

## COMPUTER MODELLING AND RECOMMENDATIONS FOR RESTORATION OF THE HISTORICAL TRANSLUCENT STRUCTURES OF THE PUSHKIN STATE MUSEUM OF FINE ARTS

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### ABSTRACT

On the basis of the previous examinations of the historical windows of the main building of the Pushkin State Museum of Fine Arts by the authors [1] using a certified software package, the multi-variant analysis of the methods of increasing efficiency of the existing translucent structures was conducted. The recommendations for restoration of the historical translucent structures which are the parts of this state-protected cultural heritage object were developed.

**Keywords:** restoration, historical translucent structure, frame, sash, impost, computer modelling, computer calculations, heat transfer resistance, air permeability, condensate, recommendations

### 1. INTRODUCTION

As a result of the surveys of historical translucent structures [1], it became obvious that they do not comply with the current requirements, neither in terms of heat transfer resistance nor in terms of air permeability. In case of preservation of metal window frames (according to the requirements of the law on protection of cultural heritage sites and the Customer's order [2]) the large-scale computer calculations should be performed to determine the best ways of window restoration.

Calculation of thermo-technical characteristics of the historical translucent structures proposed for restoration as well as temperature dis-

tribution on the inner surfaces of glazing and profiles of metal frames was performed using the certified *WINDOW – TEST* (version 2017) software package [3] with different boundary conditions for each of the compared variants of translucent structures.

The calculation method is based on modelling of a steady-state process of heat transfer through structures using PC software and thermal design of the fragments of building structures (including translucent ones), glazing systems and joints of window units and the walls.

This method allows the next performs:

- Comparative analysis of the variants of translucent structures of different designation on the basis of reduced total thermal resistance;
- Selection of optimal structural solutions on the basis of the conducted thermal designing;
- Determination of the dimensions of the areas of one-dimensional and two-dimensional temperature fields of the translucent structures for preparation to testing in a climatic chamber;
- Evaluation of the temperature mode of the joints of window units and the walls and selection of the most optimal structural solution of erection joints.

For calculation, the following 6 design variants of the translucent structures were selected:

1. The existing historical translucent structure in accordance with the detail measurements performed in the course of on-site investigations; the translucent filling is made of transparent M1 glass

with thickness of 6 mm in an inner and outer metal frames;

2. Similar to variant 1 but the translucent filling is sun-protecting glass with thickness of 6 mm in the outer metal frame and the glass with hard heat-reflective coating (K-glass) with thickness of 6 mm in the inner metal frame;

3. Similar to variant 1 but the translucent filling is sun-protecting glass with thickness of 6 mm in the outer metal frame and the 4–10Ar–4И double-glazed unit with internal heat-reflective glass in the inner metal frame;

4. Similar to variant 1 but the translucent filling is the 4C3–10Ar–4 double-glazed unit with external heat-reflective glass in the outer metal frame and the 4–10Ar–4И double-glazed unit with internal heat-reflective glass in the inner metal frame;

5. Similar to variant 1 but the translucent filling is the 4C3–10Ar–4И double-glazed unit with external sun-protecting glass and internal heat-reflective glass in the outer metal frame and heat-reflective high abrasive-resistant glass with soft low-emission coating with thickness of 6 mm in the inner metal frame;

6. The outer frame remains historical one and the inner metal frame is replaced by a contemporary fibreglass frame with similar dimensions; the translucent fillings are similar to variant 5.

The internal microclimate conditions for calculations were taken in accordance with the Pushkin State Fine Art Museum (hereinafter referred to as the Pushkin Museum) main building reconstruction project: temperature of  $20 \pm 1$  °C and relative humidity of  $50 \pm 5$  %.

