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Stanislav Dzhyrma, Assoc. Prof., PhD tech. sci., **Mykola Pashynskyi,** Assoc. Prof., PhD tech. sci., **Serhii Perun**
Central Ukrainian National Technical University, Kropyvnytskyi, Ukraine
e-mail: stas55871@ukr.net

Technological Solutions for Increasing the Energy Efficiency of Windows in new Construction and Housing Stock Reconstruction

The article considers the problem of increasing the energy efficiency of translucent enclosing structures of residential buildings. Based on computer modeling of temperature fields in the THERM software package, the influence of the geometric parameters of the windows (exterior window trim, the window's position in a wall cross-section) on the thermal performance of the junction is analysed. The effectiveness of using traditional brick exterior casing in new construction is studied and technological solutions are proposed for the reconstruction of existing housing using polystyrene foam exterior casing. The optimal position of a window in a cavity wall is determined to avoid moisture condensation and minimize the possibility of the cold bridges formation.
energy efficiency, window junction, temperature fields, cold bridge, isotherm, THERM, reconstruction, dew point

Problem formulation. Construction is one of the most energy-intensive sectors of the economy, which makes it necessary the implementation of strict requirements for energy saving at the design stage. Determining and further minimising heat loss in buildings is an important area of scientific research and practical development today. One of the most vulnerable elements of a building's thermal insulation is translucent structures, through which 20% to 30% of thermal energy is lost. At the same time, a significant part of these losses occurs through the areas of connection between windows and wall structures, as well as through the window jambs [1].

Modern regulatory requirements set high standards for the heat transfer resistance of enclosing structures. The practical implementation of these standards is often complicated by an insufficient level of research into the design features of junctions, which leads to a decrease in the energy efficiency of the building.

Analysis of recent research and publications. The theoretical foundation of thermal physics in construction is based on the works of the classics of science, which formed the basis for modern standardisation of thermal insulation. A significant contribution to the development of methods for calculating energy efficiency and adapting the Ukrainian regulatory framework to European standards was made by such Ukrainian scientists as G. Fareniuk, M. Tymofeyev, E. Fareniuk, L. Chernykh, M. Savitskyi and others [2-6]. Their research allowed us to develop methods for assessing heat loss, determining the thickness of insulation, and the required values for energy efficiency indicators of buildings.

However, general methods often consider wall structures as homogeneous elements and do not always take into account the specifics of the building structures junctions.
The issues of increasing the thermal reliability of window junctions are addressed in the works of W. Maref, A. Stolarska, C. Misiopecki, V. Pashynskyi, S. Dzhyrma and other researchers [7-12]. Their works consider the problems of window nodes sealing, the influence

of the position of the window in a cavity wall on the thermal regime of the junction, and methods for eliminating cold bridges in buildings. In particular, in works [9-11] it is proven that shifting the window block inside the building wall increase it's thermal efficiency, and the temperature on the surface of the inner jamb.

Foreign research experience confirms the importance of the geometry of the mounting unit. Studies by C. Misiopecki (Norway) [9] using thermal modeling have shown that the position of the window has a significant impact on the linear heat transfer coefficient, and for different types of walls there are optimal zones for installing windows. The work [9] presents the results of modeling, which demonstrate that the correct positioning of the window can reduce linear heat loss by more than 50%. The researcher W. Maref (Canada) [7] in his works focuses on the risks of moisture condensation in the places where windows adjoin, assessing them using full-scale tests and numerical modeling.

In a significant number of publications, most of the research is focused on the thermal characteristics of the double-glazed windows themselves (K-glass, I-glass, argon filling) and on the general insulation of facades. The issue of the complex influence of the geometry of the window opening, namely the presence or absence of the window casing and it's material (brick or polystyrene foam), on the temperature characteristics of the junction in the reconstruction of the housing stock of Ukraine conditions has not been sufficiently studied.

