mgr inż. Romana Antczak-Jarząbska[1)*)]
dr hab. inż. Maciej Niedostatkiewicz, prof. PG[1)]

Influence of the thermal modernization of window on transmission heat losses

Wpływ termomodernizacji okna na straty ciepła

DOI: 10.15199/33.2018.08.18

(Studium przypadku)

Abstract. The article presents the results of calculations of the heat transfer coefficient for the state before and after renovation for the historic windows. The aim of the analysis was to obtain the values of thermal insulation parameters demanded by the regulations, while not losing the historical value of the window. The described example of the renovation of the existing window consisted in installing an additional window panel from the inside.
Keywords: historic window; heat losses; window panel.

Streszczenie. W artykule przedstawiono wyniki obliczeń współczynnika przenikania ciepła dla stanu przed i po renowacji okien zabytkowych. Celem analizy było uzyskanie wartości parametrów termoizolacyjnych wymaganych przez przepisy, z zachowaniem historycznej wartości okna. Opisany przykład renowacji istniejącego okna polegał na zainstalowaniu od wewnątrz dodatkowego panelu okiennego.
Słowa kluczowe: okno zabytkowe; straty ciepła; panel okienny.

Window is a subject to conservation protection, as well as its remaining part if the building, is covered by conservation protection or is located in the conservation zone. Depending on the decision of the conservator, conditioned by the requirements of specific regulations in historic buildings, it is possible to completely replace the existing window frame for new one or it is necessary to modernize the existing window frame. The main advantage of this second approach is the fact that a properly renovated window woodwork will not disturb the historic character of the architectural assumptions of the building, and the original windows will testify to the historical value of the object [7, 12].

Retaining original windows certainly has to be more sustainable than replacement. The type and quality of softwood that was used for most 18th and 19th century windows cannot be sourced today and throwing it away makes little sense when the whole emphasis of the 21st century must be on making maximum use of the resources we already have [6].

Proper implementation of window frame modernization is time-consuming and difficult, because it creates a number of inconveniences and difficulties for users of rooms that need to be temporarily required to carry out works, to be excluded from use. Properly renovated window frame includes removal of old paint coatings, necessary carpentry repairs, wood disinfection treatments, wood structure reinforcement, restoration of missing wood, reconstruction of missing decorative elements, application of new protective coatings, renewal or replacement of fittings to meet conservation requirements, refurbishment or supplementation missing glazing, replacement of glazing putty and renewal or replacement of flashings. In the case of buildings not covered by conservator protection, the final solution is the complete replacement of the window.

This guidance note provide advice on the principles, risks for upgrading the thermal performance of windows by the addition glazing. Older windows can often be draughty as over time they distort and gaps open up as joints become weakened. Although adequate ventilation is important in older buildings, excessive air leakage through windows is uncomfortable for occupants and wastes heat. Additional window panel when carefully designed and installed allows the original windows to be retained unaltered, and where necessary repaired, whilst reducing air leakage and conducted heat losses. As a result there is no loss of historic fabric and in most cases the installation is easily reversible. The research [3] shows that the solution with the additional glass panes is the most energy-efficient solution. Studies [3] have shown that the insertion of a window panel reduction in heat loss through glazing by of 69%. In addition, adding a window pack is a great solution to improve the technical condition.

No historic window can reach a U-value below 1,7 W/(m²K) [3]. The article presents a solution that improves the U-value by adding a panel by removing the old glass from the inside and replacing the window panel in its place. The aim of the article is to present the results of the test to determine the heat transfer coefficient U for existing window frames in a historic building. The scope of calculations also covers the case of window frame after thermal renovation. The most frequently occurring type of window was analyzed in the object, referred to later in the article as *Type 1*. The case of a window subjected to thermorenovation was described as *Type 2*.

This article clearly demonstrates the effectiveness of the best option for reducing heat loss through windows. This article allows people to make measured judgements regarding how they can reduce fuel bills, without taking away the character of traditional buildings.

[1)] Gdańsk University of Technology, Faculty of Civil and Environmental Engineering
[*)] Correspondence adress: romana.antczak@pg.edu.pl

Test house

In the article the problem concerns on the historic building (Photo 1), which has the following parameters: building area – 1636 m^2, usable floor area – 6115 m^2. The building was built at the beginning of the 20th century and consists of three floors with an attic. The building is completely basement with an inner patio and a clock tower (Photo 1).

