Problems of Restoration of Historical Fenestration for Providing the Normalized Parameters of the Microclimate of Premises in Ancient Buildings

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Abstract. The article uses the example of the main building of the Pushkin State Museum of Fine Arts in Moscow. The problems of restoration of fenestration of old buildings with the preservation of historical elements and the creation of modern conditions and parameters of the microclimate were viewed. Also were carried out: visual and instrumental examination of existing fenestration, assessment of their influence on the microclimate of the premises, development of possible variants of their modernization with the maximum preservation of historical details and elements, modeling and calculation of these variants with the use of certified software, selection of optimal variants, as well as the development of recommendations for the restoration of windows and sky lights, ensuring the fulfillment of modern requirements to them. The results of the work will be used to restoration the main building of the museum, which in 2025 will be part of the Museum Neighborhood on Volkhonka Street in Moscow.

1. Introduction

After a period of catastrophic historical development in our architectural history in the 1990s-2000s., when entire neighborhoods of old houses were destroyed in many Russian cities, fortunately, the situation changed drastically - today there is a “boom” of building restoration. Only in Moscow in 2017 more than 300 old buildings were restored, the plans of the Moscow City Government for the coming years include the restoration of thousands of different objects.

Outwardly, everything looks very beautiful, in accordance with the old-time drawings and photographs, amazing rooms are put in order inside.

But, not everything is so good. The main problem with complex restoration of old buildings is not that it is necessary to preserve their appearance, but that it is necessary to ensure the fulfillment of modern requirements to the parameters of the microclimate of the premises, energy saving and other indicators [1, 2], which at the time when these buildings were built, didn’t even know. It is especially difficult to provide the requirements of the current regulatory documents in the buildings, which are monuments of federal importance, where the majority of construction elements should be preserved under the security regime.

Unfortunately, very often on renovated facades we find “insert teeth” - plastic windows (mostly for some reason white), which don’t fit into the beauty of buildings of 18th- early 20th centuries [3 - 5]. This is explained quite simply - one of the conditions of modern reconstruction (in addition to the restoration of the ancient appearance) is to increase the energy efficiency of old buildings to modern requirements. And with windows it’s very difficult to do it for several reasons:
- modern window technologies allow to provide very high indicators of thermal and lighting efficiency of constructions, which even at the beginning of the 20th century engineers and architects could not even dream of;
- almost all of the technologies used to produce old-style windows have been lost — so to replace rotten and lost parts, it’s very often necessary to "reinvent the bicycle";
- and the most important thing is the complete restoration of historical fenestration with bringing their characteristics to the modern level will be much more expensive than those windows, which domestic builders are used to install in typical modern buildings.

In 2018, the authors had the opportunity to take part in the development of recommendations for the improvement of fenestration (windows and covering) of the main building of the State Museum of Fine Arts in Moscow [6 - 10].

The building designed by architect Robert I. Klein was opened in 1912. The windows on the first floor and the translucent covering created by the famous Russian engineer Vladimir G. Shukhov and it haven’t changed since the construction of the museum (Fig. 1).

![Figure 1.](image1.png)

**Figure 1.** Windows (a) and sky light (b) at the Pushkin Museum of Fine Arts.

Many elements practically weren’t repaired since the moment of commissioning of a building (that is, more than 100 years), have come in relative uselessness (fig.2) and, basically, don’t correspond to requirements of modern building standard documents.

![Figure 2.](image2.png)

**Figure 2.** Current state of window elements (a) and translucent covering (b) in Pushkin Museum of Fine Arts.
The main tasks of our works were: visual and instrumental examination of existing fenestration structures; assessment of their influence on the microclimate of the premises; development of possible variants of their modernization with the maximum preservation of historical details and elements; modeling and calculation of these variants with the use of certified software; selection of optimal variants, as well as development of recommendations for restoration of windows and skylights, ensuring the fulfillment of modern requirements to them.

