Providing thermal protection when replacing window blocks in historical buildings

A Konstantinov and A Mukhin

Moscow State University of Civil engineering, 26 Yaroslavl highway, Moscow, 129337, Russia

E-mail: apkonst@yandex.ru

Abstract. The work presents the prerequisites to replace the window units in the historical buildings (primarily increased energy efficiency standards of buildings and significantly changed performance requirements of window units). The analysis of possible replacement options (full/partial) of window units of the historical buildings is done according to their architectural and historical values. A review is made of the existing technological capabilities of modern window systems and translucent filling (double-glazed windows), as well as the most common solutions used in practice. The issue of providing the temperature-humidity conditions of the nodes of adjunctions of the window blocks to the openings of the external walls in the winter operating conditions is considered. For this purpose, a numerical simulation of the temperature fields of the junction points is made for various structural embodiments of window frames. It is established that in the case of a full replacement of window blocks and maintaining the existing structure of external walls (the calculation is made using the example of the most common external wall for Central Russia – a brick wall 770 mm thick), condensation may form on the inner surface of window slopes. Different options are suggested for window blocks installation, which ensure the fulfillment of sanitary and hygienic requirements. Further directions for the research on the use of modern types of translucent structures in the historical buildings are outlined.

1. Introduction

Currently, many historical buildings built in Russia in the early 20th century and earlier require major repairs / restoration. Often this is due both to the unsatisfactory technical condition of such buildings and their discrepancy with modern standards of comfort and energy efficiency. One of the most cost-effective ways to preserve historical buildings is their adaptation to modern use [1]. This is reflected, among other things, in the implementation of a set of measures aimed at achieving regulatory requirements of thermal protection and internal parameters of indoor climate in these buildings. Issues related to the restoration or replacement of windows require special attention. This is due to the fact that a wide range of requirements are applied to the window units used in historical buildings [2–5]:
- the architectural appearance of buildings;
- thermal protection of buildings and specified parameters of indoor climate (natural lighting, temperature-humidity conditions, acoustic microclimate);
- operational safety and protection against unauthorized access;
- ease of operation and maintenance.

It is necessary to understand that the possibilities of increasing the energy efficiency of historic buildings due to increased thermal protection of external walls are significantly limited. This is due to
the fact that changes in the appearance of the facades of such buildings in many cases is not allowed. Therefore, insulation of external walls of historical buildings with energy efficient insulators is not possible in most cases. Alternative options for insulation (for example, the use of thermal insulating plaster [6]) in the climatic conditions of Russia will not obviously have a significant effect. Therefore, the use of modern designs of window units with high thermal resistance is the most effective way to increase the thermal protection of the outer shell of buildings of this type.

Modern technological capabilities of manufacturers of translucent structures allow the mass production of window blocks with the thermal resistance of 1.0 m² K/W and higher, which exceeds the thermal resistance of external brick walls with a thickness of 770 mm (3 bricks). When they are used, the heat loss of buildings through the outer enclosure in the winter period of operation differs from traditional significantly [7–15]. In this case, from the point of view of providing thermal protection, the windows will not be the most vulnerable part of the outer shell of the building.

The use of energy-efficient window units along with the implementation of measures for the installation of modern heating and ventilation systems with recuperation, as well as, possibly, the use of alternative energy sources (solar collectors, solar panels, etc.) are integral elements of improving the energy efficiency of historical buildings in modern conditions [16–20].

2. The possibility of replacing window blocks in historical buildings

Depending on the historical and architectural value of the historical buildings, there are two categories of them:

- buildings without special historical and architectural value. They are the most common ones and are currently used to accommodate residential, office and retail space, hotels and theaters;
- objects of cultural heritage, which are monuments of architecture. They may have the status of a monument of architecture of local, regional or federal significance, or be a World Heritage site.

In buildings without special historical and architectural value, special requirements to the constructive solution of the replaced window blocks are usually not presented. The most appropriate way is the use of modern energy-efficient window units (see Figure 1a). Thus, when choosing an architectural design and the color of the window frames, the characteristic features of the architectural style of the building should be taken into account.

For architectural monuments, the legitimacy of the use of modern window units in order to replace old ones is allowed based only on the historical and cultural examination and/or the security obligation of the user of the cultural heritage object [21]. The constructive solution of new window blocks (the material of bindings, translucent filling, etc.) is made based on the object of protection of cultural heritage reflected in the security commitment or developed as a part of the restoration project.

