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BINE
Informationsdienst

Vacuum glazing: When inert gas is replaced by a vacuum

- **Excellent thermal insulation properties with slim system assemblies and low weight**
- **Need for development in terms of frame assemblies and production**
- **Research group is developing products for facade systems and roof canopies**
- **Further application areas being developed**
- **Market launch expected in a few years**

Fig. 1

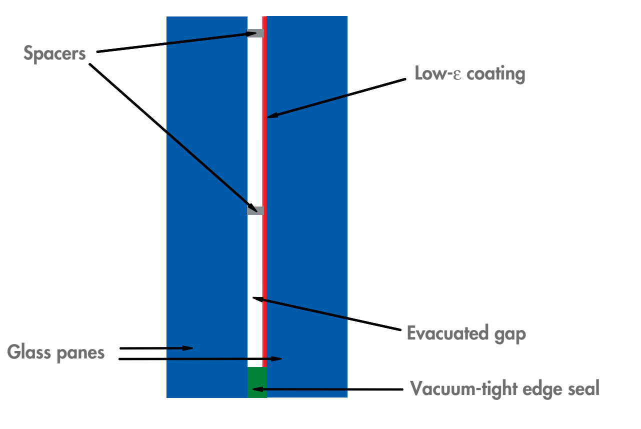
With its excellent values for thermal and noise insulation, vacuum glazing is certainly a cutting edge development. Here are two examples of vacuum-insulated glass at the glasstec trade fair in Düsseldorf.

In the last twenty years, the thermal insulation and visual properties of glazing systems have improved considerably in the construction industry. Coated with ultra-thin silver and filled with inert gas, the standard insulating glazings used today have reached a high quality. Double-glazed insulating glass units filled with the inert gas argon are now standard in new buildings. They achieve U_g values between 1.3 and 1.1 W/m^2K. High quality, triple-glazed windows have a heat transfer coefficient of between 0.6 and 0.7 W/m^2K in their glazing area. Complex assembly, several centimetre-thick glazing and the use of expensive inert gases means that there is still potential for innovation in developing these glazing systems. Vacuum glass offers such a new alternative. A Japanese and a Chinese company are already offering vacuum glass systems on the Asian market, however with U_g values between 1.1 and 1.3 W/m^2K. The research project is looking to improve these values considerably.

Using double-glazed assemblies with evacuated gaps, vacuum glass systems can achieve heat transfer coefficients of 0.8 W/m^2K for the entire window and 0.5 W/m^2K for the glazed area. With system assemblies projected to be less than 10 mm thick with 4 mm glass, vacuum-insulated glass is thinner than conventional insulating glass units. It is no longer necessary to use inert gases. However, at ten tonnes per square metre, the atmospheric pressure on evacuated flat glazing is very high and requires the use of spacers in the cavity between the panes. The goal of a research project funded by the Bundesministerium für Wirtschaft und Technologie, the German Federal Ministry of Economics and Technology (BMWi), is to investigate the technical feasibility of permanently vacuum-tight glazing systems that would be competitive on the European market. A collaboration of three research institutes and five medium-sized companies is involved in this.

▶ The composition of vacuum-insulated glass

Fig. 2: Composition of vacuum-insulated glass



The gas-tight edge seal bonds together two 3-4 mm-thick panes, of which one is covered with a low-emissivity coating (low-ε coating). With an inter-pane spacing of around 0.7 mm, this glazing is considerably thinner than the double-glazed units typically used today. The key element of the vacuum-insulated glass is the inter-pane cavity: The vacuum means that there is no medium for transmitting heat and sound from the inner 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 of the remaining gas to values less than 0.1 W/m²K, thus achieving an excellent overall heat transfer coefficient for the glazing. The atmospheric pressure is absorbed by the spacers. Important factors when selecting suitable spacers are that they have low thermal conductivity and are nearly invisible.