Most of the existing scientific works concern either new construction or complete thermal modernisation of the facade, consider standard solutions, while during reconstruction there is often a need to create artificial window casing.

Technological solutions for partial modernisation of openings are insufficiently developed, when complete insulation of the facade is impossible. The issue of the absence of a window casing, the replacement of a "cold" brick casing with a "warm" polystyrene foam casing and the simultaneous shift of the window block towards the room has not been studied sufficiently. The impact of the listed constructive and technological solutions on the thermal reliability of the junction requires a detailed study of temperature fields using computer modeling (FEM analysis) and modern software like the THERM software package [13].

Setting the task. The main heat losses through the so-called "cold bridges" occur in cases where materials with different thermal conductivity are joined or the enclosing structures change their geometric shape. In the window installation area, the wall configuration changes, which leads to a decrease in heat transfer resistance. The wall, the installation seam and the window block are made of materials that have different thermal conductivity indicators. All these circumstances create unfavoruable conditions for the stability of the temperature regime in the window installation area. As a result, additional heat losses appear in the joint area and on the jamb, which are especially noticeable in the cold season.

Isotherms (lines connecting points with the same temperature) allow for a fairly accurate assessment of temperature fluctuations in various structural elements and in the installation node areas.

Depending on the material in the wall structure, the course of the isotherms changes, which show the temperature in the thickness of the wall. When approaching the window, the parallel isotherms bend towards the outer surface and pass into the plane of the mounting seam and frame [14] (Fig. 1).

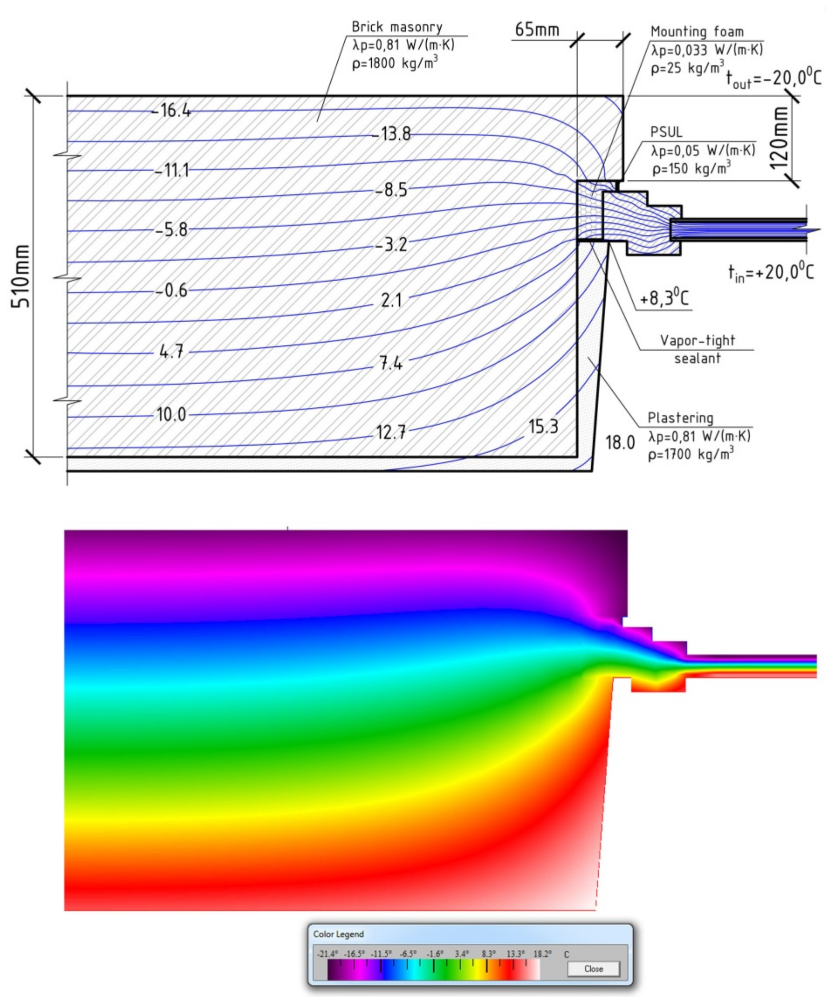


Figure 1 – Temperature distribution in a solid brick wall and window junction

Source: developed by the authors

Of particular importance is the isotherm 10.0°C, which is used to determine the so-called "dew point". This indicator is the main one for assessing the prevention of condensation and moisture formation inside and outside wall, window structures and junctions.

