SOLAR HEATING & COOLING PROGRAMME
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TASK 27

Performance of Solar Facade Components

Performance, durability and sustainability

of advanced windows and solar components for building envelopes

Final Report

Subtask C: Sustainability

Project C3:

Durability assessment of windows and glazing units

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Project C3: Durability assessment of windows and glazing units

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Abstract – Appropriate methods for assessment of the durability of window systems help to increase confidence in the selection and use of new products. Achieving an adequate service life is important with respect to receiving a payback in financial and environmental terms. One design attribute of interest for IG durability is the dimension. Windows of greater dimensions would have more severe thermal dilatation between spacer and glass. Since the temperature is different on the outer pane than on the inner pane, the damage experienced by outer and inner seals will be different. The difference in dilatations between the outer glass and spacer and the inner glass and spacer, result in different shear forces in the sealing. The temperature difference can be substantial. In Europe 30°C could be realistic. Deformations of the sealing in IG units as a result of elongation of the materials appear large compared to deformations from deflection of the cover caused by pressure fluctuations in the air gap. This is contrary to general judgment where the common test size is the most critical. In Denmark, development of new test procedures is based on loads approaching realistic loads. Increased number of cycles compared to outdoor exposure, accelerates the degradation. Interim results from tests in Canada indicate that the size of the unit does not have a significant impact on the longevity of the edge seal although evaluation of failure in windows installed may show an increase in failure occurrence for larger size of the window especially with the failure mode condensation.

Gas fillings are used in insulating glass units to improve the thermal resistance. The quality of the gas fillings could be distrusted. For that reason existing method have been used in Finland to detect gas filling without breaking the unit and this shows permanent gas filling in normal high quality insulating glass units.

Higher loads on the edge sealant, as a result of integration of solar shading devices between the glass panes of an IG, affect the durability of the IG-units especially the edge sealant. Test results is provided from Germany for different IG units tested according to European Standard DIN EN 1279-3 and DIN EN 1279-2 and a calculation to determine the internal pressure and loads on the edge sealant for two different sizes of specimen.

1 Introduction

The general objective of the project C3 in Task 27 is to develop and apply appropriate methods for assessment of the durability and reliability (fitness for use) of selected window systems. This requires experience from long-term installations, as well as measured and calculated results of behavior of constituent element of the window and interactions between elements. An important issue is a critical assessment of existing durability/reliability test procedures of windows and documentation of needed improvements of the standards.

The assessment provides improved knowledge and increases understanding of durability and reliability problems and helps to increase confidence in the selection and use of new products.

The project is directly linked to project B1 and C1 in which the methodology for the durability, reliability and environmental impact assessment is developed. Also there is a strong link to project C2, particularly with regard to FMEA and prediction of service lifetimes. Information is provided to project C2 by given inputs to FMEA analyses.

The project C3 has strong relations to “Insulated Glass Durability Knowledge Base”, a project in USA funded by a grant from the U.S. Department of Energy. This American project is capturing knowledge of Insulated Glass unit durability characteristics and disseminating the knowledge in a practical and useful manner.

Comments on FMEA analyses are given and advances are taking by using FMEA tables made for specific spacer glass configurations.

High performance in housing is achieved by reducing heating, cooling and auxiliary energy requirement, i.e. increasing useable solar gains, integration of daylighting, better insulation and ventilation heat recovery. Total costs for the high performance buildings are influenced by the durability and reliability of the solar component in the facade, and are therefore needed in a cost optimization. Optimization of energy savings in the building is issued in IEA Task 28 on “Passive Solar Houses“ and Task 31 on “Daylighting buildings” and therefore gives links to those two tasks as well as project A in Task 27.

The goal of project C3 is to have an exchange of experience with other projects on the FMEA tool capabilities and FMEA adaptation to the field of glazing and windows. Using facilities on the different laboratories modified towards larger samples, it is the goal to document “gap” in existing test protocol for accelerated test. Results from experimental use of the facilities are then used to identify opportunities for test development in support of failure mode.