Photo 1. The south elevation of the historic building
Fot. 1. Elewacja południowa zabytkowego budynku

Window characteristics. Windows, especially wooden ones, are exposed not only to the high temperature and rays of the burning sun during the summer heat, but also to the long-term dampness of external surfaces by precipitation. On the premises there were wooden window frames of box construction. In some rooms window and stained-glass windows were built in, which are not the subject of this article. Window was characterized by a high degree of operational decapitalization, which resulted in the fact that it could be described as having a very high heat transfer coefficient U.

The value of the heat transfer coefficient, both before and after the thermorenovation was determined numerically and described in detail later in this article (in chapter: results and numerical analysis). Another method of determination thermal insulation properties of building materials is Hot-Box method [4, 5]. It is often preferred for its ability to determine real values with sensitive tolerances. The basis of the Hot-Box method is that it measures the total thermal energy transferred from the sample, instead of using the main thermal transmittance principles (convection, conduction and radiation). In the article one was focus on numerical research. No laboratory tests were carried out for the model.

Window before thermomodernization – Type 1. For analysis, a wooden timber window-box 2,16 × 2,18 m was selected (Photo 2). The thickness of individual layers was respectively; 0,005 m (glass), 0,1 m (void) and 0,005 m (glass). This type of joinery (the size and method of glazing) was the most popular in the building covered by the study.

Window after modernization – Type 2. Window carpentry Type 2 refers to the described in box window, in which the window panel inside the sash was additionally arranged (Photo 3). The window panel consisted of glass (0,004 m)/air gap (0,016 m)/glass (0,004 m). In total, the window in the cross section consisted (from the inside) of: a glazing panel, air gap (0,1 m) and a glass (0,005 mm). An example scheme of a box window after adding a window panel has been shown on Fig 1.

Photo 2. A window in a historic building (Type 1) – a state before thermorenovation
Fot. 2. Okno w zabytkowym budynku (typ 1) – stan przed termorenowacją

Photo 3. Window in the historic building – a state after thermorenovation – window frame with glass panel (Type 2)
Fot. 3. Okno w zabytkowym budynku – stan po termomodernizacji – rama okienna ze szklanym panelem (Typ 2)

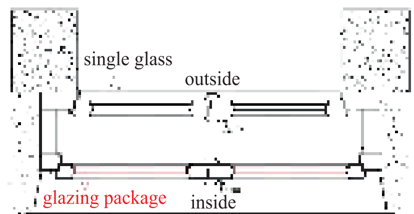

Fig. 1. Horizontal section of the window – window frame with an additional panel (Type 2)
Rys. 1. Przekrój poziomy okna – rama okienna z dodatkowym panelem (Typ 2)

Numerical simulation of the heat exchange process in window

The course of the heat exchange process in the window was determined by means of numerical simulation using the finite volume method. The calculations were performed using the ANSYS CFX 16.2 program [2]. For numerical analysis, material data according to [10] was accepted (table 1). External climate conditions were adopted according to [11] for the first climatic zone (Gdańsk): T_e = -16,0°C. The conditions of the indoor climate were adopted according to the regulation [11] for office: T_i = 20,0°C. The values of resistance to internal and external heat transfer were adopted in [8 ÷ 10] and for these values of heat transfer coefficients were determined:

- h_i = 8,00 W/m^{2}K coefficient of heat transfer on the internal surface;
- h_e = 23,0 W/m^{2}K coefficient of heat transfer on the external surface.

The geometry of the physical system in which the heat exchange process is analyzed is a simplified model of the actual window. The simplifications made in the form of window frame separation together with glass and the air gap in the box windows without a wall fragment have no effect on the heat exchange and temperature field in the analyzed physical system [1]. All thermally important window elements are included in the model in relation to what the thermal conditions should be close to the real ones (Fig. 2).

 ISSN 0137-2971, e-ISSN 2449-951X

Table 1. Thermal properties of materials
Tabela 1. Właściwości termiczne materiałów

Material	Thermal conductivity coefficient [W/m K]	Density [kg/m^3]	Specific heat [J/kg K]
Air (including convection)	0,026	1,25	1005
Glass	1,00	2500	750
Wood	0,20	500	2390

