Sustainable Advances of Windows in Energy Efficient Buildings: A Perspective Novelty Integrating of New Conceptual Solutions

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Abstract
As result of building industry and its produces, buildings account more than one third of the primary energy use and roughly a quarter of the generation of greenhouse gases worldwide. Therefore, a reduction of the energy demand of buildings and increased use of renewable energy are of a high importance of climate change mitigation as well as of whole society development. In the most essential respects related to buildings, energy savings and resultant consumption depend on building performance, both at whole building and individual components level. Building openings are one of the key elements, especially in residential area of buildings, where numbers of perspective advances are recently subjected for future directions of sustainable development. The paper specifically point out the technical aspects and key specifics in windows and doors, as those implemented in current residential buildings, especially for Central Europe locations. It practically presents an overview of recent advances and current state ideas in this field. Finally, the paper demonstrate a potential approach for future buildings, where progressive prototype based on own conceptual solution is introduced in accordance to requirements on energy performance of buildings while respecting and ensuring the principles of sustainability.

Keywords: sustainable window, energy performance, window optimization, insulated glass unit

Introduction

Windows in building structures are important transparent structures which are designed to separate the external and internal environments of buildings. The external environment (exterior) is influenced by weather changes. The temperature range in the exterior of buildings in Central Europe fluctuates between -20 °C to +40 °C. On the other hand, the internal environment of residential buildings is artificially adjusted to a steady condition comfortable for the stay of people. The indoor temperature is maintained between 20 and 29 °C. The temperature gradient between the external and internal environments significantly contributes to the overall energy balance of buildings and has a direct relationship with the environment [1]. The use of materials and structures with the best insulation properties possible are optimised [2] using computer technology so as to remove any risks [3]. At the same time, the focus is on reducing the summer overheating of interiors, especially in buildings with wood-based walls [4, 5]. The quality of details is crucial in the design of windows [6, 7, 8]. The fitting of windows and connection to the walls has a considerable influence on the resulting acoustic properties [9, 10].

History and Current Situation

The development of windows in buildings progresses in accordance with the material and the technical possibilities of the time. Glazing always plays a key role in the construction of windows. In the past, it was not possible to produce sheet glass of large dimensions, and therefore windows divided into smaller opening parts were used (fig. 1). Window frames individually bearing interior and exterior glass were exclusively made of wood [11] and the gap between them ranged between 100-300 mm. Later (approximately since 1960), the window frame was unified due to material savings and both glasses with a distance of about 40 mm were attached to a single frame (fig. 2). The operating comfort improved because handling only one element was enough to open the window. Windows reached the insulation value of the heat transfer coefficient U = 2.4 $W.m^{-2}.K^{-1}$.

Figure 1: Double casement double-pane window

Figure 2: Single casement double-pane window
Source: stavokomb

The insulating glass technology, which started to be implemented in the development of windows after 1990, significantly improved the thermal insulation properties. The principle of insulating glass is a hermetically sealed cavity with a thickness of 12-18

mm between the panes. The space between the panes is filled with an admixture of gasses in production, e.g. argon or krypton. Over the life, the insulating properties significantly depend on the quality of the sealing of the space between the panes. The newly produced insulation double-pane windows reach the value of U_w = 1.2 W.m^{-2}.K^{-1}.

Since 2010, the use of the insulating triple-pane window in the 4-16-4-16-4 (mm) composition has been gradually becoming a better standard. The glazing reaches $U_w \leq$ 0.8 W.m^{-2}.K^{-1}. The assembly puts increased demands on the bearing capacity of the frame and fittings because the triple-pane window weights upwards from 30 kg/m^2.

Materials used for window frames that carry the panes are PVC, wood and metals. PVC-based materials (fig. 3a, 3b) are gradually gaining a dominant position in the market due to the ease of production, excellent insulation properties and resistance to weather effects. In addition, recycled materials may be advantageously used in production [12, 13]. Wooden frames are used exclusively with aluminium sheeting of critical parts from the exterior (fig. 4a, 4b) [14].

The development of window structures over the past 30 years is continually heading towards improved parameters [15, 16]. Sections of conventional windows from the years 1990-2010 are shown in fig. 3a, 4a. The frame and casement sealing has only two levels of tightness and glazing of the window casement with a double pane. Frames with three levels of sealing and glazed with triple-pane glass have been becoming popular since 2010 (fig. 3b, 4b). The width of the frame and the casement is $\geq$ 90 mm, which achieves the insulation capability of the frame $U_f \geq$ 0.9 W.m^{-2}.K^{-1}.