2 General Methodology

From an end-user’s point of view a window as a whole is meant to have many functions, i.e. energy saving and light entrance, tightness of the envelope, privacy and intrusion prevention. The glazing is one product and a part of the window the frame is another one. The function is fulfilled for the combined product, which also includes the handling system, assembles of the window into wall, and the sealants (both for the double glazing and for the glazing and frame assembly). Project C3 has two case studies. In the first one, assessments are made of one of the window constituent elements, the Glazing Units, and in the second case study, work has been done to assess the behaviour of the window incorporated in the building as the assemble of windows/wall. The Glazing Unit

is a part of the window and assemble of the windows/wall is a combination of the whole window and the interaction with the wall.
The window involves many different material families: glass, metals and oxides for the coating, rubber for the sealant, wood, aluminium, steel or PVC for the frame. The interactions between the different parts of the window can result in severe failure with loss of important function for the window. In the methodology either it is developing the event tree diagram for the specific class of design or it is in the FMEA table. We are looking from the top level with the function of the system and down to the cause of failure in some of the materials, constituent elements or connections between constituent elements.
From B1 and C1, methodology has been adopted to have systematic approaches to service life prediction of components so that all essential aspects of the problem are taken into consideration.
However, Project C3 concentrates on the causes of failure, the failure mechanism, and the control and detection of the damage. Special efforts are used to see if the existing standards for Glazing Units will catch the effect of large samples resulting in failure in the sealing or adhesion loss to the substrate. Otherwise project C3 will document “gap” in the required and existing test protocol. It is intended to improve mechanistic failure models so that this specific cause to failure will be detected and to give proposals for controlling the component by exposure tests. The result from exposure tests is then verifying the concern of the effect from large samples.

3 Degradation Indicators

To meet the requirements new windows have to satisfy the consumer in relation to the general function, i.e. provide transparent view to outdoors, maintain aesthetic appearance, light entrance in the room and privacy. On top of that we have some expectations about energy savings for the building. If the general functions fail the window has to be replaced. The loss in energy savings is more difficult regarding detecting the failure. Failures are caused by change in material properties or for instance leakage of gas in the cavity between the panes. Those failures are not always visible to the eye, so degradation indicators must be identified. Change in materials properties could lead to change in optical parameters for different coatings or polymeric glazing. Failures indicated by change in material properties should be analysed by testing on a material level (project B3). On a component level, degradation indicators are the damage visible by inspection i.e., internal condensation, deflection of the glass panes, migration of the primary seal into the visible inter-pane space or structural crack. For damage detectable by instruments the degradation indicators are, e.g., change in gas leakage rate, increase of dew point of glass, change in centre U-value and g-value or change in deflection of the cover.

4 Natural Ageing

One potential design attribute of interest with respect to Insulating Glass Units durability is the length and width dimension of the Insulating Glass Units (IG units). Windows of greater dimensions would have quite severe thermal dilatation between spacer and glass. It has been almost impossible to get access to failure data from components installed. The next data are from a top-level durability assessment methodology,

presented and implemented for a box spacer system in the American project "The Insulated Glass Durability Knowledge Base" [Richard Hage et al (2002)]. From available failure data it is necessary to choose a list, which is consistent with design attributes and geographical/environmental region. The resulting system model was a block diagram series system with the following failure modes:
Condensation failure
Collapse failure
Glass failure
An environmental/geographical resolution results in four areas in the continental U.S:
Low temperature, low precipitation region
Low temperature, high precipitation region
High temperature, low precipitation region
High temperature, high precipitation region
From the data some information was derived regarding the dimensions, and two specific time periods were considered for evaluation of failure mode effect. The specific time periods are 5 years and 10 years. The definition of the product considered is shown in Table 1. A casement is a window unit, which has a side-hinged sash that opens on a vertical plane. The window is typically opened by use of a hand crank on the inside base of the unit. A Double Hung window is divided into two main sections. One section can slide up and down past the other one.

Table 1: product variations considered in the american top level assessment

Approximate Dimensions				
Product		*Height*	*Width*	*GlassThickness*
		m	*m*	*mm*
Casement (c)		1,1	0,6	2
		1,4	0,6	2
		1,7	0,6	2
		1,7	0,8	3
Double Hung-1 (DH-1)		0,5	0,7	2
		0,8	0,6	2
		0,8	0,7	2
Double Hung-2 (DH-2)		0,7	0,6	2
		0,7	0,7	2
		0,8	0,6	2