The choice of this isotherm is not accidental. According to the standards [15], to prevent the formation of condensate and moisture, the temperature on the inner surface of the structure under design conditions (20.0°C and relative humidity 50-55%) should not fall below the dew point, which is approximately +10.0°C.

Provided that the temperature isotherm +10.0°C passes within the enclosing structure and the installation joint zone, the process of water vapor condensation in the specified area does not occur. This, in turn, prevents the formation of local freezing zones and reduces heat loss. The maximally smoothed configuration of the isotherm +10.0°C and its remote location from the inner surface of the enclosure contributes to the stabilisation of the temperature regime in the junction zone. This can be achieved by shifting the window block towards the interior of the building, which allows reducing the intensity of heat losses in the installation zone. As a result, the overall energy efficiency of the enclosing system increases and the operational characteristics of translucent structures improve. The feasibility of such a constructive solution is confirmed by the results of numerical modeling and experimental studies presented in the works [10-12].

During the Soviet construction practice, window casings in brick walls (the so-called "window quarters") was necessarily made and had standard dimensions of 120x65 mm. They played an important role in protecting the junction between the window and the wall from the influence of external weather factors: rain, wind, snow and solar radiation. Even in multi-storey residential buildings, concrete panels and blocks were manufactured in factories with ready-made "quarters". Thanks to this, the junction of the window and the wall received additional heat-technical and waterproofing properties, which contributed to increasing the energy efficiency of the premises.

Today, buildings with window openings without quarters are quite common. The absence of this structural detail is explained by several factors: an increase in the area of natural lighting of the premises, improved aesthetic visualisation of facades, as well as the use of modern building materials that allow for reliable connection of windows with the wall.

In existing buildings (secondary real estate market) and often in new construction, the influence of the geometric parameters of the junction and the location of the window block on thermal fields is not taken into account.

The absence of a constructive casing or incorrect location of the window block within the thickness of the cavity wall leads to a decrease in the thermal properties of the junction. Under such conditions, the temperature of the inner surface of the window jamb decreases to values lower than the "dew point" temperature (+10.0°C), which causes the surface of the jamb and the installation joint zone to become humid. The accumulation of moisture leads to a decrease in the effective protection of the node materials, the emergence of zones of intense heat flow ("cold bridges") and creates conditions for periodic freezing of the enclosing structure. As a result, the heat-shielding characteristics of the window casing deteriorate and the energy efficiency of external enclosing structures decreases.

The purpose of the article is to substantiate effective technological solutions for window arrangement through computer modeling. The study is aimed at determining the optimal configuration of the opening (using a "quarter"), the depth of the window installation for new construction, as well as developing recommendations for the use of thermal inserts as a casing and insulation of the external jamb during the reconstruction of buildings.

Presentation of the main material. The study object is the junction of the metal-plastic window (profile system with a thickness of 70 mm) to the external load-bearing wall of the building, which is made of solid ceramic brick (density ρ = 1800 kg/m^3). The thickness of the masonry is 510 mm (two bricks). The THERM software package [13] was used to conduct numerical experiments, which is based on the finite element method and allows modeling two-dimensional heat transfer fields of building structures.

