Code of practice for the use of triple thermal insulating glass units
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## 1.0 Introduction

The Energy-Saving Ordinance (EnEV) is the German Federal government's main body of legislation in the quest for an efficient use of energy in new and existing buildings. The EnEV ordinance of 2007 served to implement the European Union's Energy Efficiency Directive. The amendment to this ordinance (EnEV) adopted in 2009 tightens the requirement level for energy demand by 30%.

A number of innovations - including in the field of glass, windows and facades - are required to satisfy these future requirements. The use of triple thermal insulating glass units to a far greater extent than is previously the case will be an important contribution to improving the thermal characteristics of windows and facades.

The Bundesverband Flachglas e.V. (Federal Association for Architectural Glazing) and its members emphatically support the Federal government's quest for the more efficient use of limited energy resources. Triple thermal insulating glass units are tried-and-tested products which were launched on the market more than ten years ago, but until now have only been used in very limited applications.

The production of triple thermal insulating glass units in far greater quantities than before has enormous effects on manufacturing technology and on the quality standards which must be met. The considerably increased use of triple thermal insulating glass units in windows and facades means that many aspects have to be recognized and taken into account. The object of this code of practice is to address important questions which the manufacturers and processors of triple thermal insulating glass units are strongly recommended to consider.

The fixing of triple thermal insulating glass units into frame sections with adhesive is not the subject of this code of practice.
2.0 Triple thermal insulating glass units

2.1 Design of triple thermal insulating glass units
Ug-values significantly below 1.0 W/m²K are achieved with triple thermal insulating glass units. For this purpose, the design of a triple thermal insulating glass unit of this type must include two highly thermally insulating coatings, one facing each cavity. In addition, both cavities must be filled with inert gas.

2.2 Standard products
The necessary materials and semi-finished products must be available in large quantities for standard products. Krypton or even xenon filler gases for achieving lower Ug-values are not available in the quantities required for using in triple thermal insulating glass units as a standard product. For this reason, argon is normally used. As a standard design, a triple thermal insulating glass unit with a 4/12/4/12/4 glass structure is recommended, with two highly thermally insulating coatings (Low-E) on surfaces 2 and 5 and with an argon filling in both cavities.

2.3 Achievable U-values
A triple thermal insulating glass unit with a 4/12/4/12/4 structure, with two highly thermally insulating coatings (Low-E) with an emission capacity $\varepsilon_n \approx 0.03$ (state of the art) and with an argon filling (gas filling level 90%) in both cavities, achieves a Ug-value of 0.7 W/m²K when calculated in accordance with DIN EN 673.

Without any further measures for improving the thermal properties, this results according to EN 10077-1: 2006, Table F.1, in the following $U_w$-values for windows with different frame structures:

- $U_1 = 1.8 \text{ W/m²K}$
- $U_2 = 1.2 \text{ W/m²K}$
- $U_1 = 1.4 \text{ W/m²K}$
- $U_2 = 1.1 \text{ W/m²K}$

Examples of possible measures for further improving the thermal properties of a window design are:

- improving the thermal properties of the frame sections
- use of a thermal insulating glass unit with thermally improved edge bond (so-called ‘warm edge’)
- thermally improving the glazing system by means of a larger glazing channel, for example.

2.4 Achievable g-values
With the standard product just described, a total energy transmittance (g-value) of about 50%, or about 0.50, is achieved for a triple thermal insulating glass unit. This can vary slightly depending on the base glass and coated glass used in each individual case.

2.5 Balancing U-values
Ultimately, the balance between heat losses (described by the U-value) and solar heat gain (described by the g-value) defines the energy saved with a triple thermal insulating glass unit or window component. The balancing U-values for a window can be calculated as follows:

$$U_{w,eq} = U_w - S \times g$$

The coefficients S for the solar heat gains depend on the direction in which a triple thermal insulating glass unit or window faces when installed. The following numerical values are used for this according to DIN V 4108-6:

- $S = 2.1 \text{ W/m²K}$ – south orientation
- $S = 1.2 \text{ W/m²K}$ – east/west orientation
- $S = 0.8 \text{ W/m²K}$ – north orientation