In accordance with set of rules [4, Table 3.1], the ambient temperature of 28 °C was used for all variants calculation. But the evaluations of thermo-technical parameters of the building structures were performed with other values ambient temperature for the variant 1 and the best of the variants 2–5 (based on the results of preliminary calculations): – 30, – 20, – 15, – 10, 0, + 10 and + 21 °C for variant 1 and – 20, – 15, – 10 and 0 °C for variant 5.

In the course of calculation, the reduced total thermal resistance for all variants of translucent structures and possibility of condensation on the internal surfaces of glazing were evaluated.

The results of computer calculations are listed in the Table.

The Table shows that the translucent structures manufactured in accordance with variants 3 and 4

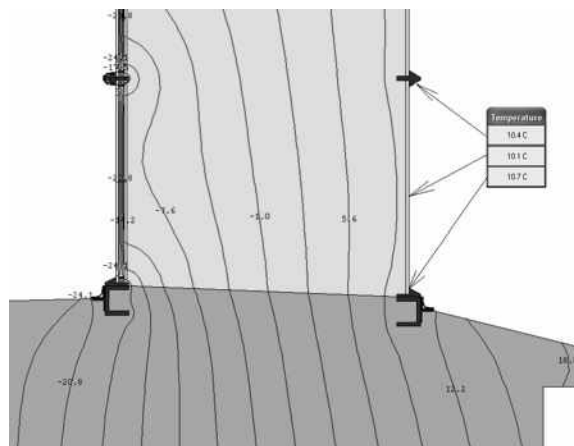


Fig. 1. Distribution of temperatures on the inner surface of the lower part of a translucent structure manufactured in accordance with variant 5 with ambient air temperature of minus 28 °C

(lines 10 and 11) comply with thermo-technical requirements of all applicable regulations and are the best in terms of glazing temperature. However, due to changing of the heat transfer mode in the space between glasses in case of installation of the double-glazed units in the inner metal frame, the possibility of condensation on the angular elements of the inner metal frame increases dramatically.

On the basis of the conducted survey of different variants of restoration of the historical translucent structures, the experts proposed to use the variant 5 (the corresponding temperature distribution is shown in Fig. 1).

On the basis of the numerous on-site investigations of the historical windows of the 1<sup>st</sup> floor of the main building of the Pushkin Museum, the following major conclusions were made:

- The historical translucent structures require immediate restoration;
- The characteristics of the translucent structures (reduced total thermal resistance, air-permeability) do not comply with the applicable standard regulations, and it is hard to comply with the requirements of the applicable standard regulations regarding reduced total thermal resistance [5] provided that the historical translucent structures are preserved but it is possible to significantly increase their thermal efficiency;
- The temperature on the inner surfaces of the existing historical translucent structures is lower than the dew point temperature almost at all negative values of ambient temperature, which causes significant condensation;

- The condensate generated on the inner surfaces of the translucent structures in cold periods causes negative impact on the pieces of art exhibited in the museum;

- It is necessary to provide special sun-protecting devices and curtains diffusing direct sunlight for the translucent structures of the East, South, and West facades of the main building of the Pushkin Museum.

Due to the fact that a clear and incontestable requirement of [2] is preservation of the historical translucent structures installed in 1912, the main goal of our recommendations was restoration and increasing of efficiency of the metal frames, elimination of condensate on the inner surfaces of the windows and protection of pieces of art from direct sunlight using the most contemporary construction technologies.

The developed recommendations based on the results of the on-site investigation and computer modelling of different variants of glazing in the historical translucent structures are divided into 6 sections related to modernisation of specific elements of the design.

## 2. RESTORATION OF METAL FRAMES OF THE HISTORICAL TRANSLUCENT STRUCTURES

The metal frames are largely corroded. Due to this fact, the following actions are required to be taken during the restoration (the word “reconstruction” probably fits more)<sup>1</sup>:

- Remove both inner and outer frames;
- Clean them from the traces of numerous paintings performed over the previous one hundred years;
- Disassemble the metal frames (including the main vertical impost consisting of a large number of elements);
- To clean absolutely *all* elements of the structures from corrosion and to treat them with contemporary corrosion preventive compounds;
- In case of possible replacement of the historical elements with newly-manufactured ones due to full impossibility of restoration of the former, it is necessary to prevent application of contemporary

materials which may cause an electrochemical reaction when contacting the historical ones;

- The elements of the metal frames should be painted only *after* taking the above listed actions.