Boundary conditions of the conducted studies. The design parameters were taken for the 1st temperature zone of Ukraine (Kropyvnytskyi city) [2]. According to [15], the indoor air temperature: t_{in} = +20.0°C, the outdoor air temperature: t_{out} = -22.0°C. Relative humidity: 50-55%. "Dew point" temperature (critical condensation temperature): t = +10.0°C. The study was conducted through a series of calculations with varying the depth of window installation from 120 mm to 270 mm from the facade surface of the wall in increments of 15 mm.

At the first stage, two variants of the window frame design were studied:

Variant 1 - straight opening (without a casing): a solution for many types of modern masonry or panel construction;

Variant 2 - opening with a brick casing: a classic solution with a size of 120x65 mm.

For both variants, the initial position of the window is determined at a distance of 120 mm from the outer surface of the wall. The shift of the window block in the direction of the room is planned in increments of 15 mm, which allows analysing the influence of the installation position of the window on the thermal insulation properties of the entire "wall-nodes-window" system.

The simulation results (option 1) presented in Fig. 2 for a straight opening (without a casing) showed that when installing a window at a standard distance of 120 mm from the facade of the wall, the temperature in the inner corner of the jamb is only +7.7°C. This value is significantly lower than the "dew point" (+10.0°C). Temperature fields visualisation demonstrates that the isotherms in this case are sharply curved, approaching the surface of the outer jamb and the isotherm (+10.0°C) is located from the facade of the wall outside the junction point and the window block. This creates a zone of guaranteed condensation and, as a result, freezing and the formation of a "cold bridge". Even high-quality sealing of the installation joint is not able to compensate for the freezing of the wall around the window frame.

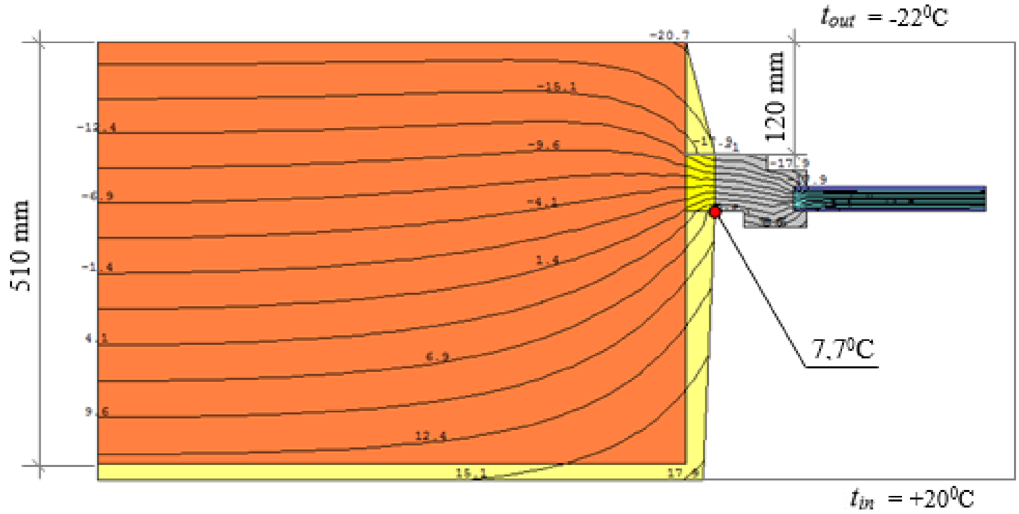


Figure 2 – Temperature distribution in the wall and in the window nodes area without a casing in a brick wall (the window is located at a distance of 120 mm from the facade surface of the wall).
Source: developed by the authors

The use of a brick casing (option 2) changes the picture of thermal fields for the better. Under the same conditions (distance 120 mm from the facade surface), the temperature on the inner jamb increases to +8.3°C (Fig. 3).