With these figures, the following approximate balancing $U_w\text{-values}$, which in turn can vary slightly depending on the base glass and coated glass used in each individual case, are achieved for the described standard product of a triple thermal insulating glass unit with a U-value of the window frame $U_r = 1.4 \text{ W/m²K}$ and a window U-value $U_w = 1.1 \text{ W/m²K}$ (cf. Chapter 2.3):

- $U_{w,eq} = 0.05 \text{ W/m²K}$ – south orientation
- $U_{w,eq} = 0.5 \text{ W/m²K}$ – east/west orientation
- $U_{w,eq} = 0.7 \text{ W/m²K}$ – north orientation

2.6 Special coatings
With the help of coatings which have been optimized especially for use in triple thermal insulating glass units, a Ug-value of 0.7 - 0.8 W/m²K and a g-value of approximately 60%, or approximately 0.60, is achieved in the standard glass structure described. The window values stated above (see items 2.3 and 2.5) then change accordingly.
3.0 Factors affecting durability

3.1 Cavity and pane format (surface area, side ratio)

The loading for the system increases with the size of the cavity (insulating glass effect, cf. section 5.2). Two cavities in triple thermal insulating glass units add up, at least with regard to their effect, in such a way that they can be considered as one continuous cavity. The resulting loads for the glass panes and the edge bond depend on the format. Small, narrow panes (side ratio 1:3) exhibit the highest loading for glass and edge bond.

For standard applications of triple thermal insulating glass units in windows, cavities of 2 x 12 mm are considered to be technically worthwhile. Smaller cavities (where argon is used as the filler gas) lead to higher $U_g$-values; larger cavities lead to greater loads on the glass and edge bond.

3.2 Rear overlap (secondary sealant bite)

The mechanical loads on the edge bond are greater with triple thermal insulating glass units. For this reason, the rear overlap (secondary sealant bite) should be increased, particularly for narrow formats.

3.3 Glass sizing

As a basic principle, all standards and directives apply as for double-pane insulating glass units. On account of the increased loading mentioned above, special questions relating to the sizing of glass should be answered with the help of structural strength software such as the GLASTIK industry solution jointly released by BF. Examples of load-increasing factors are asymmetrical glass structures or the use of special glasses, laminated glasses and laminated safety glasses, and highly absorbent glasses. Furthermore, patterned or wired glass has a lower mechanical strength than float glass. Tempering is recommended when using patterned glass and highly absorbent glass for the middle pane.

3.4 Coating surfaces

It is recommended that the coatings on the two outer panes be arranged to face the cavities (coating on surfaces 2 and 5). Tempering of the uncoated middle pane for single-pane safety glass is then not generally necessary.

If a coating is provided on the middle pane (surfaces 3 and 5 or 2 and 4) - for example to affect the $g$-value of the triple thermal insulating glass unit - the middle pane must usually be tempered.

3.5 Special functions

Empirical values for double-pane insulating glass units cannot simply be transferred to triple thermal insulating glass units. Combinations with special functions such as safety (overhead glazing, protection against falling), noise protection, solar control etc. impose particular requirements.

3.5.1 Safety (overhead glazing, protection against falling)

The technical regulations for linear supported glazing and accident-proof glazing (TRLV and TRAV) do not make express mention of triple-pane thermal insulating glass units. In the opinion of Bundesverband Flachglas, the requirements which have been generally formulated for ‘multipane insulating glass units’ therefore apply equally to triple-pane and double-pane insulating glass units.

Attack-resistant glazing (resistance to thrown objects, penetration, bullets and explosion) and glazing for fire prevention must be determined for the individual case.

3.5.2 Noise protection

Noise protection characteristics can be combined with the thermal insulating characteristics of triple thermal insulating glass units. The load on the thinner outer glass panel increases significantly with the asymmetrical structures that are typical for noise insulating glasses. For this reason, tempering to produce single-pane safety glass is recommended with edge lengths up to approx. 70 cm.

