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Restoring historical fenestration to normalize physical parameters of the microclimate of premises in historical buildings

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Abstract: The problems related to restoring the fenestration of old buildings while preserving their historical elements and achieving modern acceptable conditions and parameters of the buildings' microclimate were studied. A visual and instrumental examination of existing fenestrations was conducted assessing their influence on the microclimate of the premises. Development of possible variants of modernization while ensuring the maximum preservation of the historical details and elements of the buildings was carried out, including the modelling and calculation of these variants by certified software. The most optimal variants were selected, and recommendations for the restoration of windows and skylights, ensuring the fulfillment of modern requirements, were developed. The results of the work will be used in the restoration of the main building of the Museum of Fine Arts, which in 2025, will make up part of the town museum on Volkhonka Street, Moscow.

Keywords: fenestration, translucent covering, historical windows, parameters of microclimate, heat transfer resistance, condensate, software complex

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Introduction

After a period of catastrophic historical development in our architectural history during the 1990s and 2000s, entire neighborhoods of old houses were destroyed in many Russian cities. Fortunately, the situation has changed drastically and today there is a “boom” in building restoration. In 2017, in Moscow alone, more than

300 old buildings were restored. The Moscow city authorities plan in the coming years to restore thousands of different objects throughout the city.

Outwardly, the buildings look extremely beautiful and match with the old-time drawings and photographs that show impressive rooms neatly ordered. But, not everything is as it seems. The main problem with the 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 building requirements for the microclimate of the premises including energy conservation and other indicators (SP 50.13330.2012; GOST 30494-2011), which at the time these buildings were built, were not known about.

It is especially difficult to meet the requirements of the current regulatory documents related to buildings that include monuments of federal importance and where the majority of the construction elements should be preserved under protection laws. Unfortunately, it is common to find modern elements, such as white plastic windows, imposed on the facades of these buildings that don't fit into their 18th-early 20th century beauty (*Replacement of windows*; Shestov, 2013; Anderson, 2014). This situation is simply explained, as one of the conditions of modern reconstruction (in addition to the restoration of the historical appearance of the building) is the conformation of the old buildings to modern energy-efficiency requirements and in the case of windows, this can be very difficult for several reasons:

– modern window technology provides high thermal and lighting efficiency undreamed of by engineers and architects even at the beginning of the 20th century;
– almost all the techniques and knowledge used to produce old-style windows has been lost so replacement of rotten and lost parts requires "reinventing of the bicycle";
– and most importantly, the cost of completely restoring historical fenestration while bringing the buildings in line with modern requirements is much cheaper if typical domestic market windows, such as those used in modern buildings, are used.

1. Developing recommendations for the improvement of fenestration

In 2018, the authors had the opportunity to take part in developing recommendations for the improvement of fenestration (windows and covering) of the main building of the State Museum of Fine Arts in Moscow (*Documentation prepared by the Federal State Unitary Enterprise*; *Scientific and Technical Report* 2018a; 2019b; Spiridonov, Umnyakova, 2019a; 2019b). 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, has not changed since the construction of the museum (Fig. 1). Many elements have not been repaired since the commissioning of the building more than 100 years ago having lost their effectiveness (Fig. 2) and do not meet the requirements of modern building standards documentation.

a b

Fig. 1. Windows (a) and skylight (b) at the Pushkin Museum of Fine Arts (*own photo*)

a b

Fig. 2. Current state of window elements (a) and translucent covering (b) in the Pushkin Museum of Fine Arts (*own photo*)

The main task of the project was: a visual and instrumental examination of existing fenestration structures assessing their influence on the microclimate of the premises, and the development of possible variants of modernization ensuring the maximum preservation of historical details and elements. This included the modelling and calculation of these variants with the use of certified software, the selection of the most optimal variants, as well as developing recommendations for the restoration of windows and skylights ensuring the fulfillment of modern building requirements.