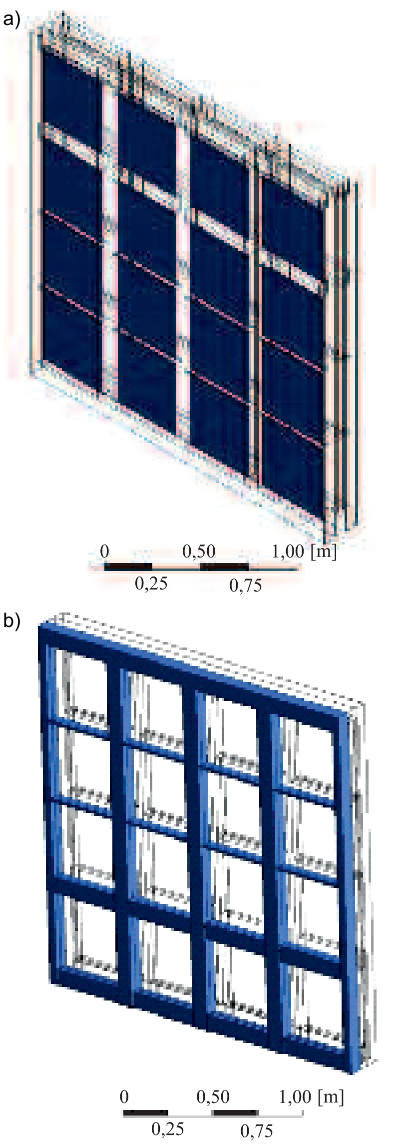

Fig. 2. Numerical model of window joinery: a – glass, b – frame
Rys. 2. Model numeryczny stolarki okiennej: a – szyba, b – rama

In the computer simulation, a model of thermal conductivity, described by the Laplace equation for a three-dimensional, stationary of heat conduction was adopted:

$$\partial^2T/\partial x^2 + \partial^2T/\partial y^2 + \partial^2T/\partial z^2 = 0 \quad (1)$$

with the boundary conditions of the third type:

$$-\lambda(\partial T/\partial x) = h(T_F - T_p) \quad (2)$$

where:
T – temperature [°C];
λ – thermal conductivity coefficient [W/m K];
x – positing vector;
h – heat flow rate [W/m^2 K];
T_F – surface temperature [°C];
T_p – fluid temperature far from the solid surface [°C].

Models were „cut" from the actual physical system by means of adiabatic planes, adopting the boundary conditions of the second type:

$$q/s = 0 \quad (3)$$

where:
q – thermal flux density [W/m^2];
s – adiabatic surface.

The finite volume grid was adopted for the analyzed model. Triangular and quadrangular elements of different degrees of compaction were used for the calculations depending on the size of the modeled areas (Fig. 3).

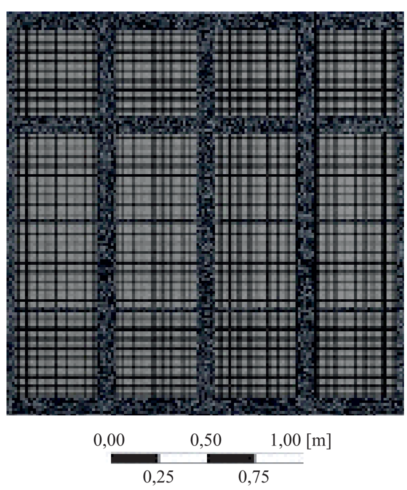

Fig. 3. Finite volume grid for the analyzed window
Rys. 3. Siatka objętości skończonych dla analizowanego okna

Results of numerical analysis

As a result of numerical analysis, the distribution of the velocity of the air flow in the center of the void was checked for Type 1, that is box window before thermorenovation (Fig. 4). The result has showed that the air movement is at a very low level, because the air velocity does not exceed 0,1 m/s. Therefore, it is an air gap going from the warm to the cold side of the window, which does not cause air circulation and

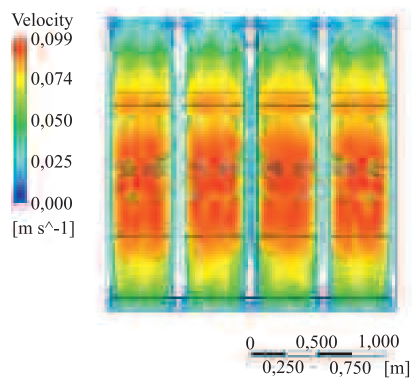

Fig. 4. Distribution of air flow velocity in the air gap in the window
Rys. 4. Rozkład prędkości przepływu powietrza w szczelinie powietrznej w oknie

has no significant effect on the heat transfer coefficient. However, in order to determine the heat transfer coefficient U for Type 1, based on numerical simulation, the following values had to be determined:

- temperature – is shown in Fig. 5a, b, c, d
- density of heat flux – is presented in Fig. 6a, b, c, d.