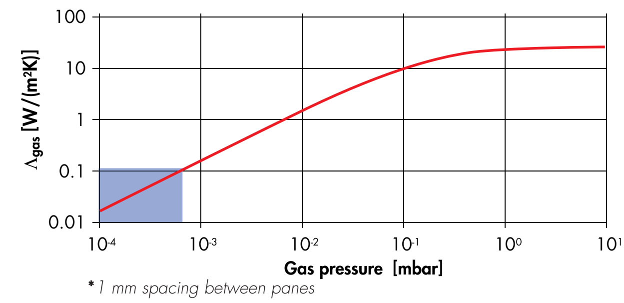
Thermal transfer in the window

When assembling a thermal insulating window, it is important to reduce the thermal transfer using three different mechanisms:

■ **Thermal conduction** is the main form of heat transmission in solids, such as window frames and the edge seals in glazing. The amount of heat loss can be reduced by using appropriate insulating material and by reducing the amount of solid material such as by using hollow profiles.

■ **Thermal convection** is the transfer of heat via moving particles. In the cavity between the panes, this thermal transfer mechanism plays an important role together with conduction via the fill gas. The lighter the gas molecules, the more heat is transferred. For this reason, the inter-pane cavities in insulating glazing systems are filled with heavy inert gases such as argon. Very high-quality windows are filled with krypton, which is even heavier but much more expensive. In an ideal vacuum there is of course no thermal convection. But a partial vacuum also reduces heat transfer considerably. If the pressure is reduced enough so that the molecules can move without impacting on one another, the thermal transfer reduces linearly with the gas pressure (Fig. 3).

Fig. 3: Heat transfer coefficient as a function of the gas pressure*

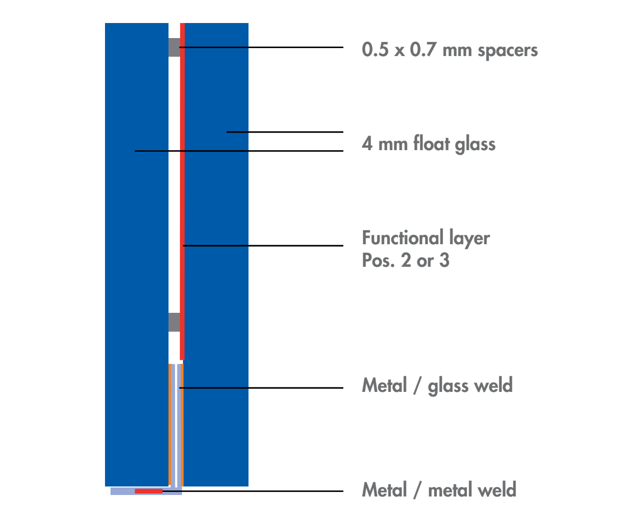


* 1 mm spacing between panes

■ **Thermal radiation:** All bodies radiate electromagnetic waves with a spectrum that is characteristic for their temperature and therefore exchange energy with their environment. In contrast to thermal conduction and convection, thermal radiation also occurs in a vacuum. A so-called low-Â coating on insulating glass reduces these thermal losses. The ultra-thin metal-oxide films enable short-wave radiation (light) to pass through almost unhindered, but reflect long-wave infrared radiation (thermal radiation).

▶ Challenges in the research project

Fig. 4: Vacuum-tight edge seal with welded metal strips



Edge seal

The materials used in the edge seal should be vacuum-tight and thermally insulating for the duration of the window's service life under all influences and loads. This means that the residual gas pressure of less than 0.001 hPa in the space between the panes should remain stable for more than 25 years in a temperature range between -40 °C to +60 °C. In addition to the vacuum-tightness, it is also necessary to have a certain amount of elasticity. This balances out stresses and thus prevents cracks developing through overstressing the glass edges. The method of rigidly bonding the glass panes with glass solder used by Asian manufacturers cannot meet these requirements. Their production requires temperatures of more than 300 °C, which makes it impossible to use high-quality, low-ε soft coatings since these cannot withstand high temperatures. The stresses in the edge seals increase proportionately to the size of the glass panes, which can lead to the glass shattering with larger windows and when there are high temperature differences between the inner and outer panes. The developers were able to solve the problem by using thin metal foil as the material for the edge seal. Its elasticity balances out