## 3. MODERNISATION OF JOINTS

Currently, the translucent structures are fixed to the wall directly, which increases the possibility of condensate penetration due to negative impact by the enclosure structure.

It is necessary to perform heat insulation of the historical window frames from the enclosure structures using contemporary materials.

For this purpose, after removal of the metal frames for restoration (see the first part of our recommendations), it is necessary to perform wall chasing in the areas of installation of the outer metal frames, to install a contemporary and efficient heat insulation material in the chases, e.g. penoplex, and to install the historical translucent structures into position only after that.

The recommended cross-section dimensions of the heat insulation materials are 200 (width) × 20 (depth) mm. In Fig. 2, one of the variants of the recommended heat insulation of the perimeter of the window opening in the course of restoration of the historical translucent structures.

## 4. MODERNISATION OF DRAFT-PROOFING OF THE HISTORICAL TRANSLUCENT STRUCTURES

In the course of installation of the restored historical translucent structures in the window openings, it is necessary to provide maximum draft-proofing of the inner metal frame to prevent penetration of internal moist air in the space between the glasses as far as possible to minimise the possibility of condensation on the inner surface of the outer metal frame.

For the same purpose, it is necessary to restore and to adjust the historical hardware of the window leaf (both in the outer and especially inner metal frame) and to open them only if strictly necessary. The ledges of the leaves should be equipped with

<sup>1</sup> The experts are afraid that some elements of the frames cannot be restored and will require to be replaced (in particular, it is definitely required to replace steel angle elements underneath the lower inner decorative plates of many frames which are mostly affected by the condensate as well as the lower inner parts of the main vertical impost).

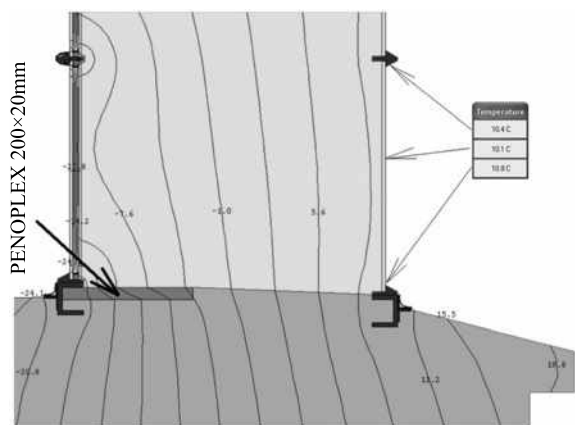


Fig. 2. Heat insulation of the perimeter of the outer metal frame

a contemporary sticky sponge material (there are lots of such sealants nowadays).

In the course of draft-proofing of the outer metal frame, it is necessary to provide air drains for natural ventilation of the space between the glasses and for access of relatively dry ambient air during the cold period for minimisation of condensation on the inner surface of the outer metal frame. The total length of the openings for natural ventilation of the space between the glasses should not exceed (1–3) % of the overall perimeter of the joint of a window and an enclosure structure.

### 5. MODERNISATION OF GLAZING OF THE HISTORICAL TRANSLUCENT STRUCTURES

In the course of the on-site [1] and computer investigations and based on the results of evaluation of the 6 variants of restoration of the historical translucent structures, the variant 6 (see above) was selected.