Fig. 5 shows the temperature distribution for the window glass and window frame, depending on the type of contact with hot or cold air. The value of the minimum temperature on the glass surface was respectively for the glass in contact with external air $T_{min,glass\_ext}$ = -15,1°C, for glass in contact with internal air $T_{min,glass\_int}$ = 10,8°C. The value of the maximum temperature on the glass surface was for the glass in contact with external air, $T_{max,glass\_ext}$ = -10,7°C, for glass in contact with internal air $T_{max,\ glass\_int}$ = 17,7°C. In contrast, the value of the minimum temperature on the surface of the window frame was respectively for the window frame in contact with the outside air $T_{min,window\_ext}$ = -15,9°C, for the window frame in contact with the internal air $T_{min,\ window\_int}$ = 17,1°C. The maximum temperature value on the surface of the window frame was respectively for the window frame in contact with external air $T_{max,window\_ext}$ = -15,4°C, for the window frame in contact with the internal air $T_{max,window\ int}$ = 19,7°C.

Fig. 6 shows the distribution of heat flux density of glass and window frame depending on the type of contact with hot or cold air. The value of the minimum

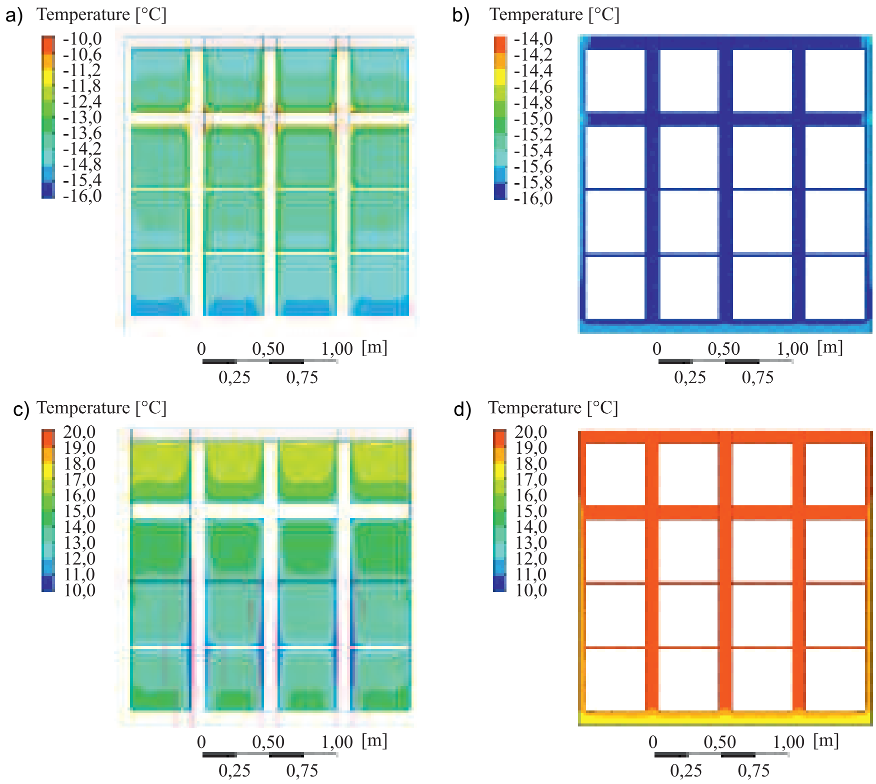

Fig. 5. Temperature distribution field for glass and for window frame in contact with air: a) and b) external; c) and d) internal (Type 1)

Rys. 5. Pole rozkładu temperatury szkła i ramy okna w kontakcie z powietrzem: a) i b) strona zewnętrzna; c), d) strona wewnętrzna (typ 1)