the temperature-related stresses. In looking for a suitable method for combining metal foil and glass, a combination of ultrasonic and laser welding proved to be the best solution (Fig. 4). First of all the metal foil is ultrasonically welded to the glass. The resulting chemical bond between the metal and the glass remains permanently vacuum-tight. The two panes are then laid together with the spacers between them. In order to hermetically seal the unit so that it remains vacuum-tight, the metal strips on the inner and outer panes must be laser welded to one another. Any protruding metal bur can then be trimmed off, producing a flexible and durable edge seal. The entire process takes place in a pressure chamber under vacuum.

Spacers

The aim was to identify spacers which are hardly visible but nonetheless mechanically durable. Whereas small spacers with compact surface areas are better in terms of the appearance and thermal performance of the vacuum glass, the opposite is the case as far as the mechanical performance is concerned. It needed to be taken into account that the size of the spacers, the distance between them (spacing) and the thermal conductivity of the material used affect the overall heat loss through the vacuum glass. Spacers less than 0.35 mm in size cannot be seen by observers from a distance of one metre, whereas spacers 3.5 mm in size can be seen very easily. Investigations into the thermal performance showed that metal supports and glass cylinders led to comparable results: with 40 mm spacing, the U_g value of the former was 0.49 W/m² K and 0.51 W/m²K for glass cylinders. The scientists examined the mechanical durability of the spacers by inserting them between panes of float glass and testing them in a universal testing machine with regard to their compressive strength. Here metal supports were the safest in terms of overloading. Hail impact simulations also showed metal supports to be better than glass supports because they have a considerably lower damage threshold. In the conflicting area between appearance, thermal and mechanical performance, the scientists ultimately identified metal cylinders as the most suitable supporting material. They developed a model that provides sufficient mechanical stability and elasticity and is glare-free. The spacers are arranged on a 30-40 mm grid. With a 0.5 mm diameter, the spacers can only be seen against a low-contrast background and when less than one metre away.

Fig. 5: Vacuum-tight edge seal with welded metal strips

Need for research on window frame assemblies

Creating window frame and facade interconnections with low thermal bridging for vacuum-insulated glass has been problematic up to now. An optimal window frame for vacuum glazing should cover the thermally bridging edge seal, be slim and have good thermal insulation properties. Standard models on the market have not been able to meet this task. In the HWFF project, a collaboration between science and industry is developing such highly insulating window and facade systems with slim frames and highly efficient glazing. The German Ministry of Economics and Technology (BMWi) is funding this project.

New production method developed

In order to create a vacuum, it was previously necessary to pump air out of the space between the panes through an opening in the window. This had to be carried out for several hours while maintaining a high temperature (up to 400 °C) until all the moisture in the cavity was removed. With the new procedure (sputtering), the moisture is removed from the glass surfaces by bombarding them with energy-rich ions (plasma). The pane edges are welded together in a large pressure chamber under vacuum. The aim of the ProVIG research project, which is funded by the BMWi, is to construct a production plant suitable for industry in which this procedure is integrated. This is scheduled to be completed in 2009. It is planned to produce vacuum-insulated glass panes in sizes up to 2500 mm x 1500 mm.

▶ Positioning in the current window market

Standard insulating glass products on the market use argon. The excellent U_g values of triple-glazed insulating glass units produced with krypton are achieved at a very high cost since the inert gas is very cost-intensive. In order to achieve a U_g value of 0.5 W/m²K, it is necessary to have a 12-14 mm cavity between the panes, which means that the overall system is correspondingly thick. The considerable weight can cause problems in terms of the hinges, fittings and frames. In contrast, double-glazed vacuum glass achieves U_g values of 0.5 W/m²K with less weight and a slim construction. Since only one low-ε coating is used, this has a relatively high g value compared to triple-glazed insulating glass and therefore, in terms of the energy balance, it has greater solar heat gain.