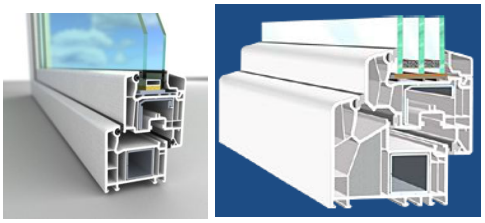

Figure 3a, 3b: PVC window section
Source: Veka

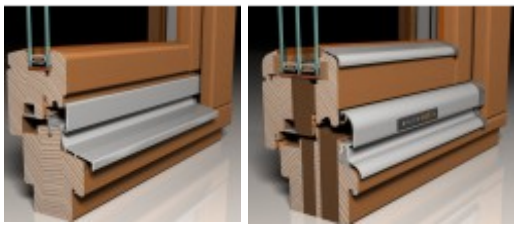

Figure 4a, 4b: Wooden window section
Source: Makrowin

The insulating glass is placed deeper into the casement to limit the linear thermal bridge around the glazing frame. This measure increases the visible height of the window frame and the casement which reduces the area remaining for glazing. For example, in a window opening with dimensions 1250/1500 mm, the proportion of the frame: glazing is 35 : 65 %!

Progressive manufacturers use low casement frames hanging in the interior in an effort to increase the area of glazing (fig. 5, 6), thereby improving the ratio of the frame areas in favour of glazing to 26 : 74 %. The casement remains as the carrier of fitting, the glazing is glued to it to increase the torsional stiffness.

Figure 5: Section of PVC window with a low frame Source: Internorm

Figure 6: Section of wooden window with a low frame. Source: Slavona Progression

A great disadvantage of standard windows from the architectural point of view is the immediately identifiable opening part which has a wide frame and casement (fig. 7 in the middle). In the new design, the casement is integrated using a smart solution (fig. 8).

Figure 7: Opening and fixed window.

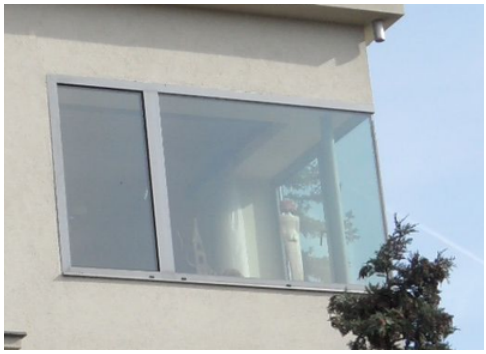

Figure 8: Window with integrated casement frame.

The problem of limiting the effective area of the glazing is successfully resolved and other benefits are brought by a new patented design solution developed by the author of the paper.

The New Design

The basic idea that triggered the development of a window without a casement was the optimisation of production costs and elimination of redundant elements. The principle is based on the assumption that the insulating glass is self-supporting under certain conditions. The goal was to arrange the assembly so that the glazing has integrated fittings that provide the opening and tilting of the self-supporting casement (glass) (fig. 10).

#	Description	Thermal conductivity λ [W.m.K^{-1}]
1a	External pane	1.0
1b	Second pane	1.0
1c	Internal pane	1.0
2	Composite profile	0.08
3	Window frame, wood	0.13
4	Fitting mechanism	50
5a	Tightness	0.35
5b	Exterior tightness	0.35
6	Inter-glazing spacer	0.25
7	Putty	0.5
8	Decompression cavity	0.025
9	Decompression cavity ventilation	-
10	External sill	-

Figure 9: Used materials and their properties

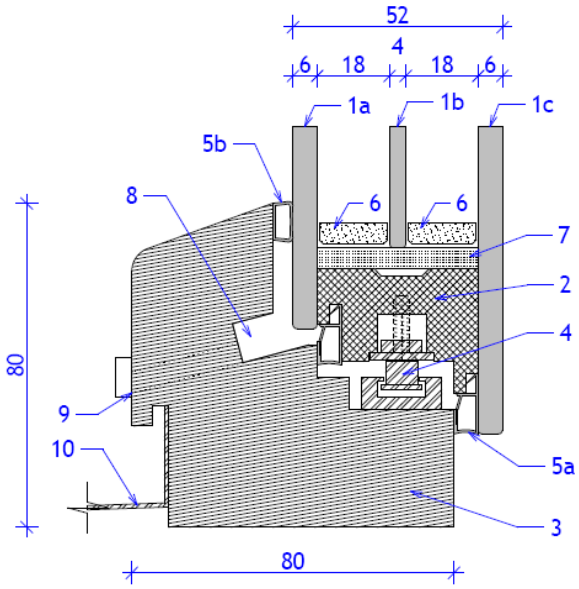

Figure 10: Cross-section at the sill

Used Materials

1. Insulating triple glazing (fig. 11). Glazing from the panes 6-18Ar-4-18Ar-6 weighing 40 kg.m^{-2} with insulation properties U_w = 0.6 W.m^{-2}.K^{-1}.