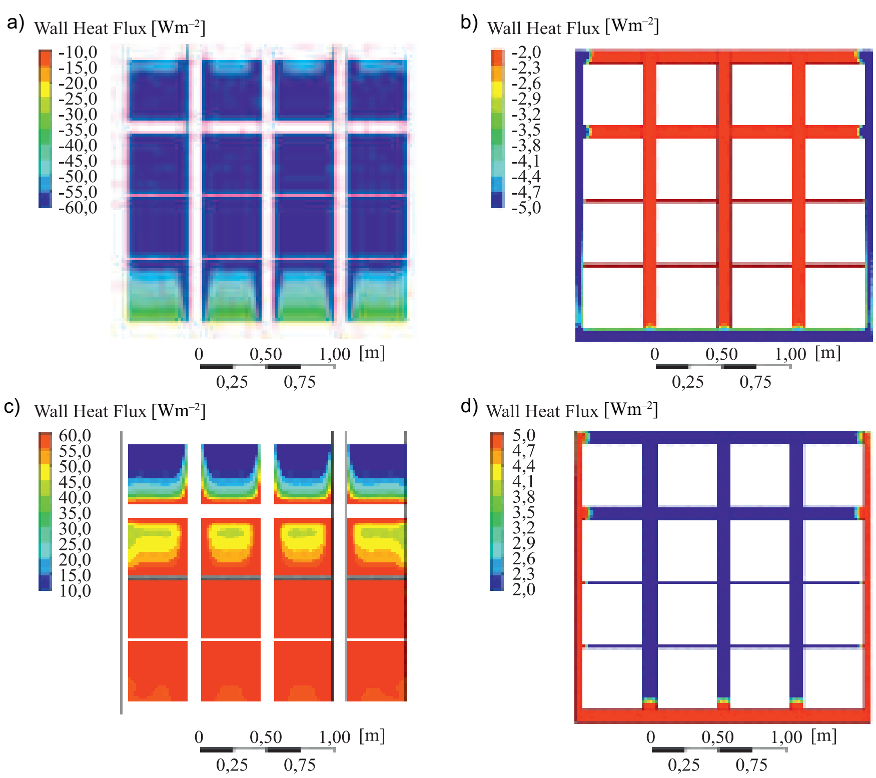

Fig. 6. Density of heat flux for glass and for window frame in contact with air: a) and b) external; c) and d) internal (Type 1)

Rys. 6. Gęstość strumienia cieplnego w przypadku szkła i ramy okna w kontakcie z powietrzem: a) i b) strona zewnętrzna; c) i d) strona wewnętrzna (typ 1)

heat flux density on the surface glass in contact with external air was $q_{min,glass\ ext}$ = -60 W/m², for glass in contact with internal air, $q_{min,glass\ int}$ = 10,0 W/m². The value of the maximum heat flux density on the surface glass in contact with external air was $q_{max,glass\ ext}$ = -35 W/m², for glass in contact with internal air, $q_{max,\ glass\ int}$ = 60,0 W/m². The value of the minimum heat flux density on the surface window frame was respectively for the window frame in contact with external air $q_{min,window\ ext}$ = -5,0 W/m², for the window frame in contact with the internal air $q_{min,window\ int}$ = 2,0 W/m². The value of the maximum heat flux density on the surface window frame was respectively for the window frame in contact with external air, $q_{max,window,\ ext}$ = -2,0 W/m², for the window frame in contact with the internal air $q_{max,window,\ int}$ = 5,0 W/m². The same numerical calculation scheme was made for the window after thermal modernization – Type 2. To determine the heat transfer coefficient U, the following value shad to be determined:

- temperature – is shown in Fig. 7a, b, c, d;
- density of heat flux – is presented in Fig. 8a, b, c, d.

Fig. 7 presents the temperature distribution for the glass and window frame, depending on the type of contact with warm or coldair. The value of the minimum temperature on the surface glass was respectively for the glass in contact with external air $T_{min,glass\ ext}$ = -16,0°C for the glass in contact with the internal air $T_{min,glass\ int}$ = 12,2°C. The maximum temperature value on the surfaceglass was for the glass in contact with external air $T_{max,glass\ ext}$ = -13,1 °C, for glass in contact with internal air $T_{max,glass\ int}$ = 20,0 °C. In the minimal value the temperature on the surface window frame was respectively for the window frame in contact with the external air $T_{min,window\ ext}$ = -16,0°C, for the windowframe in contact with the internal air $T_{min,window\ int}$ = 17,4°C. The maximum temperature value on the surface window frame was respectively for the window frame in contact with the outside air $T_{max,window\ ext}$ = -15,4°C, for the window frame in contact

 ISSN 0137-2971, e-ISSN 2449-951X www.materialybudowlane.info.pl

with the internal air $T_{max,window\ int}$ = 19,8°C.

