamp (Fig. 1).

The calculation of the thermal technical characteristics of historical and proposed for reconstruction translucent coatings, as well as the temperature distribution over the inner surfaces of glazing and profiles of metal frames was carried out in accordance with the certified software package "WINDOW TECT" for thermal engineering calculations and the calculation of thermal technical coefficients of translucent structures as part of programs "WINDOW THERM TEMPER", according to [26], under different boundary conditions for each of the applied options for filling translucent structures. The

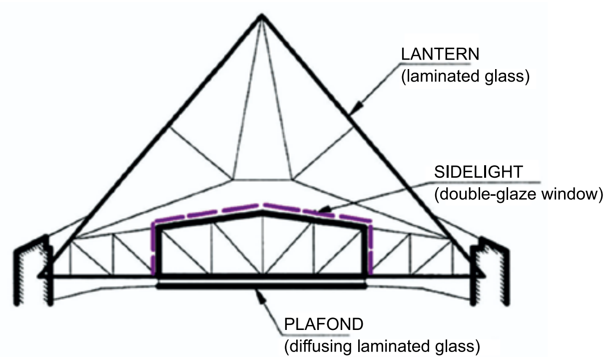


Fig. 1. Reconstruction project of translucent coverings

calculation technique and the area of its application are described in more detail in [27, 28].

3. CALCULATION RESULTS

To carry out these calculations, the following options for the execution of light-transparent structures were proposed, the general diagram of which is shown in Fig. 1:

Skylight:

Option 1 – the existing historical design of the skylight glazing: 4 mm thick glass installed in metal brackets (35×35×3) mm;

Option 2 – instead of glass, laminated glass is installed in the existing historical structure (option 1) in accordance with the strength calculations carried out [28].

Sidelight:

Option 3 – an existing metal frame made of a brand with dimensions of (35×35×3) mm, glazed with 4 mm thick plain glass;

Option 4 – the existing metal frame (option 3), glazed with a two-chamber glass unit 4I-10Ar-4–10Ar-4I (I-glass: "PLANITHERM 4S", emission coefficient 0.013, "warm" distance frame "TGI");

Option 5 – the existing metal frame (option 3), glazed with a two-chamber glass unit 4I-10Ar-4–10Ar-4I (I-glass: "PLANITHERM 4S", emission coefficient 0.013, "warm" spacer "TGI"); on the side of the under-roof space on the T-profile there is a 10 mm thick foam polystyrene pad;

Option 6 – an existing metal frame (option 3), glazed with a two-chamber glass unit 4I-10Kr-4–10Kr-4I (I-glass: PLANITHERM 4S, emission coefficient 0.013, "warm" spacer "TGI");

Option 7 – existing metal frame (option 3), glazed with a two-chamber glass unit 4I-10Kr-4–10Kr-4I (I-glass: "PLANITHERM 4S", emission coefficient 0.013, "warm" spacer "TGI"); on the side of the under-roof space on the T-profile there is a 10 mm thick foam polystyrene pad;

Option 8 – a repetition of the historical design with an exact replica made of fiberglass with glazing with a double-glazed unit 4I-10Ar-4–10Ar-4I (I-glass: PLANITHERM 4S, emission coefficient 0.013, "warm" spacer "TGI");

Option 9 – a repetition of the historical structure with an exact replica made of glass-fiber-reinforced plastic with glazing with a double-glazed unit 4I-10Ar-4–10Ar-4I (I-glass: "PLANITHERM 4S", emission coefficient 0.013, "warm" spacer "TGI"); on the side of the under-roof space on the brand there is a 10 mm thick pad of foam-polystyrene;

Option 10 – a repetition of the historical design with an exact replica made of fiberglass with glazing with a double-glazed unit 4I-10Kr-4–10Kr-4I (I-glass: "PLANITHERM 4S", emission coefficient 0.013, "warm" spacer "TGI");

Option 11 – a repetition of the historical structure with an exact replica made of glass-fiber reinforced plastic with glazing with a double-glazed unit 4I-10Kr-4–10Kr-4I (I-glass: "PLANITHERM 4S", emission coefficient 0.013, "warm" spacer "TGI") from the side of the under-roof space on the T-profile there is a 10 mm thick foam polystyrene pad;

Option 12 – frame – facade system "Raico", made according to the geometry of the existing side lamp using a box-shaped steel profile 50×50 mm with glazing with two-chamber glass unit 4I-10Ar-4–10Ar-4I (I-glass: "PLANITHERM 4S", emission factor 0.013, "warm" spacer "TGI").

