The thermal insulation performance required of building envelopes is rising all the time. This is especially true in the context of the more stringent thermal insulation standards demanded by the German Energy Saving Ordinance. There is still room for improvement here, particularly in the area of windows.

The thermal-insulation properties of glazing have indeed improved considerably in the last thirty years: the best example of this is the current development of vacuum-insulated glass, where a vacuum in the cavity between the panes leads to a heat transfer coefficient for the glazing unit of 0.5 W/m²K. Nonetheless, windows still represent a weak point in terms of the energy performance of building envelopes. One reason for this is the type of frames currently available. The thermal insulation values of conventional window frames are still significantly above the heat transfer coefficients of the best glazing. Even passive-house windows with very good thermal insulation provided by the frames and the triple glazing rarely achieve $U_w$ values below 0.8 W/m²K. The downside here is that these are inelegant systems with larger profiles and fittings and with increased installation depths. All in all, window frames that are highly insulating and are nonetheless sleek and light are well overdue.

The goal of the “Highly Insulating Window and Facade Systems” research project is the development of frame designs which fulfil these requirements. The participating researchers have the task of developing these frames for use as standard windows in new residential buildings and in the refurbishment of older structures, while also incorporating modern glazing such as vacuum-insulated glass.

In all, two research institutes and seven medium-sized companies are participating in this research project which is supported by funds from the German Federal Ministry of Economics and Technology (BMWi).
The new frame is made entirely of polyurethane (PU), but is divided into two structural parts. The insulation core is filled with PU insulating foam (density: 110 g/l). The foaming process creates thin walls with air pockets, which results in a low thermal conductivity. The warm and cold sides are thermally separated from one another as much as possible.

A thin layer of form-stable and weather-proof solid polyurethane covers the foam core. Polyurethane is solid and heat-resistant even at temperatures around 80 °C. The functional outer layer has a variable wall thickness and guarantees the frame’s mechanical and static properties. Moreover, it provides design freedom: there are virtually no limitations to how the surfaces can be glued and painted. Thus, the new profile is a ‘single piece’ made of a single material. This facilitates the sorting and recycling of the frame when it is to be disposed of. The weight of the sandwich structure is composed of 95% hard foam core and 5% casing.

The required stability can be achieved for the frame described without using steel or aluminium reinforcement. This also results in a lower weight and lower thermal insulation values. As regards the installation of these windows, there are no differences compared to conventional frame systems. For example, the distances between the screw connections are similar to those for conventional windows.

Highly insulating frames – a brief summary

The highly insulating frames currently available have heat transfer coefficients of between 1.1 and 0.7 W/m²K. There are also cases where slightly lower values are achieved. Uₜ values of between 0.7 and 0.8 W/m²K are possible using improved spacers. However, this also leads to increased installation depths. Values of around 120 to 130 mm apply for passive-house window frames. The following categories of frame can be identified:

- Extruder frame profiles made of PVC with interior steel reinforcement and a number of air chambers. Additional PU foam elements can further improve the thermal insulation performance of the frame.
- Wooden frame with core insulation or as a sandwich structure with an insulating middle or exterior layer. The insulating material is either PU integral foam, PU recycled material (Purenit), Styrodur or soft-fibre insulating material. The arrangement of the insulating layers differs among the various manufacturers. There are also wood-aluminium windows with a PU insulation core.
- Aluminium frames where the frame shell is filled with a PU insulation core.
- Other developments: foam-filled plastic profiles where steel reinforcement is replaced by profiles strengthened with glass fibre; wooden frames which are combined with externally fitted profiles that are strengthened with wood fibres.

Testing of materials and components

The SKZ plastics technology centre carried out tests on individual components and conducted mechanical simulations with the aim of investigating the complete window system’s suitability for use and its long-term stability. The scientists measured mechanical performance under strong temperature fluctuations (warm/cold shock) and under swelling wind loads (suction/compression) combined with temperature or rain. Shock resistance, profile stability, corner stability and other properties were tested. The results identified very good stability behaviour for the newly developed profile, and the adhesive technology used resulted in good strength.