Fig. 8 shows the distribution of heat flux density of glass and window frame depending on the type of contact with warm or cold air. The value of the minimum heat flux density on the surface glass was respectively for glass in contact with outside air $q_{min,glass\ ext}$ = -50 W/m^2, for glass in contact with internal air $q_{min,glass\ int}$ = 26,0 W/m^2. The value of the maximum heat flux density on the surface glass was for the glass in contact with external air $q_{max,glass\ ext}$ = -21 W/m^2, for glass in contact with internal air $q_{max,glass\ int}$ = 50,0 W/m^2. The value of the minimum heat flux density on the surface window frame was respectively for the window frame in contact with the outside air $q_{min,window\ ext}$ = -5,0 W/m^2, for the window frame in contact with the internal air $q_{min,window\ int}$ = 2,0 W/m^2. The value of the maximum heat flux density on the surface window frame was respectively for the window frame in contact with external air $q_{max,window\ ext}$ = -2,0 W/m^2, for the window frame in contact with the internal air, $q_{max,window\ int}$ = 5,0 W/m^2.

Results

On the basis of the numerical analysis, the average temperatures T of the window surface and the average heat flux density values were determined q. The average values were determined on the basis of numerical analysis. On the basis of the numerical analysis from Fig. 5 and Fig. 7 you can see the effect of the panel used on the temperature flow. In Fig. 7c with the window panel in the numerical analysis, the temperature distribution field is characterized by higher temperature values on the surface than in Fig. 5c, which indicates an increase in thermal insulation. In addition, the temperature of the window surface with the panel from the inside Fig. 7c, in the lower parts, reaches high values of about 19°C, which favorably eliminates the possibility of condensation on the cold surface of the windows, which can be very intense and troublesome. The obtained values of the average temperature T of the window surface and the average values of heat flux density q from the

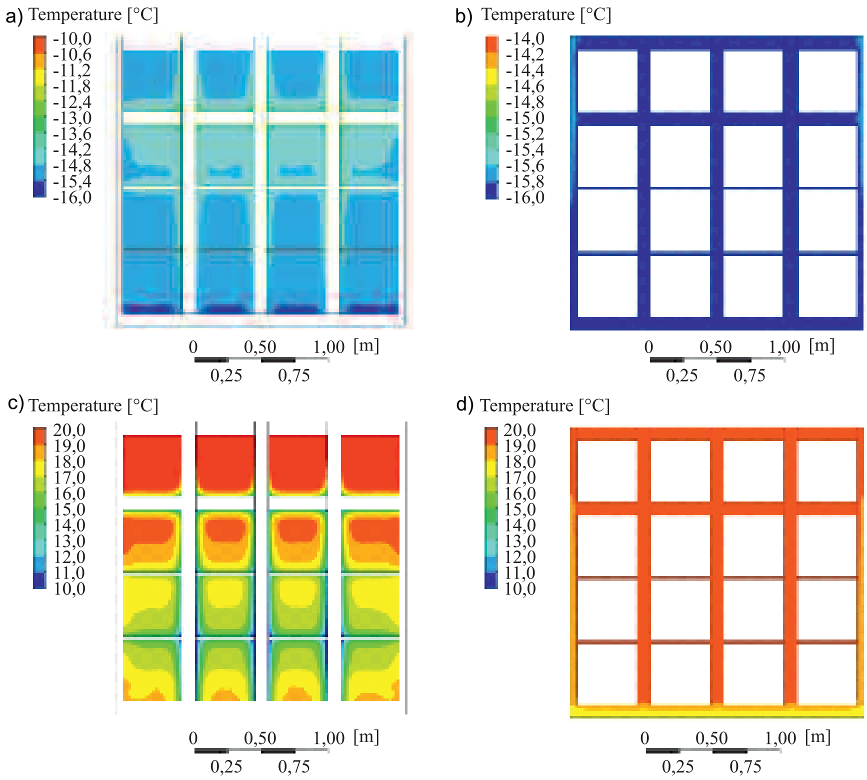

Fig. 7. Temperature distribution field for glass and for window frame in contact with air: a) and b) external; c) and d) internal (Type 2)

Rys. 7. Pole rozkładu temperatury szkła i ramy okna w kontakcie z powietrzem: a) i b) strona zewnętrzna; c) i d) strona wewnętrzna (Typ 2)