The results of a visual and instrumental examination of historical windows on the first floor of the main building of the Pushkin Museum of Fine Arts are as follows:

– the outer and inner frames are made of suitable material with steel-intensive corners, channel-shaped profiles, T-profiles, I-profiles and figured profiles, which have been repeatedly repainted but never treated for corrosion protection;
– the outer and inner frames are fitted with the usual 6 mm transparent glass;
– the given resistance to heat transfer of the tested structure (GOST 26602; GOST R 54853; GOST 31167) according to the results of tests is in the range of R_o = 0.37-0.39 m^2 K/W;
– the conducted thermal imaging studies (GOST R 54852; Levin et al., 2012) have shown the presence of numerous unfavorable zones, in which heat is lost from the premises;
– condensation was observed on practically all the window constructions at external negative temperatures, though there was no indication of this in halls with painting exposure.

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

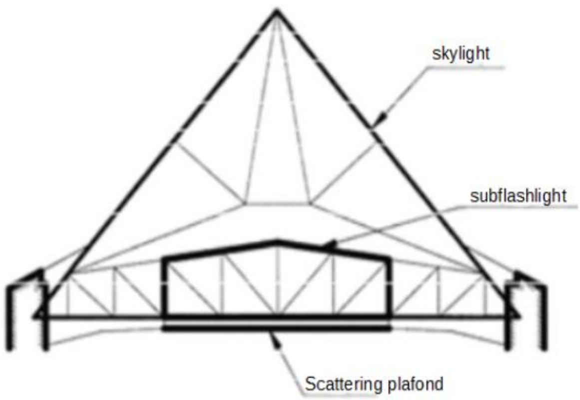

Fig. 3. Diagram of fenestration of the Pushkin Museum of Fine Arts (*own study*)

At the moment, all the contours of the glazing are made from a single piece of 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).

The results of our survey of the translucent covering are briefly summarized below:
– the sloping roof of the skylight is made of pieces of glass 4-5 mm thick (the average size of the piece is 415 x 1110 mm), the angle of inclination to the horizon is 50 degrees;
– the glass pieces are arranged with the upper glass overlapping the lower (as with tiling) with a small clearance which provides both additional ventilation and natural condensation drainage that forms on the inner surface of the glass;

- the ventilation of the subflashlight space is achieved at the expense of extra ventilation holes, which are 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;
- the glazing on the lamp is dirty and has not been serviced for a long time, significantly reducing its lighting effect.

The glazing of the second contour is a translucent covering (subflashlight), which consists of a single pane of glass with a thickness of 5-6 mm. The angle of inclination of the horizontal glazing is from 10 to 15 degrees to the horizon. The current state of the subflashlight glazing is not suitable for its purpose, to provide natural lighting of the exhibition halls. At the moment, in order to eliminate leaks into the main halls, the whole of the subflashlight is covered. Consequently, 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 with the other contours of the fenestration coating.

One of the important conclusions of the survey was that the difference between the outdoor temperature and the temperature under the main skylight in the under-roof space was 8-10°C, which was taken into account when planning the thermal regime of translucent covering during the restoration,

The results of evaluating the reduced transmission resistance were:

- fenestration filling of the skylight – R_o = 0.18-0.20 m^2 K/W (coefficient U = 5.00-5.56 W/(m^2·K);
- fenestration filling of the subflashlight – R_o = 0.18-0.20 m^2 K/W (U = 5.00-5.56 W/(m^2·K);
- fenestration filling of the subflashlight + plafond – R_o = 0.40-0.45 m^2 K/W (U = 2.22-2.50 W/(m^2·K).

An important conclusion from this part of the survey, again used in restoration planning, was that with a joint assessment of the glazing of the subflashlight and the plafond, the heat transfer resistance increased by 0.20-0.25 m^2 K/W; U = 4.00-4.50 W/(m^2·K).

In view of the results of field investigations conducted, the following conclusions were made:

- the fenestrations are in very poor condition (in some cases non-repairable);
- the characteristics of the historical fenestration do not correspond to the current regulatory documents;
- condensation that forms on the internal surfaces of the fenestration during cold periods of the year adversely affect the safety of the 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.