Typically, the historical buildings used to have isolated window units installed with the outer and inner window sash made of one glass. The following options are possible for the given design of windows:

A) The subject of protection is both the facade and the interior of the building. In this case, it is necessary to restore the existing window blocks or completely recreate the damaged/lost items. Due to the fact that it is necessary to use materials and technologies applied in the old window blocks, a qualitative improvement of their operational characteristics, as well as energy efficiency of buildings, will not generally occur.

B) The subject of protection is the facade of the building. In this case, it is necessary to preserve (restore) the outer part of the existing window block, or to recreate it from identical materials according to the measurement drawings. Instead of an internal frame, it is possible to install a modern design of window units (see Figure 1b). In this case, the outer part of the window unit will provide architectural requirements of security obligations and the inner part – regulatory requirements for the thermal protection of buildings and indoor climate. In order to increase the natural lighting, reduce the cost of production, as well as maximum preservation of visual perception of the interior of the
building when viewed from the side of the street, it is most optimal to use window units without additional decorative elements.

C) The subject of protection is the interior of the building or its separate room. In this case, it is necessary to save/recreate the internal part of the window, as well as possible replacement of its outer part with a modern one (see Figure 1c). At the same time, the architectural pattern, color and texture of the external part of the window block must comply with the architectural style of the building and the color palette of its facades. The outer part of the window unit in this case ensures compliance with the regulatory requirements for thermal protection of buildings and the inside climate, anti-burglary.

D) The facade and interior of the building are not eligible for protection. If the material and appearance of the window blocks are not specifically negotiated in the security obligation, thus, as in the case with buildings without a special historical and architectural value, it is possible to completely replace the old window units with modern ones (see Figure 1a).

Figure 1. Possible schemes for replacing window blocks in historical buildings
a – for buildings without special historical and architectural value and architectural monuments (the facade and interior of the building is not a subject to protection);
b – for monuments of architecture (the subject of protection – the facade of the building);
c – for monuments of architecture (the subject of protection – the interior of a building)
3. Technological capabilities of modern window systems and translucent filling
Replaceable window units can be made based on modern window systems from wood, PVC, aluminum, combined materials (wood-aluminum, aluminum with wooden plates), etc. Thus, there are technical solutions for restoration in the developed window systems of leading manufacturers (for example, restoration of the frame, which can be installed in the opening on top of the old ones without dismantling them). Modern windows can be painted in any color, and PVC profiles can have lamination of different colors and textures that allows to make window frames to fit any color scheme of the facade. Their use in conjunction with modern designs of double-glazed windows allows to achieve high rates of thermal resistance of window units and significantly improve the thermal protection of buildings.

The most common type of window units used in historical buildings and objects of cultural heritage due to their relatively low cost are PVC window frames (see Figure 2).

![Figure 2. Examples of the use of PVC window frames in the objects of cultural heritage](image)

A perspective solution for historical buildings is the use of vacuum insulating glass as a translucent filling. Due to the high thermal resistance [22, 23], low weight and the overall thickness of the insulating glass unit (8 mm), they can also be used in the storable/reconstructed window blocks (after additional milling of the window fillets).

4. Temperature-humidity conditions of the junction points of window blocks during the winter period of operation. Analysis of results
Let’s consider the temperature conditions of the junction points of different types of window blocks in the opening of the outer wall. The analysis of temperature-humidity conditions of the junction points will be produced based on the calculations of the temperature fields of the considered nodes performed in the Flixo 6 software package. Calculations will be made for the conditions of Moscow city (outside temperature of the coldest five-day period of -25 °C) and internal air temperature of + 20 °C.
Figure 3. Results of the calculation of the side junction of different constructions of window blocks to the openings of the external walls of historical buildings

a – for the old window unit;

b – for a window unit made of PVC (without additional measures);

c – for window units made of PVC with the insulation of a window slope
The outer walls of most buildings built on the territory of Russia are made of ceramic bricks and, typically, have a thickness of at least 770 mm (excluding plaster). The old window blocks are usually made of a single window frame with the hanging outer and inner window sashes on it. Generally, window units are installed in the outer wall outside of the window quarter with a thickness of one brick (120 mm). Due to the homogeneous construction of the external wall, in terms of heat engineering, such positioning of the window unit in the outer wall is optimal because the internal part of the window unit is in the zone of positive temperatures of the external wall. Thus, the formation of condensation on the window slopes does not occur (see Figure 3a).