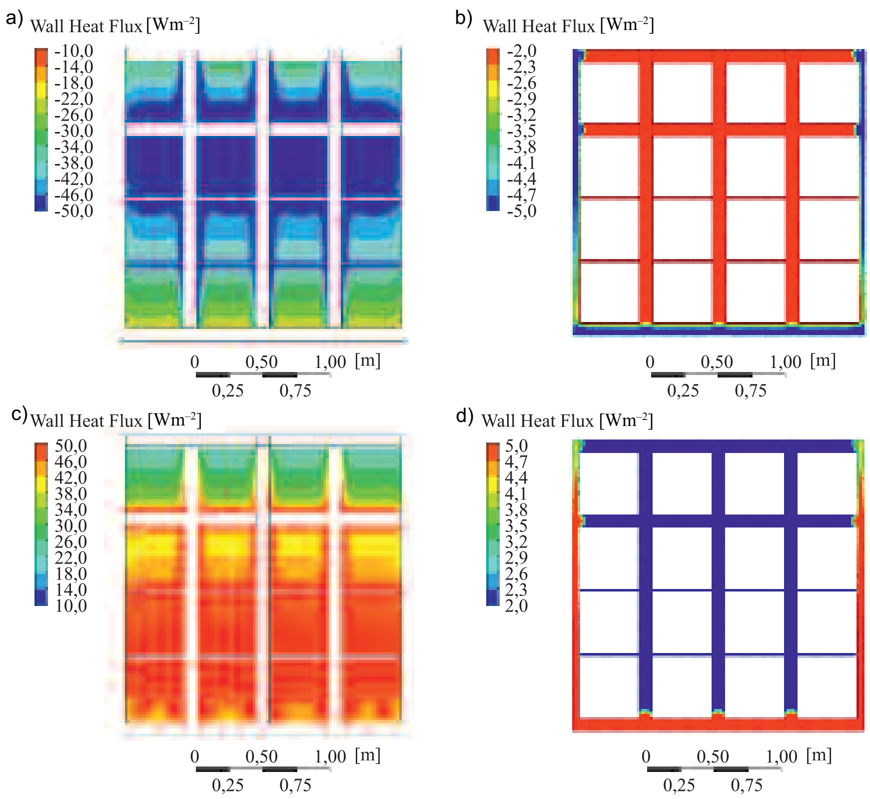

Fig. 8. Density of heat flux for glass and window frame in contact with air: a) and b) external; c), and d) internal (Type 2)

Rys. 8. Gęstość strumienia cieplnego w przypadku szkła i ramy okna w kontakcie z powietrzem: a) i b) strona zewnętrza; c) i d) strona wewnętrzna (typ 2) numerical analysis were used to determine the heat transfer coefficient U (table 2).

Table 2. Summary of the results
Tabela 2. Podsumowanie wyników

Temperature [°]	Density of heat flux [W/m²]
	Type 1
$T_{ave,glass\ ext}$ = -11,85	$q_{ave,glass\ ext}$ = -59,25
$T_{ave,window\ ext}$ = -15,25	$q_{ave,window\ ext}$ = -2,60
$T_{ave,glass\ int}$ = 12,10	$q_{ave,glass\ int}$ = 59,35
$T_{ave,window\ int}$ = 18,05	$q_{ave,window\ int}$ = 2,50
	Type 2
$T_{ave,glass\ ext}$ = -14,35	$q_{ave,glass\ ext}$ = -45,25
$T_{ave,window\ ext}$ = -15,55	$q_{ave,window\ ext}$ = -2,20
$T_{ave,glass\ int}$ = 17,10	$q_{ave,glass\ int}$ = 45,35
$T_{ave,window\ ext}$ = 18,05	$q_{ave,window\ int}$ = 2,10

Determination of the heat transfer coefficient. The heat transfer coefficient was calculated as the equivalent, and the equivalence criterion is the heat flux density for the one- and three-dimensional model:

$$U_{3D} = 1/R_{eqv} \quad (4)$$

R_{eqv} – equivalent thermal resistance of a thermal barrier in a 3D model [m²K/W];

$$R_{eqv} = R_i + R_e + R_{peqv} \quad (5)$$

where:
R_i – resistance to heat transfer on the inner surface [m²K/W];
R_e – resistance to heat transfer on the outer surface [m²K/W];
R_{peqv} – equivalent thermal resistance [m²K/W].

The equivalent thermal resistance R_{peqv} was calculated for a three-dimensional model of stationary and average values of surface temperatures and heat flux density:

$$R_{peqv} = (T_1 - T_2)/q_{avr} \quad (6)$$

where:
T_1 – average temperature of the inner surface [°C];
T_2 – average temperature of the outer surface [°C];
q_{avr} – the average value of the density of the heat flux transient through the inner surface [W/m²].