2. Calculation of the thermal performance of the historical fenestration

The calculation of the thermal performance of the historical 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 (*User's Guide*, 2006).

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

During the complex of calculations, the following was 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 4СЗ-10Ar-4И 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 Figure 4.

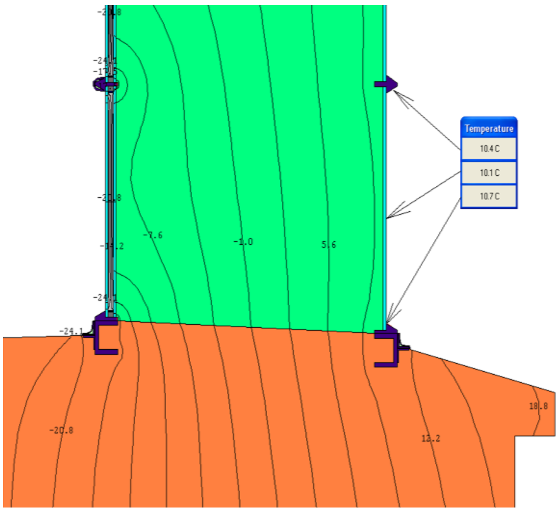

Fig. 4. Temperature distribution over the inner surface of the lower part of the fenestration, manufactured according to Option 5, with $t_н$ = –28°C (*own study*)

The reduced resistance to heat transfer of this option (while preserving historical steel frames) is R_o = 0.58 m^2 K/W (U = 1.72 W(m^2·K). 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 make 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 sublashlight with modern glass units, while isolating the exposition halls from the under-roof space.

For the 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 the historical structures made from fiberglass.

When preserving the historical structures, Option 7 was the best – the existing metal frame glazed with a triple IGU 4И-10Kr-4-10Kr-4И (4И – low-E glass: PLANITHERM 4S, emission coefficient ε = 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 $R_o = 0.92$ m^2 K/W ($U = 1.09$ W/(m^2·K), while ensuring the absence of condensation on the metal parts of the translucent structure of the subflashlight.

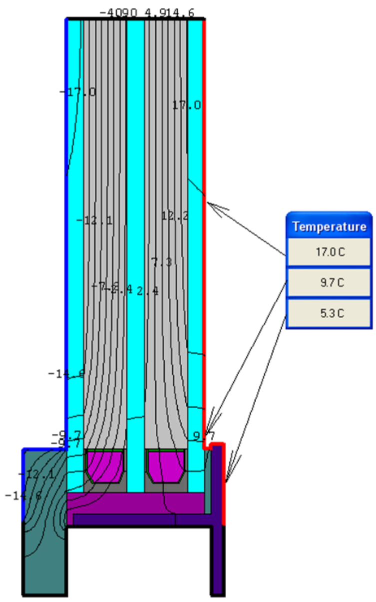

Fig. 5. Temperature distribution over the inner surface of the glazing of the subflashlight when using a IGU 4И-10Kr-4-10Kr-4И (*own study*)

According to the results of field surveys and modelling of the historic windows on the 1st floor and translucent covering of the main building of the Moscow State Museum of Fine Arts detailed recommendations were developed for their improvement, which were passed on to the restorers. It is hoped that these recommendations will be taken into account.

The authors hope that the research conducted and the developed recommendations for the reconstruction of the complex historical fenestration of one of Moscow's most 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 historical buildings, and also show the main direction of such work. The authors are ready to take part in similar work on other historical buildings where there is a duty to stay faithful to the plan of the original architect while ensuring these buildings meet modern requirements for energy efficiency. There are so many possibilities today, using modern window technologies, to breathe new life into old translucent structures.

Conclusions

In conclusion, it should probably be noted that at least some control over the restoration of translucent structures should be established during work on historical buildings and the cost-focused approach to these projects should be changed – high-quality window restoration is not cheap. "Cheap" solutions lead only to the mutilation of these beautiful old buildings, of which, unfortunately, very few remain (*International Charters for Conservation*, 2004).

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