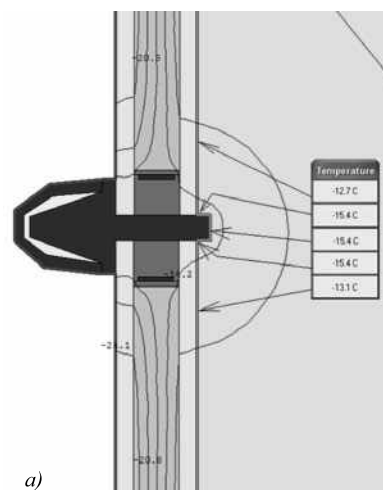
It is this variant which provides the best temperatures of the inner surfaces of glazing excepting condensation at the standardised air temperature in Moscow  $-28\text{ }^{\circ}\text{C}$ .

The reduced total thermal resistance of such translucent structure will be equal to  $0.58\text{ (m}^2\cdot^{\circ}\text{C)/W}$ , which complies with the requirements of SP (set of rules:  $0.54\text{ (m}^2\cdot^{\circ}\text{C)/W}$ ) for the Moscow climate conditions. But after introduction of the Amendment No. 1 to the above mentioned SP (which is expected soon), the standardised reduced total resistance of windows will be equal to at least  $0.70\text{ (m}^2\cdot^{\circ}\text{C)/W}$ .

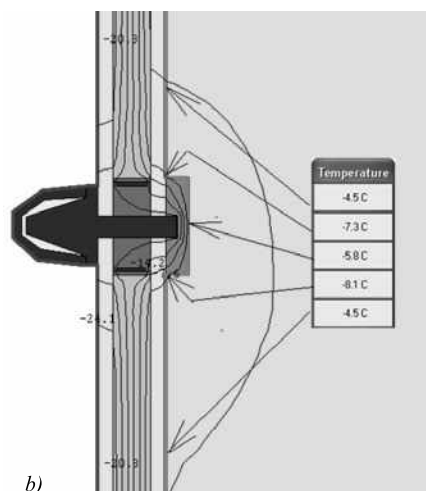
It is recommended to use a “warm” SWIGGLE STRIP spacer bar in the double-glazed unit since it will change the exterior of the translucent structures minimally. It is possible to select black upper colour of the spacer (like that of the frame itself) and minimal available thickness of the spacer.

It is necessary to install standard plastic plates of minimal possible thickness between the double-glazed unit and the metal frame and the double-glazed unit shall be fixed by means of one of the sealants for structural glazing along its perimeter. The glass of the inner metal frame should be fixed too.

The width of the seat of the metal frame where the double-glazed unit will be installed is 21 mm, therefore it is impossible to use more efficient units with spacer bars of (12–16) mm in width. But even the proposed type of the double-glazed



a)



b)

Fig. 3. Temperature fields in the area of the main vertical impost of the outer metal frame without (a) and with (b) installed water bar calculated in accordance with variant 5

**Table. Generalised Results of Computer Calculation of Variants of Restoration of Historical Translucent Structures**

( $R_{op}^{np}$  is reduced total thermal resistance,  $t_h$  is ambient air temperature,  $t_{oct}$  is the temperature in the middle of the inner glass,  $t_{pam}$  is the temperature of the inner surface of the metal frame)

Variant of glazing	$R_{op}^{np}$ , (m <sup>2</sup> ·°C)/W	$t_h$ , °C	$t_{oct}$ , °C	Condensate generation possibility	$t_{pam}$ , °C	Condensate generation possibility
1		-681	-1.9	yes	-1.1	yes
	0.34	-681	-1.0		-681	
		-20	3.2		3.5	
		-681	4.8		5.5	
		-681	6.8		7.7	yes*
		0	11.2	yes**	11.5	yes**
		10	15.6	no	15.8	no
		21	20.4		20.4	
2	0.38	-681	-681	yes	-681	yes
3	0.56	-681	13.0	no	-681	
4	0.67	-681	14.6		-681	
5	0.58	-681	11.4	yes**	10.4	yes**
		-681	11.5		11.1	
		-681	12.6	no	12.0	no
		-681	13.6		13.1	
		0	16.1		15.6	
6	0.66	-681	5.8	yes	12.8	

Notes:

\* Only in one situation (air temperature: 19 °C, relative humidity of air: 45 %, dew point temperature: -6.81 °C), condensate generation is excepted;

\*\* Only in one situation (air temperature: 21 °C, relative humidity of air: 55 %, dew point temperature: -11.62 °C), condensate generation is excepted.

unit (4C3-10Ar-4И) with thickness of 18 mm provides required temperature on the inner surface of glass.