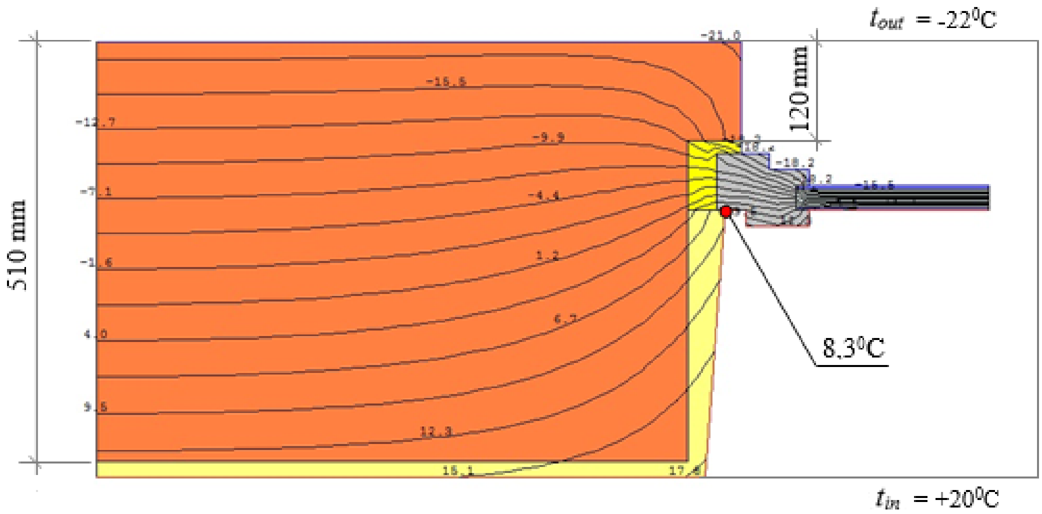
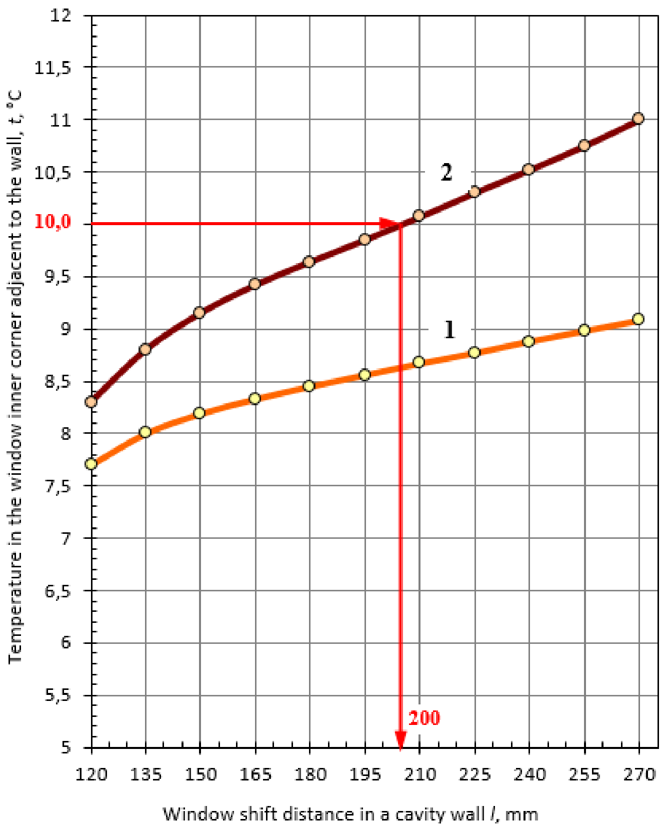


Figure 3 – Temperature distribution in the wall and in the area where the window adjoins the wall with in a brick wall with a casing (the window block is located at a distance of 120 mm from the facade surface of the wall).
Source: developed by the authors

This value is still insufficient to exceed the "dew point" value (+10°C). However, the presence of a casing allowed to increase the temperature in the inner corner of the window frame to the wall, since this zone is potentially critical in terms of the formation of cold bridges and moisture condensation. The increase in temperature can be explained by the fact that the presence of a casing creates an additional barrier to heat loss, protects the installation seam from cold air and atmospheric influences.