The investigation is to determine if general statements can be made concerning the relative frequency of failure modes. Only the region with low temperature and high precipitation environment is chosen as it contains the highest volume of product and thus will allow the greatest amount of resolution. The effect of variation in the dimension of product is considered. For the casement product the cumulative failures increase as the product height increases. This can give the impression that large samples are more critical than small samples. It seems reasonable with this effect from the product dimension although the standard size sample (0.352mx0.502m) used in durability tests is claimed to be the most severe dimension for capturing failures. There could be many reasons for this relationship between length and failure, e.g., greater amount of crack initiation sites for glass failure, greater flexure of the window, resulting in collapse or cyclic dishing, and also more perimeter area for condensation to occur. This relationship may also be strongly influenced by the sash and frame design imparting unusual force on the glazing unit. For the Double Hung product the width of the dimension is varied as

well therefore it is more difficult to draw a conclusions. While comparisons with the casement window may not be valid, two different sash and frame designs are contrasted. For the Double Hung-2 type the dimension effect is opposite the casement, with the large product failure occurring in the units with smaller dimensions. This contrary trend seen with the Double Hung-2 type may indicate that sash and frame design or undefined process variables have a strong influence on durability and that no generalization can be made regarding system reliability as a function of dimensions. There are opportunities for miscoding between the failure modes, as there is some judgement required for instance between collapse and condensation. A condensation ring detects collapse failures, but the failure code chosen is sometimes condensation.
Condensation failure as well as collapse failure can be caused by dilatation between spacer and glass. Condensation will come out when water has penetrated the sealing, and collapse will appear if the gas content has disappeared from the air gap between the panes in the IG unit. What we can see from the analyses is that in this particular casement design with respect to condensation, there is a dependence on glass size showing an increase in failure occurrence for larger height of the window.

5 Stress on edge seals

5.1 Introduction

During their lifetime Glazing Units are exposed to a variety of environmental factors, such as temperature, atmospheric pressure fluctuations, wind loads, working loads, sunlight, water and water vapour. The edge-seal system in the unit provides a gas and moisture barrier and has the function to structurally bind the panes and spacer together. Important failure modes are consequently dedicated to the structural seal.

5.2 Causes

The diurnal temperature difference experienced by an IG unit has a major influence on its life expectancy. Temperature fluctuations produce variations in pressure within the air gap of the IG unit and induce stresses in the edge seal and causes premature failure of the PIB primary seal once its fatigue resistance is exceeded. Furthermore, the shear and peel stresses caused by the differential thermal expansion between spacer and glass cause delamination (loss of adhesion). Temperature fluctuations exert mechanical stresses on the edge seal. Those stresses are strongest for small units. [Wolf A. T. (2002)] For windows at standard test size the expected range of edge force for a temperature fluctuation with temperature increased 35°C, is 0.75 N/mm. Wind loading at 1000 Pa leads to edge forces at 0.06 N/mm. Wind load exerted stresses are strongest for larger units. The temperature difference between the outer and inner glass pane can be substantial. In Europe 30°C could be realistic, in some other climates the difference can be even higher. Dilatation factors as much as 2 inside the sealing, defined as the ratio of length in sealing before and after temperature load, could be attained for construction with aluminium spacer and a side length of the glazing of 2 m. This will lead to large shear forces in the sealing.

5.3 Mechanism of failure mode

Temperature induced pressure differentials exert a higher force on the edge seal than do wind loads or atmospheric pressure variations. The ambient moisture level exerts an indirect influence on the opening and closing of the primary seal. At high moisture levels

secondary sealants absorb water, which increases their volume and degrades their mechanical properties.
Large elongation in the primary seal could be serious. This might depend on how many cycles it takes until failure occurs. This depends on the speed of the movement and under what temperature condition this movement occurs. Polyisobutylene (PIB) is an essentially thermoplastic material with limited elastic recovery. The physical properties (modulus, elastic recovery) are highly temperature dependent. A fast movement and a low temperature result in higher elastic recovery. A slow movement and high temperature result in higher plastic flow. Which option that is more damaging depends on the movement direction (tensile or shear) and to some extent on the edge seal design. Assuming pure shear movement, the material essentially allows the glass panes and the spacer to slide past each other acting like a lubricant. Therefore structure could have advantage of plastic flow behaviour of the sealing. An elastic behaviour would induce strong tensile stresses under shear that leads to adhesive failure. Under pure tensile load, especially cyclic load, the plastic material will experience the "chewing gum" effect (thinning at the area of highest flow, resulting in cohesive failure), while a purely elastic material will recover perfectly.