Option 13 – frame – facade system "Raico", made according to the geometry of the existing side lamp using a box-shaped steel profile 50×50 mm with glazing with two-chamber glass unit 4I-10Kr-4–10Kr-4I (I-glass: "PLANITHERM 4S", emission factor 0.013, "warm" spacer "TGI").

The options 8–13 calculation are related to the replacement of the existing metal frame, which would be possible if the replacement of the historical design of the side of the restorers was agreed upon.

The internal (in the exhibition halls) microclimatic conditions for calculations were taken in accordance with the project for the reconstruction of the main building of the Pushkin Museum – the temperature of the internal air (20 ± 1) °C, relative humidity (50 ± 5)%.

The calculations for the glazing of the lantern were carried out at an outside air temperature of minus 28 °C (in accordance with the document [29, Table 3.1]).

At the same time, the air temperature in the under-roof space according to the survey results was taken (in the absence of solar irradiation) minus 18 °C.

When calculating the thermo-technical characteristics of the side lamp, the following boundary temperature conditions were taken: air temperature in the under-roof space is the minus18 °C and air temperature inside the space under the lamp is the + 21 °C.

In accordance with the recommendations [30, 31], it was assumed that the heat transfer coefficients at the inner surface of the glass unit, at the inner surface of the bindings (frames) and at the outer surface of the glass unit are equal to 8.0 W/(m^2·°C), 8.7W/(m^2·°C), and 23W/(m^2·°C) respectively.

Thermal conductivity coefficients [W/(m^2·°C)] of some materials, taken in calculations are equal to 0.25 (EPDM sealant), 160 (aluminium), 58 (steel), and 0.17 (polyurethane).

The following conditions were accepted when calculating the glazing of the lantern: dimensions of the structural element are (1300×435) mm, glass dimensions are (1110×415) mm, and tilt angle to the horizon is the 50°.

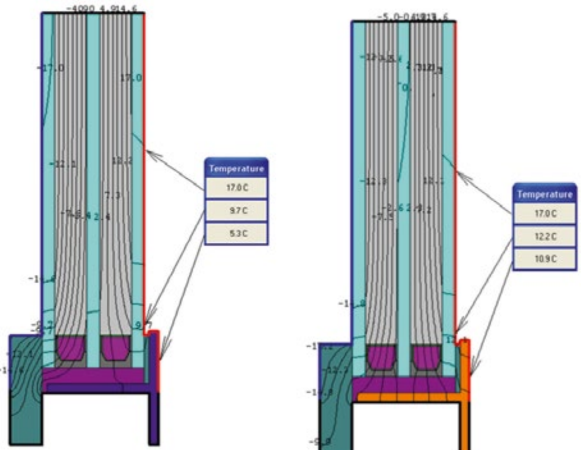
When calculating the sidelight glazing, the following conditions were accepted: dimensions of the structural element are (2240×890) mm, glass dimensions are (2200×850) mm, and inclination to the horizon is the 13°.

The results of assessing the resistance to heat transfer, [m^2·°C/W], for different versions of the two circuits (lantern and sidelight) of the translucent coating are as follows:

Skylight: 0.18 (option 1) and 0.16 (option 2);

Sidelight: 0.17 (option 3), 0.68 (option 4), 0.74 (option 5), 0.82 (option 6), 0.92 (option 7), 0.82 (option 8), 0.85 (option 9), 1.03 (option 10), 1.08 (option 11), 0.71 (option 12), and 0.85 (option 13).

Other results of calculations of translucent structures are shown in Fig. 2 for two of the above options.



a) *b)*

Fig. 2. Temperature distribution on the inner surface of the sidelight glazing for options 7*a* and 11 *b*

The main conclusions based on the results of the calculations are as follows:

– The thermal technical characteristics of the historical translucent structures of the flashlight and side lamp (options 1 and 3) do not correspond to the current regulatory documents [32], including after replacing the glazing of the lantern in accordance with strength calculations (option 2);