As part of the study, 12 numerical calculations were carried out in the THERM program for each of the study options. Different locations of the window at a distance of 120 to 270 mm from the outer surface of the wall with a window block shift step of 15 mm were taken into account.

Based on the obtained research results, a graphical dependence was compiled for two variants of window configurations and different positions of the window block, demonstrating the temperature change in the inner corner of the window junction depending on the depth of its installation in the cavity wall. For each variant, corresponding curves were constructed separately (Fig. 4), which makes it possible to assess the thermal conditions and the nature of the temperature fields distribution at the junction.



1 – window without casing; 2 – window with a 120x65 mm brick casing
Figure 4 – Graphical dependences demonstrating the temperature change in the inner corner of a window depending on the depth of its installation in the brick wall cavity
Source: developed by the authors

Analysis of temperature change graphs (Fig. 4) allowed to establish a clear correlation: shifting the window block into the room (into a warmer zone of the wall) linearly increases the temperature of the internal jamb. For a brick wall with a casing, the optimal installation depth is determined to be 200-210 mm. With this arrangement, the +10°C isotherm shifts inside the structure, and the jamb surface temperature reaches safe values, which makes it impossible to form moisture and eliminates the possibility of freezing of the window junction.

A significant part of the existing houses has windows without casing or with destroyed external jambs. The formation of a new brick casing during reconstruction is a labor-intensive process that requires special work to connect the brick casing with the main mass of the masonry and loads the facade.

As an alternative, a technological solution with the formation of an artificial casing from an effective insulation of expanded polystyrene (EPS) (option 3) is proposed, which involves the installation of an EPS casing measuring 120x65 mm, instead of a classic brick one. This technological solution does not cause difficulties, since the expanded polystyrene casing is not difficult to manufacture and it is easily glued and fastened using special dowels to the brick side surface of the window.

The study of the windows with an EPS casing was carried out similarly to previous studies with similar conditions (Fig. 5).

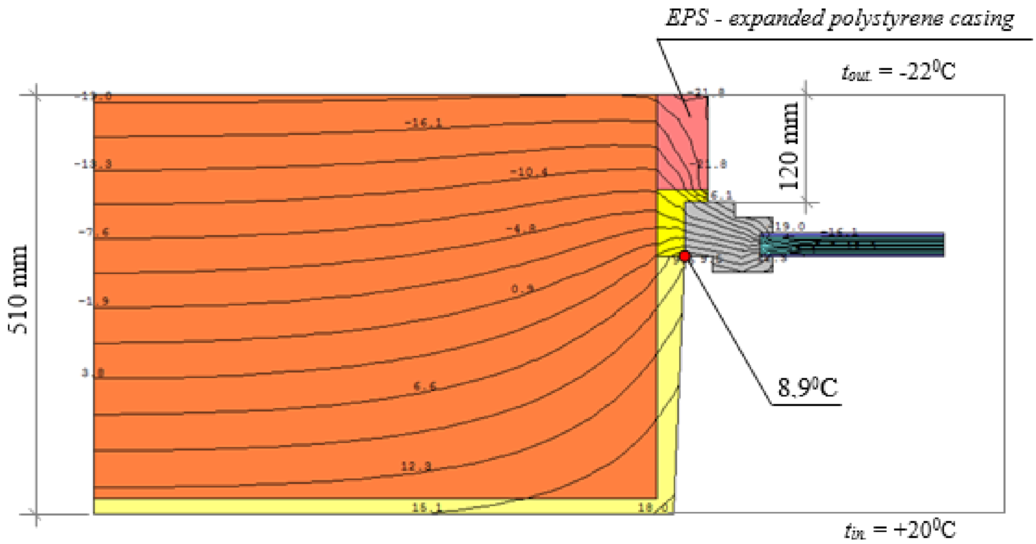


Figure 5 – Temperature distribution in the brick wall and window junction, with a polystyrene foam casing measuring 120x65 mm (the window is located at a distance of 120 mm from the facade surface of the wall).
Source: developed by the authors

Comparison of modeling results revealed the advantage of the method with the EPS casing in the window opening. At the same installation depth (120 mm from the facade surface of the wall), the brick casing provides a jamb temperature of +8.3°C, and the EPS casing provides a jamb temperature of +8.9°C.