Average values of surface temperatures and heat flux density were defined as:

$$q_{avr} = \int_{S1} q dS/S_1 \quad (7)$$

$$T_1 = \int_{S1} T dS/S_1 \quad (8)$$

$$T_2 = \int_{S2} q dS/S_2 \quad (9)$$

S_1 – inner surface;
S_2 – outer surface.

On the basis of the above assumptions, the value of heat transfer coefficient U was determined for two types of window:

Type 1:

$$R_{eqv} = 0,13 + 0,04 + 0,4 = 0,57 \quad (10)$$
$$U_{type1} = 1,75\ W/m^2K$$

Type 2:

$$R_{eqv} = 0,13 + 0,04 + 0,64 = 0,81 \quad (11)$$
$$U_{type2} = 1,19\ W/m^2K$$

From 2017, new technical requirements have started to apply to buildings. Stricter requirements are aimed at improving the energy efficiency of buildings. Products used to build new buildings, including windows and doors must have better thermal insulation parameters. An additional glazing panel in the box window causes the window to qualify for the applicable technical regulations [11], which from 01.01.2017 provide for the heat transfer coefficient value at U_{max} = 1,6 W/(m²K), while from 01.01.2021 requirements they tighten to U_{max} = 1,4 W/(m²K).

Conclusions

The aim of thermal renovation of windows in historic buildings is to improve their technical parameters in order to adapt to the requirements of specific regulations and restore their technical condition in a way that ensures that historical values of the windows as well as building objects as a whole are not lost.

Old windows have a reputation for being draughty, but would originally have been made as accurately as the considerable skills of a traditional joiner would allow. Cracked joints and voids in masonry similarly allow liquid water to penetrate where sound mortar would once have effectively kept it out. Repair of such decay using materials which match the originals as closely as possible, particularly in their technical characteristics, will greatly enhance both the performance and the durability of the building.

In the analyzed box windows, the assembly of the additional glazing panel improved the heat transfer coefficient U by almost 30%. The improvement of the window heat transfer coefficient value by adding a glazing panel caused that the historic box window qualifies for use in buildings after thermal modernization.

References

[1] Adamus Janina, Marta Pomada. 2017. „Analysis of heat flow in composite structures used in window installation". *Composite Structures (3)*. DOI: 10.1016/J.COMPSTRUCT.2017.12.077.

[2] ANSYS Inc. *ANSYS CFX-Solver Theory Guide, Release 15.0*. 2013. Canonsburg. USA.

[3] Baker Paul. 2017. „Improving the Thermal Performance of Traditional Windows: Metal-framed Windows". *Historic England. Building and Landscape Conservation*. Research Report Series no. 15-2017. ISSN 2059-4453.

[4] BS EN ISO 12567-1:2010. Thermal performance of windows and doors. Determination of thermal transmittance by hot-box method. Complete windows and doors.

[5] BS EN ISO 8990:1996. Thermal insulation. Determination of steady-state thermal transmission properties. Calibrated and guarded hot box.

[6] English Heritage. 2004. *Building Regulations and Historic Buildings – Balancing the needs for energy conservation with those of building conservation: an Interim Guidance Note on the application of Part L*. London. Product Code 50900.

[7] Lucchi Elena. 2016. „Simplified assessment method for environmental and energy quality in museum buildings". *Energy and Buildings vol. 117* (2): 216 – 229. DOI: 10.1016/J.ENBUILD.2016.02.037.

[8] PN-EN ISO 10456:2009. Materiały i wyroby budowlane. Właściwości cieplno-wilgotnościowe. Tabelaryczne wartości obliczeniowe i procedury określania deklarowanych i obliczeniowych wartości cieplnych.

[9] PN-EN 12831-1:2017-8. Charakterystyka energetyczna budynków. Metoda obliczania projektowego obciążenia cieplnego. Część 1. Obciążenie cieplne, Moduł M3-3.

[10] PN-EN ISO 6946:2017-10. Komponenty budowlane i elementy budynku. Opór cieplny i współczynnik przenikania ciepła. Metody obliczania.

[11] Rozporządzenie Ministra Infrastruktury „W sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie" z 12 kwietnia 2002 r. ze zmianami z 2015 r.

[12] Santoli Livio, Francesco Mancini, Stefano Rossetti, Benedetto Nastasi. 2016. „Energy and system renovation plan for Galleria Borghese Rome". *Energy and Buildings* vol. 129: 549 – 562. DOI: 10.1016/J.ENBUILD. 2016.08.030

Przyjęto do druku: 30.07.2018 r.