3.5.3 Solar control

Solar control characteristics can be combined with the thermal insulating characteristics of triple thermal insulating glass units. This changes the physical light and radiation properties compared with double-pane solar-protection insulating glass units.
4.0 Glazing specifications

As with double insulating glass units, the basic requirements which can be found, for example, in the BF's 'Guidelines for the handling of multi-pane insulating glass units' apply: protection against the continuous effect of moisture (vapour pressure equalization), protection against direct UV radiation (alternatively: UV-resistant edge bond), material compatibility, and use in temperature ranges usually found in buildings and zero-stress installation. Frame designs must be suitable for accommodating the triple thermal insulating glass units. The manufacturer of the insulating glass does not have to be responsible for defects which are beyond his control and occur as a result of non-compliance with these basic requirements.

The glazing trade's Technical Directive No. 17, 'Glazing with insulating glass', must be observed.

4.1 Blocking

The functional properties of the glazing blocks must be maintained throughout the whole period of use. To ensure that this is the case, they must be adequately resistant to pressure in the long-term, resistant to ageing and be suitably compatible.

When fitting the blocks, it must be ensured that the supporting and spacer blocks are straight and parallel to the edge of the glazing unit. The block must take up the full thickness of the glazing unit and thus carry the dead weight of all three panes. In systems with free rebates, the block must not impair vapour pressure equalization. The block must not cause the edges of the glass to chip. Shear loading of the edge bond must be minimized.

The glazing trade's Technical Directive No. 3, 'Blocking of glazing units', must be observed.

4.2 Larger glazing channel

With regard to the risk of glass breakage caused by thermally induced stresses in highly thermally insulated frame systems, a larger glazing channel may be considered acceptable for triple thermal insulating glass units (HIWIN research project, sub-project B: investigations into the risk of glass breakage due to a larger glazing channel, final report April 2003, ift Rosenheim and Passivhaus Institut Darmstadt).

5.0 Other characteristics

5.1 External condensation

The following applies to any insulating glass units: the smaller the heat transfer – and the lower the U_g value – the warmer the room-side pane and the colder the external pane. This naturally also applies to triple thermal insulating glass units. In addition, the external pane directly 'exchanges radiant heat' with the sky.

Depending on the individual installation situation, this radiant heat exchange leads to considerable additional cooling of the external pane, particularly on clear nights. If the surface temperature of the external pane falls below the temperature of the adjacent external air, this leads to condensation, and in special cases even the formation of ice, on the surface of the external pane. This process is generally known in nature as the formation of dew or hoar frost. The condensation will disappear again due to the heating of the external pane together with the external air, for example by the morning sun. This phenomenon is not a malfunction as such, but more an indication of the outstanding thermal insulation value of the triple thermal insulating glass units.
Because of the even better thermal insulation of triple thermal insulating glass units, it must be expected that condensation will form on the external surface of the pane more frequently than with the previously common double thermal insulating glass units. To avoid confusion and irritation of customers and consumers, it is recommended that this phenomenon be pointed out in advance.

5.2 Insulating glass effect
Section 4.2.2 of the ‘Guidelines for assessing the visual quality of glass for building’, issued by the Bundesverband Flachglas amongst others, describes the ‘insulating glass effect’ which results in concave or convex curvature of the individual panes and therefore optical distortion in the event of temperature changes and variations in the barometric air pressure. Because of the larger volume of gas enclosed in two cavities, this effect can be greater with triple thermal insulating glass units.

5.3 Optical quality
5.3.1 Inherent colour
Section 4.1.1 of the ‘Guidelines for assessing the visual quality of glass for building’ describes the inherent colour of all glass products, especially those made from coated glass. Due to the presence of a third glass pane and a second coating, the inherent colour of triple thermal insulating glass units can be seen more clearly than that of dual-pane insulating glass units.

5.3.2 Edge bond and glazing bars
It is possible for glazing bars to be used in triple thermal insulating glass units; it is recommended that the arrangement be limited to one cavity.

Visual impairments (see ‘Guidelines for assessing the visual quality of glass for building’), such as a slight offset of the spacers or glazing bars when arranged in both cavities, for example, have no effect on the functionality of triple thermal insulating glass units and cannot be completely ruled out.

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