The results of visual and instrumental examination of historical windows on the first floor of the main building of the Pushkin Museum of Fine Arts are the followings:
- the outer and inner frames are made of sufficiently material-intensive steel corners, channel-shaped profiles, T-profiles, I-profiles and figured profiles, which were repeatedly repainted, but never treated with special formulations for corrosion protection;
- the outer and inner frames are fitted with usual 6 mm transparent glass;
- the given resistance to heat transfer of the tested structure [11 - 13] according to the results of the tests is in the range of $R_o = 0.37 - 0.39 \text{ m}^2 / \text{W}$;
- the conducted thermal imaging researches [14, 15] have shown the presence of numerous unfavorable zones, in which there are heat losses from the premises;
- condensate was observed on practically all window constructions at negative temperatures of external air, that is categorically contraindicated in halls with painting exposure.

The fenestration consists of three contours (Fig. 3): the main skylight, subflashlight and scattering plafond.

At the moment, all the contours of the glazing are made of single glass, mounted in metal T-shaped plates. All structures were installed during the construction of the museum at the beginning of the last century (some restoration work was carried out in the 1970s).

Briefly summarizing the results of our survey of translucent covering, we can note the following:
- the slopes of the roof of the skylight are made of fragments of glass 4-5 mm thick (the average size of the fragments of glass is $415 \times 1110 \text{ mm}$), the angle of inclination to the horizon is 50 degrees;
- the glasses are arranged with an overlap of the upper glass on the lower (as a tile) with a small clearance, which provides both additional ventilation and natural condensate drainage, that forms on the inner surface of the glass;
- the ventilation of the subflashlight space is carried out at the expense of extra ventilation holes, made of sheet steel, at the bottom of the roof slope (step through one segment);
- on the glazing of the skylight there are numerous traces of leaks, as well as broken glass, which in some areas have been replaced with plywood sheets and/or galvanized iron.

Figure 3. Diagram of fenestration of the Pushkin Museum of Fine Arts.
- the glazing of the lamp is dirty and has not been serviced for a long time, which significantly reduces its lighting qualities.

The second contour of the glazing of a translucent covering (subflashlight), the glazing of which is today carried out by single glass with a thickness of 5-6 mm. The angle of inclination of the horizontal glazing of the subflashlight is from 10 to 15 degrees to the horizon.

The current state of the glazing subflashlight completely does not correspond to its purpose - to provide natural lighting of exhibition halls. At the moment, in order to eliminate leaks into the main halls, the whole of the subflashlight is covered with a cloth, a plastic film, etc. That is why numerous additional light sources are installed in the space between the diffusing plafond and the subflashlight.

Diffusing laminated glass (with a rather dense matting) in the plafond is set horizontally on the same metal T-profiles as in the other contours of the fenestration coating.

One of the important conclusions of the survey, which was used when we planned the thermal regime of translucent covering during their restoration, is that the difference between the outdoor temperature and the temperature under the main sky light in the under-roof space is 8-10 ° C.

The results of evaluating the reduced transmission resistance:
- fenestration filling of the skylight - Ro = 0.18 - 0.20 m2 o C / W;
- fenestration filling of the subflashlight - Ro = 0.18 - 0.20 m2 o C / W;
- fenestration filling of the subflashlight + plafond - Ro = 0.40 - 0.45 m2 o C / W.

An important conclusion of this part of the survey, which was used in the planning of the thermal regime of translucent covering during its restoration, is that with a joint assessment of the glazing of the subflashlight and plafond, the heat transfer resistance increases by 0.20 - 0.25 m2 o C / W.

According to the results of field investigations of the historical structures of the fenestration of the main building of the Pushkin Museum of Fine Arts made the following main conclusions:
- fenestration are in very poor condition (in some cases non-repairable);
- the characteristics of historical fenestration do not correspond to the current regulatory documents;
- condensate that forms on the internal surfaces of fenestration during cold periods of the year adversely affect the safety of structures;
- on the structures of the skylight facing the horizon, it is necessary to provide special sun-protection devices and curtains that diffuse direct sunlight.