– All options for replacing glass in the lamp holder with the proposed double-glazed windows (options 4–13) seem to meet the requirements [32], however, the above calculations were carried out for the vertical arrangement of structures; at the same time, for an inclined structure (13° to the horizon), a reduction factor must be introduced, which is associated with the peculiarities of convection processes in the inter-glass space of glass packets and is recommended by the developers of the software package (Lawrence Berkeley National Laboratory, National Fenestration Rating Council), and confirmed to the testing laboratories of NIISF RAASN; however, only options 7, 10 and 11 meet the regulatory requirements [32];

– In museum premises it is necessary to exclude the possibility of condensation on the surfaces of glazing and frames – condensation is fraught with the danger of damage to works of art; at the same time, within the framework of computer modelling, an assessment of temperatures at critical points of structures was carried out, and it is pointless to assess the likelihood of condensation formation on the inner surfaces of the lantern – their temperature is almost equal to that of the street, and condensation in the under-roof space will be guaranteed; however, in accordance with the project of a comprehensive restoration [25], it is proposed to isolate the under-roof space from the under-lamp and exhibition spaces, and when assessing the possibility of condensation formation on the inner surfaces of the under-lamp contour, the same microclimate parameters were adopted in the under-lamp space, as in the exhibition halls;

– If the historical metal structures of the lantern and side lamp (options 1–7) are preserved during the restoration process, condensation is very likely to fall on them; however, in option 7, this is possible both for a short time and at "especially extreme" negative outside temperatures (below minus 30 ^{0}C);

– Thermal insulation linings made of polystyrene foam do not greatly affect the resistance to heat transfer, but they significantly increase the tempera-

Fig. 3. Amazing "resoration" of translucent structures

tures at critical points of the structure, which reduces the likelihood of condensation on the frames.

4. RECOMMENDATIONS FOR RESTORATION OF HISTORICAL TRANSPARENT COATINGS

Based on the results of the surveys carried out the following recommendations were issued for the restoration of historical translucent coatings of the Pushkin State Museum of Fine Arts aimed at restoring and increasing the efficiency of metal structures of two circuits (skylight and plafond) installed in 1912 according to the project of V.G. Shukhov.

4.1. General results:

1. Despite the fact that the reports [33, 34] made a conclusion about the possibility of further operation of the structures of translucent coatings, the authors strongly recommend an additional assessment of the strength and performance of the load-bearing and other metal structures. This is largely due to both their unsatisfactory condition and the fact that, in accordance with the calculations carried out, it is recommended to use glass for the lantern one and a half times heavier than the existing one, and for the side-lamp – a glass unit three times heavier than the glazing available today.

2. It is necessary to provide for the restoration of the natural ventilation systems of the under-roof space, originally planned by the architect R.I. Klein and muffled, apparently, during repeated subsequent repairs.

3. It is necessary to provide for a high-quality vapour barrier of the exposure area from the under-roof space to exclude the ingress of moist air and the formation of condensation and frost on the inner surfaces of the lantern.

4.2. Skylight:

1. In accordance with the calculations of the strength of the glass, it is recommended to use laminated glass instead of 4 mm thick glass 3.3.1. If it is impossible to use laminated glass due to insufficient strength of the metal structures, it is possible to use sun-protective tempered or heat-strengthened glass with a thickness of 5 mm.

2. Metal structures are affected by large-scale corrosion, and therefore during their restoration it is necessary:

– To disassemble and replace defective structural elements;

– To clean them from traces of numerous paints carried out over the past 100 years;

– Carry out a thorough cleaning of rust, as well as processing with modern anti-corrosion compounds of absolutely all structural elements;

– There is a fear that some structural parts cannot be restored and will require replacement;

– With the possible replacement of historical elements with "remakes" due to the complete impossibility of their restoration, it is necessary to exclude the use of modern materials that can enter into an electrochemical reaction with historical materials;

– New painting of elements of metal structures should be carried out only after carrying out the above measures.