Fig. 6: Thermal and visual characteristic values for insulating glass based on various manufacturer specifications

Type of glass	Construction* (Glass thickness, inter-pane cavity), [mm]	U_g value [W/m²K]	G value [Overall energy transmittance]	τ_v [Light transmittance]
2 IGU, argon	4/12 – 16/#4	1.4 – 1.1	0.63 – 0.53	0.80 – 0.75
3 IGU, krypton	4#/8 – 12/4/8 – 12/#4	0.7 – 0.5	0.55 – 0.47	0.72 – 0.68
In comparison:				
2 Vacuum	4/0.7/#4	0.5	0.54	0.73

** From outside inwards*
IGU = insulating glass unit, # = position of the low-ε coating(s)

▶ Potential applications

With almost invisible spacers, excellent thermal properties and different glass assemblies (float, toughened safety glass, laminated safety glass), vacuum glass shall already be ready for the market in a few years. The applications could range from new buildings (low-energy and passive houses) and refurbished old buildings to lightweight glass structures, vehicles and cooling devices. The research project is currently concentrating on developing vacuum glass for facade systems and roof canopies. There are still no window frame systems available on the market for either area that can optimally use the advantages of vacuum glass. In the aforementioned HWFF research project, a window has been constructed with a U_f value of 0.8 W/m²K for the frames. The thermal insulation values are comparable to glazing systems used in passive homes. With a thickness of 90 mm, the system assembly is considerably thinner than those used in passive houses, which have widths between 110 and 130 mm. In future vacuum glass will also be available as solar protection glass and laminated safety glass. There is also interest in combining this glass with other panes or panels. For example, the use of vacuum-insulated glass is being considered in the field of solar thermal energy. These could be used as highly insulating cover panels in collectors and so improve the efficiency.

Fig. 7: Example assembly with vacuum-insulated glass (skylight to the right)

▶ Conclusion

The scientific projects described above have already laid the main foundations for introducing vacuum glass products to the market. There is still need for further development in terms of producing suitable frame assemblies as well as in manufacturing vacuum glass. With its excellent values for thermal and noise insulation, this type of glazing is certainly a cutting edge development. This is particularly evident when further developments in thermal insulation standards are taken into account, which in a few years will require thermal values that are currently only achieved by triple-glazed insulating glass. Vacuum-insulated glass products are planned to be on the market from 2010.

▸ PROJEKTADRESSEN

- Overall project coordinator
  on behalf of Grenzebach
  Glaser FMB GmbH & Co. KG
  Am Kapellenberg 53
  D-37688 Beverungen
- Grenzebach Maschinenbau GmbH
  Albanusstr. 1
  D-86663 Asbach-Bäumenheim
- FHR Anlagenbau GmbH
  Am Hügel 2
  01458 D-Ottendorf-Okrilla
- Schunk Sonosystems GmbH
  Hauptstraße 95, D-35435 Wettenberg
- Roto Frank Bauelemente GmbH
  Wilhelm-Frank-Straße 38-40
  D-97980 Bad Mergentheim
- Visio-Glas GmbH
  Amalienruher Weg 1, D-8617 Sülzfeld
- Fraunhofer-Institut
  für Solare Energiesysteme ISE
  Heidenhofstr. 2, D-79110 Freiburg i. Br.
- Fraunhofer-Institut
  für Werkstoffmechanik IWM
  Wöhlerstraße 11, D-79108 Freiburg i. Br.
- Bayerisches Zentrum für Angewandte
  Energieforschung e.V. (ZAE Bayern)
  Am Hubland, D-97074 Würzburg

▸ ERGÄNZENDE INFORMATIONEN

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PROJECT ORGANISATION

Project Funding
Federal Ministry of Economics
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D-11019 Berlin

Project Management Organisation Jülich
Research Centre Jülich
Dr. Hendrik Wust
D-52425 Jülich

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BINE
Informationsdienst

FIZ Karlsruhe, Büro Bonn
Kaiserstraße 185 – 197
D-53113 Bonn

Tel.: +49 228 92379-0
Fax: +49 228 92379-29

bine@fiz-karlsruhe.de
www.bine.info