5.4 Failure mode

The IG edge seals will experience variations in temperature and movement and both tensile and shear is present at the same time. The ratio of tensile to shear depends on the size of the IG unit. The degree of damage experienced in the movement cycles depends on the rate of movement, the direction of movement and the temperature at which the movement occurs. Since the temperature is different on the outer pane than on the inner pane, the damage type and degree experienced by the PIB in the outer and inner seals will be different. This is not only a result of the material properties dependence on temperature but also the difference in dilatations between the outer glass and spacers and the inner glass and spacer, resulting in different shear forces. For a spacer with large elongations the elongation from the warm pane reduces the dilatation more than the cold pane. The largest shear stress is at the cold side with less thermoplastic behaviour in the sealing, consequently it could lead to adhesive failure.
Simultaneous action of water, elevated temperatures and sunlight result in a disproportionately higher stress on the edge seal. The degradation effect is most pronounced at the sealant/glass interface.
Shear movements in joints induce a tensile stress component close to the sealant/substrate interface that could be approximately twice as high as the original shear stress.

6 Stress and deformations due to temperature difference

6.1 Introduction

The energy saving properties of glazing units are obtained by use of low-e coatings, solar control coatings, gas fill and better insulating edge constructions. The design has influence on the temperature of the panes and new situations show up that can have an effect on the durability of the system. This may raise doubts about existing procedures for testing of the durability of the glazing units.
The use of coated glass units with warm edge is increasing and a total change from traditional insulating glass units to coated glass units is expected in the next ten years.

6.2 Objective

To prevent unexpected failure of coated glass units, it is important to sort out bad unit designs. The purpose of this study is to analyse the impact of thermal dilatations on the durability of the interface between panes and spacer, and to have a critical view on the sample size used in existing durability test procedures.

6.3 Insulating glass unit systems

In principle, insulating glass units consist of two equal pieces of glass that are placed on each side of a spacer. The glass is sealed on to the spacer with a sealant mass, the purpose of this is to keep the glass unit together and to keep the cavity tight. The difference between the former insulating glass units and the coated glass units used today is that there are one or more invisible coatings on the glass.

Insulating glass unit designed as a double-sealed box spacer system is constructed with a butyl string placed on the edge of the spacer profile before the assembling of the unit (Primary Sealant, MVTR Sealant), and subsequently a sealant is carried out with sealant mass outside the spacer (Secondary Sealant, Structural Sealant). The thickness of the butyl string is not more than 0.25 mm. In Figure 1 is shown a cross sketch of a double-sealed box spacer system. The secondary seal is made of polysulphide, polyurethane or silicone. Hollow profiles of aluminium, galvanised steel, stainless steel or non-metallic, i.e. glass-fibres reinforced polymer as base material or modified polycarbonate, are used as spacer profiles between the glass pieces. The assembly of these profiles varies from bent corners to assemblies with corner pieces of metal or plastic. On the market two different elaborations of the spacer are found. The normal is a low profile that allows production of insulating glass units with bent corners. Formerly it was common to use a higher profile that was assembled with metal or plastic corners. Moreover, on the market there is a diversity of corrugated spacers and spacers with outcrops like flanges or bulges. The purpose could be aesthetic or to give better stiffness of the spacer or to prevent the sealing to migrate. The corners, where the movements along the two edges meet each other have a risk of buckling of the spacer. As a result of the sealant glued along the long and short edges, the form of the buckling line of the spacer will probably follow the edge of the glass, at the middle of the four edges of the glass pane, and will buckle out in the corner. The shape of the buckle line is depending on the shearing force and the bending moment. Assuming a shape of a circle, a geometrical determination of the deflection in the corner is possible. For a square formed window the movement is 30% higher and for a rectangle 2 times 1 the movements are 10% higher compared to movements with no influence from the adjoining spacer.

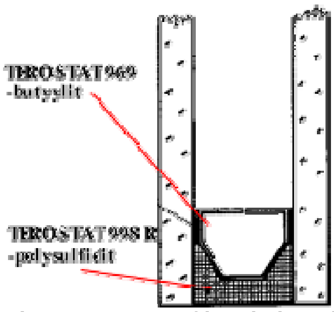

Fig. 1: Systems of insulating glass units (double-sealed box spacer)

Cross section temperature profile

In figures 2 and 3 isotherms are shown for an aluminium spacer and a stainless steel spacer. For the stainless steel spacer the temperature gradient is more distinct than for the aluminium spacer. Structural problems could turn op for the stainless steel spacer due to the difference in temperature from the outer side to the inner side. For the aluminium spacer the missing warm edge will reduce the temperature difference and with that eliminate the structural problem. If we look at an edge length of one meter, the strain in the materials is roughly 0.4 mm ($4x10^{-4}$). This strain corresponds to a stress in the materials of 80 MPa and will not attract any attention. The spacer will act as having a temperature averaging the warm and cold pane temperature and the strains will be built in on both sides of the spacer kept on line by the glass panes.
If the material of the spacer instead of iron is made of non-metallic material, some serious problems can be expected, particularly in the corners.