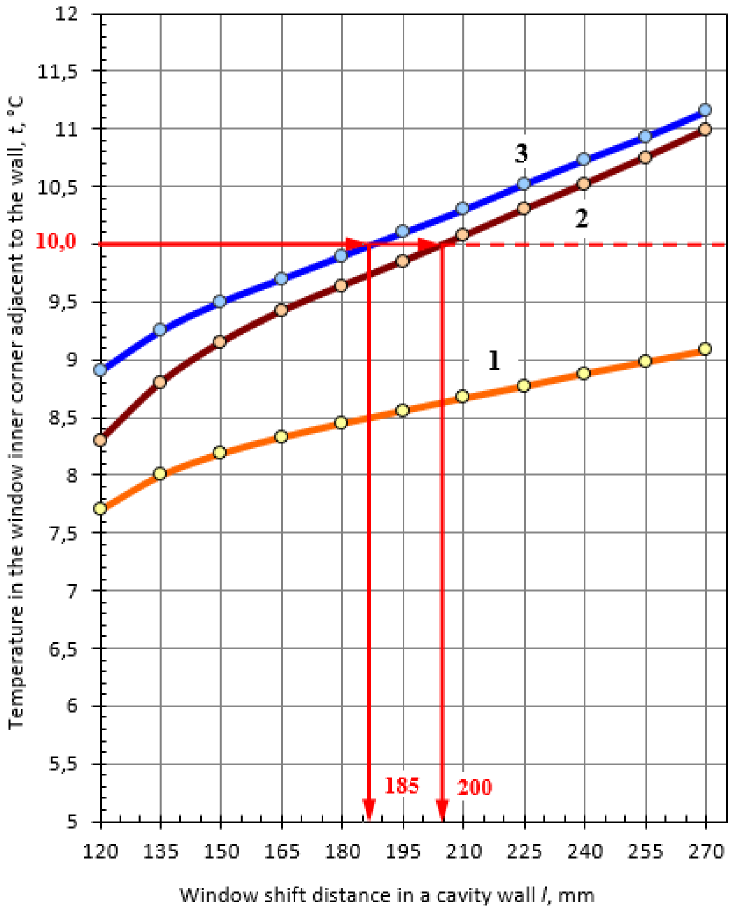
This is explained by the fact that polystyrene foam has a significantly lower thermal conductivity coefficient compared to brick, playing the role of a thermal break that cuts off the cold bridge along the perimeter of the window.

Similar numerical studies of thermal fields were conducted for different window locations at a distance of 120 to 270 mm for window blocks installed in openings with an EPS casing. When the window is shifted, the external jamb is mandatory insulated, which can be performed using a thermal insert (for example, polystyrene foam). The conditions are similar to previous studies.

Thus, during thermal modernisation of old buildings, the arrangement of window casing with polystyrene foam and external jamb insulation is a technological measure for restoring the geometry and an effective way to increase the energy efficiency of the building.

The summarized research diagram (Fig. 6) allows to draw the following conclusions and demonstrates three variants of the behavior of the temperature field at the window junction with the wall.

Curve 1 (window block without a casing) has the worst performance. All temperatures are less than the "dew point" (+10°C). Even a deep shift of the window (to the maximum possible distance), without additional insulation of the external jamb does not guarantee the absence of condensation and the probability of freezing of the junction is quite high.