When the old window unit is replaced with a new one (for example, PVC), the temperature-humidity mode of this unit significantly changes. Before installing a new window block, the old block is dismantled or cut off. Installation of a new window unit is made directly outside of the window quarter. Thus, the new window unit is located in the zone of negative temperatures of the outer wall, which leads to condensation of the internal surface of the window slopes (see Figure 3b).

In order to eliminate the above-described phenomenon and to ensure the regulatory requirements for the temperature-humidity mode in accordance with [2], it is necessary to perform one of the following measures before installing the window units:
- insulation of the window slope with subsequent plastering;
- the device of a warmed slope from a sandwich panel (not always possible from an architectural point of view);
- forming groove in wall with its subsequent warming (with an unsatisfactory technical condition of the masonry, this measure is not possible).

These measures make it possible to change the temperature-humidity mode of the considered junction nodes significantly. This statement is confirmed by calculations (see Figure 3c).

5. Discussion
Conducted studies in the article certainly do not affect all the factors that must be taken into account when replacing window blocks in historical buildings. It is planned to conduct further research in the future:
- thermal characteristics of combined structures of window blocks (for the case of a partial replacement of the old window unit) based on winter and summer operating conditions (overheating of the space between the old and the new window unit);
- the issue of providing natural illumination of rooms when using combined constructions of window blocks;
- thermal characteristics of window blocks when using vacuum insulating glass.
- economic efficiency of design options discussed above.

Based on the data of the research, it is planned to develop a methodology for assessing the economic and technical feasibility of various designs of windows in historical buildings.

6. Conclusions
The existing possibilities for replacing window blocks in historical buildings of different historical and architectural value were analyzed. The technological capabilities of modern window systems with their application in buildings of this type were considered.

A computer simulation of temperature conditions of junction points of window blocks to openings of external walls of a typical external wall was conducted. It was established that the use of standard window blocks in the external walls of historical buildings without additional measures for the insulation of walls in the junction zone may lead to a violation of the temperature and humidity conditions during the winter period of operation. Proposed technical solutions eliminates this problem.

References
[1] Spigliantini G, Fabi V and Corgnati SP 2017 Energy Procedia 134 376–385
[2] SP 50.13330.2012 Thermal performance of the buildings. The updated edition of SNIP 23-02-2003
[3] GOST 23166-99 Windows. General specifications
[4] DIN EN 14351-1:2016-12 Windows and doors – Product standard, performance characteristics – Part I: Windows and external pedestrian doorsets; German version EN 14351-1:2006+A2:2016
[5] DIN 18055:2014-11 Criteria for the use of windows and exterior doors in accordance with DIN EN 14351-1
[6] Bianco L, Serra V, Fantucci S, Dutto M and Massolino M 2015 Energy and Buildings 95 86–91
[7] Huber A, Korjenic A and Bednar T 2013 Bauphysik 35(2) 107–18
[8] Kain G, Gschwandtner F and Idam F 2013 Bauphysik 39 (2) 144–47
[9] De Berardinis P, Rotilio M, Marchionni C and Friedman A 2014 Energy and Buildings 80 415–23
[10] Mozzarella L 2015 Energy and Buildings 95 23–31
[11] Milone D, Peri G, Pitruzzella S and Rizzo G 2015 Energy and Buildings 95 39–46
[12] El Mankibi M, Cantin R and Zoubir A 2015 Energy Procedia 78 2470–75
[13] Ciampi G, Rosato A, Scorpio M and Sibilio S 2015 Energy Procedia 78 2669–74
[14] Garau G and Rosa-Clot M 2017 Energy Procedia 134 244–55
[15] Litti G, Audenaert A and Lavagna M 2018 Journal of Building Engineering 17 135–53
[16] Ascione F, De Rossi F and Vanoli GP 2011 Energy and Buildings 43 1925–36
[17] Lopes CSP and Frontini F 2014 Energy Procedia 48 1493–02
[18] Vietes E, Vassiliva I and Arias JE 2015 Energy Procedia 75 1679–85
[19] Pisello AL, Petrozzi A, Castaldo VL and Cotana F 2016 Applied Energy 162 1313–22
[20] Tomšič M, Mirtič M, Šijanec Zavrl M and Rakušček A 2017 Procedia Environmental Sciences 38 212–19
[21] GOST R 55528-2013 Composition and content of scientific and project documentation for the conservation of cultural heritage. Monuments of history and culture. General requirements
[22] Colins RE and Simko TM 1998 Solar Energy 62(3) 189–213
[23] Cuce E and Cuce PM 2016 Renewable & Sustainable Energy Reviews 54 1345–57