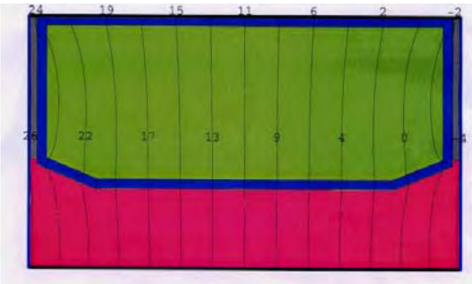

Fig. 2: Isotherms for an aluminum spacer with a conductivity of 160 W /m K. Thickness of metal 0.36 mm

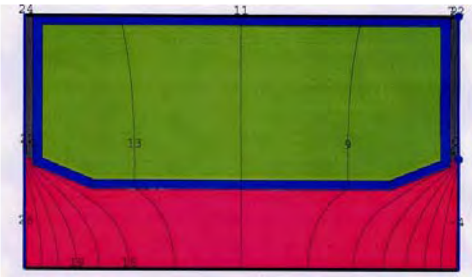

Fig. 3: Isotherms for a Stainless Steel spacer with a conductivity of 14.3 w /m K. Thickness of metal 0.18 mm. Equivalent conductivity is 7.15 W/ m K

6.4 Thermal dilatation

Calculations have been carried out by use of the WIS software. From the library of WIS, two sealed glazing units were selected. An InterpaneFloat Glass with solar control coating on the inside of the outer pane. Another glazing unit is an InterpaneFloat Glass with low E coating (Iplus R). The coated surface is inside the cavity of the unit, applied on the second pane.
With a solar control coating on the inside of the outer pane, two calculations have been carried out. These calculations are using environmental data for a summer situation, outdoor temperature 24°C, indoor temperature 25°C, one with a solar radiation of 800 W/m^2 and another with 1000 W/m^2. For the unit with low e coating the calculations are using environmental data for a winter situation, outdoor temperature -12°C, indoor temperature 20°C, one with solar radiation 800 W/m^2 and another with 1000 W/m^2. The

results from those calculations in form of the centre temperature of the panes are listed below in Table 2.

Table 2: results from calculations with WIS. Centre temperature of the panes for two edge-sealed units.

Temperatures in°C	Summer 800 w/m^2	Summer 1000 w/m^2	Winter 800 w/m^2	Winter 1000 w/m^2
Centre of outer pane.	37.8	41.2	-4.7	-3.5
Middle of air gap	32.8	34.9	10.8	12.9
Centre of inner pane.	27.8	28.6	26.3	29.2

Table 2 shows us that the winter situation with a low e coating is the case with highest difference in temperature between the inner pane and the outer pane. The temperature difference is 32.7°C.
The current sizes of test specimens used for standard tests are generally of small dimension is in the order of 40 x 60 cm (described in prEN 1297). In the market there is concern with respect to the validity of the results extrapolated to large size glazing. In table 3 below the dilatation between the two panes due to the temperature difference of 32.7°C is listed for the small test size and a 2 m edge size.

Table 3: Dilatation between the two panes in addition to the dilatation of aluminium, iron and polycarbonate.

Dilatation	Small test size (60 cm)	Larger size glazing (200 cm)
Glass	0.09 mm	0.29 mm
Aluminium	0.24 mm	0.78 mm
Iron	0.12 mm	0.39 mm
Polycarbonate	0.69 mm	2.29 mm

The dilatation of the larger size of glazing is the same size as the thickness of the sealant mass between the spacer and the panes. The failure mode “Sealant cohesive failure due to shear stress” needs technical discussions. Focus on the corner is important. The dilatation is a result of the thermal elongations of the different materials and therefore the strain is predetermined. The “elongation at break” must then be an important parameter for the sealant material. A preferable elongation capability is 200% [Richard Hage et al (2002)] but this is not always enough. Detailed material properties of sealant material are needed, particularly the elongation capability. By calculations it is found that 200% is not sufficient for non-metallic spacers. In Table 4 polycarbonate shows us that, for a thickness of the primary seal of 0.25 mm, the elongation is 369% (dilatation factor 4,69 defined as the ratio of length in sealing before and after temperature load,**)**. The thermal expansion coefficient for polycarbonate used in Tables are $70 \cdot 10^{-6}$ K^{-1}, rain forced or modified plastics could have lower coefficients.