The calculation of the thermal performance of historical and fenestration proposed for the reconstruction, as well as the temperature distribution on the inner surfaces of the glazing and frames of metal profiles was carried out in accordance with the certified WINDOW - TEST software package, certificate RA.RU.AB86.N00994 [16].

8 different window variants and 13 translucent covering options with various glazings were proposed for calculation.

During the complex of calculations, the following were evaluated:
- reduced resistance to heat transfer of all versions of translucent structures;
- the possibility of condensation on the inner surfaces of the glazing.

For windows, the following option was considered optimal:

**Option 5.** historical fenestration, but fenestration filling – single IGU (insulated glass units) window with an outdoor sunscreen and an internal Low-E glass 4C3-10Ar-4H in an external metal frame and heat-reflecting glass with a soft Low-emission coating with an increased abrasion resistance 6 mm thick in an internal metallic frame with an internal metallic frame 6 mm thick. Temperature distribution is shown in Fig.4.
Figure 4. Temperature distribution over the inner surface of the lower part of the fenestration, manufactured according to Option 5, with $t_\text{n} = -28 \, ^\circ\text{C}$.

The reduced resistance to heat transfer of this option (while preserving historic steel frames) is $R_\text{o} = 0.58 \, \text{m}^2 \cdot ^\circ\text{C} / \text{W}$. At the same time, we were able to provide temperatures on the internal surfaces of fenestration, which ensure that condensation does not occur under all possible climatic conditions in the Moscow region.

Due to the fact that the features of the existing structures of the main skylight and the diffusing ceiling plafond it impossible to use modern energy-saving solutions (the inability to replace because of the building’s security status, insufficient bearing capacity to install, for example, triple-glazed IGU), it was decided to leave them single glazed.

To reduce heat losses from the building, it was decided to equip the subflashlight with modern glass units, while isolating the exposition halls from the under-roof space.

For computer evaluation, 13 different options for the glazing of the subflashlight were proposed. A number of them are based on the use of the existing metal construction, the rest are connected with the use of modern facade aluminum systems or an exact replica of historical structures made of fiberglass.

While preserving the historical structures, Option 7 turned out to be the best - the existing metal frame glazed with a triple IGU 4И-10Kr-4-10Kr-4И (4И – Low-E glass: PLANITHERM 4S, emission coefficient 0.013, warm edge TGI); on the side of the under-roof space, a 10 mm thick foam polystyrene overlay was installed on the brand (Fig. 5).

The heat transfer resistance of this design is $R_\text{o} = 0.92 \, \text{m}^2 \cdot ^\circ\text{C} / \text{W}$, while ensuring the absence of condensation on the metal parts of the translucent structure of the subflashlight.
Figure 5. Temperature distribution over the inner surface of the glazing of the subflashlight when using a IGU 4И-10Kr-4-10Kr-4И.

According to the results of field surveys and modeling of historic windows on the 1st floor and translucent covering of the main building of the Moscow State Museum of Fine Arts was developed detailed recommendations for their improvement, which are transferred to the restorers. We hope that when creating the Museum neighborhood on Volkhonka Street in Moscow will take into account our recommendations.

2. Conclusion
The authors hope that the research conducted and the developed recommendations for the reconstruction of very complicate historical fenestration of one of the significant federal cultural monuments will allow experts to draw attention to the need to take into account the features of old-style windows when restoring old buildings, and also show the main directions of such work. We are ready to take part in similar works in other historical buildings - they deserve that all their elements on the one hand correspond to the plan of the architects, and on the other hand - meet modern requirements for energy saving. Today there are so many possibilities, using modern window technologies, to give new life to old translucent structures.

And, in conclusion, it should probably be noted that at least some control over the restoration of translucent structures should be established during complex works on old buildings and the price approach to these works should be changed - high-quality window restoration cannot be cheap. “Cheap” performers lead only to the mutilation of beautiful old buildings, of which, unfortunately, very few remain [17, 18].

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