1 – window block made without casing; 2 – window block with a brick casing of 120x65 mm; 3 – window block equipped with a polystyrene foam casing (120x65 mm)

Figure 6 – Graphical dependences demonstrating the change in temperature at the inner corner of the window structure depending on the depth of its installation in the cavity of a brick wall.

Source: developed by the authors

Curve 2 (window block with a brick casing) and curve 3 (window block with an EPS casing) show similar dynamics, but the option with an EPS casing consistently shows higher temperatures (by 0.7-0.5°C) in the junction zone.

A good level of energy efficiency is achieved with a comprehensive solution, a combination of two factors, the optimal depth of the window in a cavity wall (260 mm) and the installation of a "warm" casing made of expanded polystyrene. In this case, the temperature of the junction rises to +11.0°C, which is a safety margin relative to the dew point (+10.0°C). This completely eliminates the risk of moisture condensation, freezing and the formation of a "cold bridge" even when the humidity in the room rises above the standard 55%.

Conclusions. Designing window openings in brick walls without casing for new construction is an erroneous decision from the point of view of thermophysics. It is recommended to install brick casing and shift the window block to a depth of 200-220 mm from the outer (facade) surface of the wall, which corresponds approximately to the middle of the brick wall structure with a thickness of 510 mm (two rows of bricks). This ensures that the +10°C isotherm is located inside the enclosing structures and indicates optimal thermal conditions for the operation of the junctions.

During reconstruction, the most effective technological solution for the modernisation of windows in existing residential buildings is the installation of artificial casing made of expanded polystyrene. This solution allows to restore the architectural appearance of the facades and provides better thermal performance of the window junction (+8.9°C as opposed to +8.3°C in the brick version with the classic location of the window right behind the casing) and to ensure a temperature in the junction of 11.0°C by installing the window in the zone of positive temperatures at a distance of 260-265 mm from the outer surface of the wall.

The implementation of the proposed technological and design solutions allows to significantly reduce the likelihood of the "cold bridges" formation that occur along the perimeter of the window, minimize heat losses through the assembly unit and, accordingly, increase the overall level of energy efficiency of buildings, which meets modern requirements for reducing energy consumption.

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С. О. Джирма, доц., канд. техн. наук, **М. В. Пашинський**, доц., канд. техн. наук, **С. С. Перун**
Центральноукраїнський національний технічний університет, м. Кропивницький, Україна

Технологічні рішення для підвищення енергоефективності віконних прорізів при новому будівництві і реконструкції житлового фонду

У статті розглянуто проблему підвищення енергоефективності світлопрозорих огороджувальних конструкцій житлових будинків. На основі комп'ютерного моделювання температурних полів у програмному комплексі THERM проаналізовано вплив геометричних параметрів віконного прорізу (наявність чверті, місце встановлення віконного блоку в товщі стіни) на теплотехнічні показники вузла примикання. Досліджено ефективність застосування традиційних цегляних чвертей у новому будівництві та запропоновано технологічні рішення для реконструкції існуючого житлового фонду з використанням пінополістирольних чвертей і вставок. Обґрунтовано оптимальну глибину монтажу віконних блоків від фасадної поверхні зовнішніх стін для уникнення конденсації вологи та мінімізації можливості утворення містків холоду. Встановлено, що під час реконструкції найбільш ефективним технологічним рішенням для модернізації віконних прорізів існуючих житлових будівель є влаштування штучних чвертей з пінополістиролу. Це рішення дозволяє відновити архітектурний вигляд фасадів і забезпечує кращі теплотехнічні показники вузла примикання віконних блоків (+8,9°C на відміну від +8,3°C у цегляному варіанті при класичному розташуванні вікна відразу за чвертю), забезпечити температуру у вузлі примикання не меншу за 11,0°C, встановивши вікно у зоні позитивних температур на відстані 260-265 мм від зовнішньої площини стіни.

енергоефективність, віконний проріз, вузол примикання, температурні поля, місток холоду, ізотерма, THERM, реконструкція, точка роси

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