The Bavarian Centre for Applied Energy Research (ZAE Bayern) was entrusted with the task of thermally optimising and characterising the new frame. The scientists calculated the thermal conductivity behaviour and the influence of thermal bridges using simulations. These calculations were used in the manufacture of optimised sample profiles and windows. Hotbox measurements and numerical methods were used by the scientists to investigate the prototype’s thermal behaviour in a number of ways.
New approaches in manufacturing

Instead of pressing or extruding the profiles as has been common up to now, the core of the new frame is made by filling foam into a die and then covering this foam core with a plastic layer. The system prerequisites for this type of polyurethane processing are a high-pressure foaming unit, equipment for supporting the die, and foam-working tools. Window manufacturers buy six-metre lengths of PU and then cut these down according to their needs. Pilot production of the prototype is currently underway, and forty sample windows have already been manufactured and tested. Manufacture of the new profile can be integrated into an existing production process, providing an additional profile option. Production concepts for intermediate (200,000 running m² p.a.) and large (1.2 million running m² p.a.) annual amounts have been developed.

Vacuum-insulated glass: Suitable frame sought and found

Among the goals of the research project presented here was the development of a frame that makes optimal use of the advantages of vacuum glass. The key component of this glazing (see also BINE-Projektinfo 01/08) is located inside the cavity between the panes: the vacuum means that there is no medium for transporting heat from the inner pane to the outer pane. In order to achieve this, the pressure in this area is reduced to less than 10⁻³ hPa. Only then is it possible to reduce the heat transfer through the residual gas to values less than 0.1 W/m²K, thus achieving a heat transfer coefficient of 0.5 W/m²K for the glazing. The atmospheric pressure is resisted by the support pillars. The edge seal bonds together two panes of 3-4 mm-thickness together with a low-emissivity film (low-e coating).

With an inter-pane spacing of around 0.7 mm, this glazing is considerably thinner than the double-glazed units typically used today. Nonetheless, the weak point in the case of vacuum-insulated glass is the metallic edge seal, which forms a thermal bridge. This problem has not been resolved on the market. The newly developed frame represents a solution to this problem, as the large insertion depth of the glass into the frame prevents the presence of temperatures below the dew point at the edge of the pane.

Comparison of frame systems

It became evident during the first project phase that the opportunities for optimising standard pressed aluminium profiles and standard extruded PVC profiles are limited. It is currently very laborious from a technological and production point of view to achieve profile widths of less than 90 mm for standard extruded PVC profiles and less than 50 mm for standard pressed aluminium profiles and that they are not longer than those typical for PVC windows.

In contrast to conventional frames, profiles made entirely from polyurethane cannot be welded; instead the corners are stuck together, as too are the frame and the glazing. The cut surfaces of the frame are coated with a newly developed adhesive, which hardens in a matter of seconds and can then be reactivated for the next production step using a welding machine. Because the adhesive dries so quickly, work on the part can continue at normal production pace. Window production can proceed while the adhesive is achieving its ultimate strength level, which occurs after four to five hours. Thus production cycle times are possible that are not longer than those typical for PVC windows.

![Fig. 5: Die for foam-filling of the insulation core](image)

![Fig. 6: Composition of vacuum-insulated glass](image)

![Fig. 7: Overview of thermal properties](image)
Conclusion

With its low thermal insulation values, the new profile is at the level of passive-house window frames, but it weighs less and is significantly thinner.

With this frame, the research team had to innovate as regards materials and manufacturing methods. The entire profile is made of polyurethane, which has implications for production and further processing. Special machines are necessary for foaming, casting and coating. BBG GmbH developed the production process for future series production and produced the prototype tools. Pilot production and initial discussions with system manufacturers are currently underway.

The PU frame cannot be welded. The solution here is provided by an innovative technology where the frame and the glazing are joined using a newly developed adhesive. Various tests on sample windows have shown that the adhesive method means that windows can be manufactured simply and also have high strength. Industrial use with the integration of the frame into existing window production is feasible.

The newly developed standard window with triple glazing and vacuum-insulated glass has already been presented to a wide audience under the brand name “TopTherm90” at glasstec 2008 in Düsseldorf and at the International Congress on PVC Windows 2009 in Würzburg.

The profile is suitable both for new buildings and for refurbishment of existing buildings. The project presented focussed on the development of a frame profile for standard windows. A profile made entirely from plastics is not suitable for facade systems with sizes covering a number of storeys. It is possible to use these profiles in mullion-and-transom structures, but they cannot support mechanical loading. For this reason, a thermally optimised mullion-and-transom structure based on aluminium supports is to be developed as part of a follow-up project.