Due to the fact that there are metal plates installed on the glass in the upper quarters of the historical translucent structure, double-sided porous adhesive tapes should be installed between the plates and the glass/double-glazed unit (there is a wide selection of such materials in the market).

If necessary, to increase safety, it is possible to apply a polymer film on the glass located in the inner metal frame like it is done currently.

## 6. PREVENTION OF CONDENSATION ON THE METAL SASHES

Among the most critical elements of the historical translucent structures in terms of condensation are the metal sashes, especially the main vertical metal impost.

On its inner surface, sub-zero temperatures were registered almost at all sub-zero temperatures of ambient air, which will obviously assist in condensation or even generation of frost on them.

For enhancement of temperature mode of this element of structure, it is proposed to install a special

plate made of, for example, extruded foamed PVC and painted black (so that it cannot be seen against the background of the metal frame) on the invisible part of the element so that the temperature on the inner surface of the main vertical impost of the historical translucent structure will be significantly increased.

According to the variant 5 recommended for application in the course of the said restoration of the historical translucent structure, it is necessary to insulate the main vertical impost only of the outer metal frame inside the space between the glasses (Fig. 3).

At the most sub-zero ambient temperatures, condensation on the inner surfaces of the main sashes of the inner metal frame is possible.

We propose to place a special heating cable along the perimeter of these sashes in the space between the glasses hidden from view from the premises. It is recommended to use adjustable cables with maximum temperature of up to 38 °C made of composite materials (there are a lot of variants of such devices on the market).

It is necessary to provide uninterrupted convection of warm air from heating devices which are now hidden behind the decorative racks and windowsills. For this purpose, it is necessary to install special ventilating grids in the windowsills (there are lots of variants on the market).

One of possible solutions of the problem of temperature increasing of the inner glazing and metal frames surfaces is installation of convector heaters in the space between the glasses, but it is considered not the best solution for prevention of condensing on glazing.

## 7. INCREASING OF VISUAL COMFORT

A large amount of the translucent structures of the main building of the Pushkin Museum is oriented towards the solar rhumbs of the horizon.

Apart from the fact that excess direct and diffuse solar irradiation of the premises causes negative impact on efficiency of the air conditioning systems, direct sunlight may also negatively affect the pieces of art and interfere in perception of the same.

In that respect, the experts propose to install special electric-driven sun-protecting curtains in the space between the glasses. Such sun-protecting devices are manufactured by many companies.

Due to the fact that there are metal staples installed between the inner and the outer metal frames which, apart from the ladder function, also connect the frames, it is practically impossible to install integrated sun-protecting curtains and it will be necessary to divide them into two parts.

The authors hope that:

- The conducted surveys and the developed recommendations regarding restoration of very complicated historical translucent structures of one of the important federal cultural heritage objects will allow drawing attention of specialists to necessity of consideration of distinctions of the old-design windows in the course of restoration of old buildings and will show the main aspects of this work;
- After the comprehensive restoration, the facades of the main building of the Pushkin Museum will be included in the next summary of achievements of the *International Council on Monuments and Sites* [6] which also describe the translucent structures.

The authors are ready to participate in similar works regarding other historical buildings as they deserve all their elements to comply with the concept of architects from the one hand and to comply with the contemporary energy saving requirements from the other hand. Nowadays there are many opportunities to give a new lease of life for old translucent structures by means of contemporary window technologies.

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