2. The integrated composite profile Purenit is glued between the inner and outer glass (fig. 12).

Figure 11: Section of PVC window with a low frame

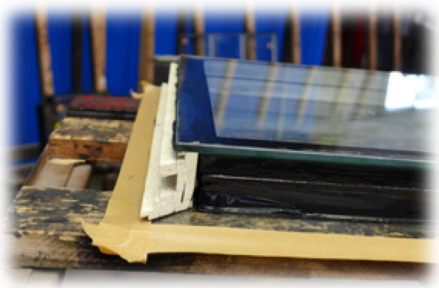

Figure 12: Section of wooden window with a low frame

The prototype development workshop of the Technical University in Zvolen collaborated in the production. From the perspective of separation of glued joints, the glued joint was developed and tested in terms of cohesion of the composite material and glass (fig. 13) [17]. The test results confirmed that the bearing capacity of the glued bond exceeds the bearing capacity of the material (fig. 14). The glued joint exhibits excellent strength values and is safe and durable.

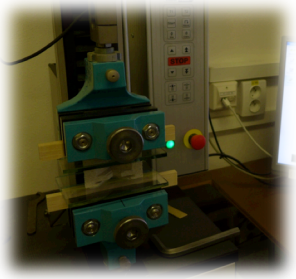

Figure 13: Pull-off test

#	Fmax (N)	A (m^2)	τ (Mpa)	note
1	860	0,001131	0,76	adhesive bond
2	1579	0,00144	1,097	adhesive bond
3	1473	0,00072	2,046	mass
4	1434	0,00072	1,992	mass

Figure 14: Pull-off test results

3. Window frame. The frame material is made of a base prism of laminated timber 84 x 86 mm (fig. 15) and provided with finishing. In terms of durability, the use of the PVC material is preferable. The possibilities of production of moulds for the special PVC profile are examined.

Figure 15: Manufacture of window frame

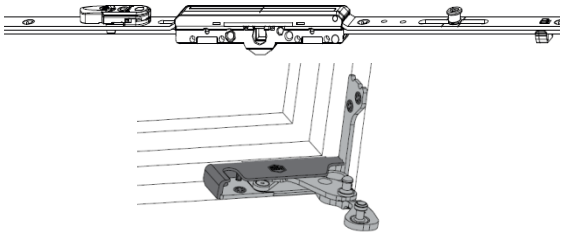

Figure 16: Window fittings. Low operator and concealed hinge. Source: Maco

4. Window fittings. We have negotiated with all major European manufacturers regarding the delivery of fittings for production. A low operator and hidden hinges from the manufacturer Maco won due to savings of space (fig. 16).
5. Sealing Ethylene-propylene-diene-monomer-rubber-based sealing is used at three levels of tightness.

Thermal Insulation Properties

The most critical part - bottom area of the window at the sill - was selected to assess the thermal technical properties. In other parts - lining and head, covering the window structure frame with a thermal insulation of the façade is considered, therefore the field of temperature will always end up being better. A comparison of the development of the temperature fields observed using software Therm 7.1. is shown in figures 17 and 18.

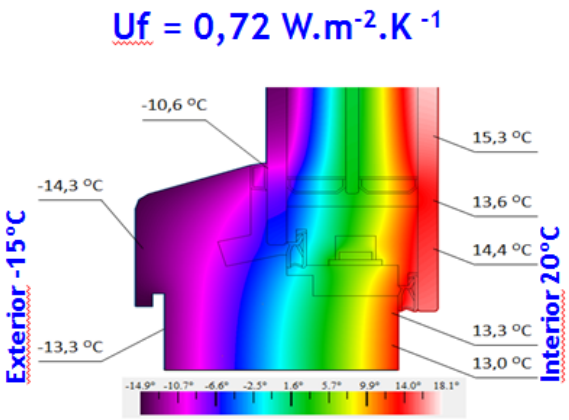

Figure 17: New window.
Temperature field and surface temperatures.

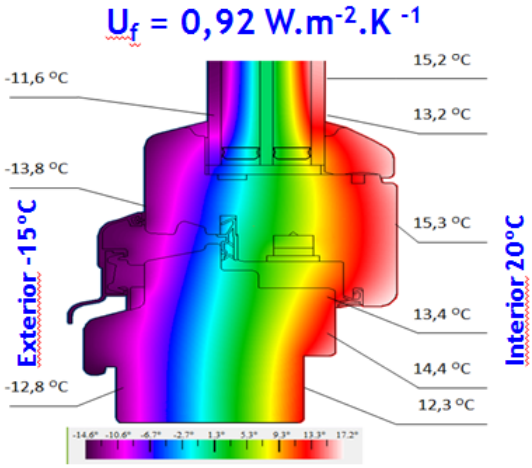

Figure 18: Standard window.
Temperature field and surface temperatures.

Conclusion

Based on two years of intensive development, a functional sample of an opening and tilting window without a glazing frame was manufactured. The design brings advantages in the elimination of the casement frame, thus reducing production costs and increasing the effective area of the glazing. The architectural appearance of buildings greatly benefits from the uniform appearance of the opening and non-opening assembly of windows when viewed from the exterior. Finally, we managed to optimise the thermal insulation properties of the innovated frame which reaches an excellent value U_f = 0.72 $m^{-2}.K^{-1}$ (fig. 17). The use of a new window element in buildings contributes to a reduction in energy demands which is in line with the principles of sustainability and efficiency in terms of the resources on the planet.

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