3. When replacing glass, should be noted:

– The glasses in each segment must have such horizontal dimensions that there is a gap of (5–6) mm between the glass and the T-profiles (on both sides); the vertical size of the glass in the segment is considered equal to the distance between the midpoints of the horizontal steel corners minus 10 mm;

– Glass fixing should be done using spacer double-sided self-adhesive gaskets, for example, "Robiflex", which 2 mm thick on one side is glued to the horizontal shelf of the T-profile along its entire length, and the other side to the glass, and Gasket "Robiflex" 5 mm thick on one side is glued to the outer flange of the steel corner along the entire length, and the other side to the glass;

– After the glass is placed in the segments, the formed gaps ((5–6) mm between glass and T-bars, 10 mm between glasses horizontally) must be filled with a structural glazing sealant;

– Work on replacement of glass and restoration of the frame must be carried out in conjunction with roofers to prevent damage to glass after replacing steel sheets at the bottom of the slope and in the ridge of the roof;

– The installation of double-glazed windows or energy-saving glass for this glazing circuit is impractical, because "Puffs" for ventilation of the under-glass space practically "to naught" the heat-saving properties of these glasses;

– Restoration of the translucent cover of the lantern is possible in two main variants: a) reproduction of the existing system developed by V.G. Shukhov, using special clamps to create additional ventilation; b) reproduction of the standard for modern translucent coverings of solid glazing of the lantern. In the first of them, it is necessary to preserve (restore) the additional ventilation system envisaged during the initial construction through the slots in the glazing, which are formed by metal clamps. For this, it is necessary to develop and manufacture new clamps, possibly from modern polymer materials.

4. Due to the unsatisfactory maintenance of this translucent coating, it becomes completely "not translucent". Probably, one should consider the issue of using modern self-cleaning (hydrophobic) glasses, which are produced by all major glass companies, as part of the triplex. The coatings of these glasses allow natural precipitation to wash off a significant part of the dirt on the glasses.

5. It is absolutely imperative that devices are provided to protect the under-roof space from direct sunlight. On clear days, even during the cold season, the temperature in this zone exceeds all permissible limits. In this regard, we recommend motorized curtains made of metallized polymer fabrics, which should be installed on the slopes of lanterns overlooking the solar rumba of the horizon (southern, southeastern, southwestern and western). Such sun protection devices are produced by many companies (for example, one of the leading manufacturers of solar protection systems, Renson, Belgium). These devices can be installed under the ridge and will not disturb the architectural appearance of the building.

4.3. Sidelight

1. The scheme of the restoration of the sidelight contour depends on the decision on whether the historical metal structures will be preserved or replaced. Until the moment this article was submitted to the editors, this decision had not been made.

2. In the first case, option 7 is optimal (see above). In this case, heat-strengthened or tempered outer glasses should be used – in order to minimize the risks of their destruction and the ingress of foreign objects on the glass of the plafond.

3. In the second case, we consider it expedient to use one of the options for effective aluminium profiles with thermal break, for example, option 13 (see above), and change the geometry of the lamp post from trapezoidal to triangular.

4. In any reconstruction option when using double-glazed windows (with the exception of options 12 and 13), heat-insulating linings should be used, which can significantly increase the temperatures at critical points of the structure.

5. When carrying out computer modelling, the thermal characteristics of the side lamp were considered separately from the cover. However, the instrumental examinations carried out showed that when jointly assessing these contours of translucent structures, approximately 0.25 $m^2\cdot{}^\circ C/W$ can be added to the calculated heat transfer resistance of the headlamp structure.

4.4. Plafond

1. In the shade, it is advisable to use a laminated glass composed of two tempered or heat-strengthened glasses with a thickness of 4 mm each or tempered glass with a thickness of 6 mm with a protective scattering film, which simultaneously functions as a glass lamination and protection from falling of glass fragments into the exhibition halls.

2. The degree of matting of laminated glass should be discussed with the museum specialists responsible for the lighting of the exhibits. In this case, a film with a maximum light transmission coefficient should be used.

We present these recommendations in such detail precisely because they all work only when they are fully implemented.

5. CONCLUSION

The main purpose of surveys of historical windows and translucent coverings of the main building of the Pushkin Museum [1, 24, 27, this article] were an objective assessment of the current state of these structures, mounted in 1912, and the development of recommendations for their improvement and energy efficiency with the maximum preservation of the elements that are subject to protection in accordance with the Federal Law of June 25, 2002?73-FZ "On Objects of Cultural Heritage (Monuments of History and Culture) of the Peoples of the Russian Federation." The authors are sure that as a result of numerous examinations and computer assessments, they have developed rational recommendations for the use of modern materials and identified optimal solutions to improve the energy efficiency of historic windows and light-transparent coatings.

The results of these surveys can be useful in the restoration of historic buildings. NIISF RAASN is ready to take part in similar works both in Moscow and in other regions of the Russian Federation.

The authors hope very much not to come across any more "restorations" like the one shown in Fig. 3.

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