Table 4: Dilatation factor in sealing (temperature difference 32.7°C)

Size of length, mm 2000	Dilatation	Dilatation between materials	Distortion angle			
Thickness of Primary Sealant	mm		0.1	0.25	0.3	13
Glazing	0.29					
Stainless steel	0.20	0.20	62.99	38.12	33.18	0.86
Aluminium	0.39	0.39	75.70	57.50	52.60	1.73
Polycarbonate	1.14	1.14	85.01	77.68	75.31	5.03

	Difference	Dilatation factor in sealing			
Thickness of Primary Sealant		0.1	0.25	0.3	13
Spacer material					
Stainless steel	0.20	2.20	1.27	1.19	1.00
Aluminium	0.39	4.05	1.86	1.65	1.00
Polycarbonate	1.14	11.49	4.69	3.94	1.00

For the window with solar control coating the difference in temperature between the inner pane and the outer pane is less. The temperature difference is 12.6°C. This temperature difference for the non-metallic spacer gives significant elongations higher than 100%. See table 5.

Table 5: Dilatation factor in sealing (temperature difference 12.6°C)

Size of length, mm 2000	Dilatation	Dilatation between materials	Distortion angle			
Thickness of Primary Sealant	mm		0.1	0.25	0.3	13
Glass	0.11					
Stainless steel	0.08	0.08	37.09	16.83	14.14	0.33
Aluminium	0.15	0.15	56.52	31.17	26.75	0.67
Polycarbonate	0.44	0.44	77.22	60.45	55.77	1.94

	Difference	Dilatation factor in sealing			
Thickness of Primary Sealant		0.1	0.25	0.3	13
spacer material					
Stainless steel	0.08	1.25	1.04	1.03	1.00
Aluminium	0.15	1.81	1.17	1.12	1.00
Polycarbonate	0.44	4.52	2.03	1.78	1.00

What we have clarified is that the elongations of the materials will cause higher stresses that allowable and therefore the “elongation at break” will be one of the determining parameters for the sealant material. In addition to this the buckling situation of the spacer in the corner will increase the risk of cohesive failure due to shear stress. It is apparent that realistic deformations of the sealing in IG units as a result of elongation of the materials are large compared to deformations from deflection of the cover caused by pressure fluctuations in the air gap. This is contrary to general judgment claiming that the standard size used in exiting durability tests is the most critical size. IG-units edge seal systems that minimise differential thermal movement, especially within the sensitive corner region, tend to perform significantly better in terms of gas loss rates than systems with high thermal movements [Wolf A. T. (2003)], some spacer systems designs have even taking this into account by making systems that could accommodate some movement within the spacer itself.

7 Accelerated INDOOR test procedure of glazing units

7.1 Introduction

Through climatic loading of the Edge Sealed Glazing Unit, it is possible for some types of Edge Sealed Glazing Units that unacceptable differential deformation takes place.
This situation might not occur during the test according to [prEN 1279] as it performed at uniform temperature. Therefore the goal is to set up a test procedure that catches this category of failure.
In the climate chamber facilities CliSim on BYG.DTU the unit can be exposed to extreme climatic conditions and temperature varied in an accelerated and cyclic way, and during this process the function of the unit will be tested.

7.2 Objective

The interactions of the degradation factors for IGU is not well understood, and it is not known if the conventional test methods catch all categories of failures. In CliSim the loads on the component are approaching realistic loads, but with increased number of cycles compared to outdoor exposure. It is the aim to clarify the consequence of new procedures by comparing test results in the facility CliSim with conventional ageing procedures in prEN 1279-2 and 3. It is intended to assess the influence of the dimension of a solar control glazing unit on the results from tests with different weather conditions on the inward looking face and the outward looking face and thereby on the longevity of the component.

7.2.1 Test program:

The standard sizes of all sample types are tested in accordance with prEN 1279.
All tests are accomplished with a standard format size of 352 x 502 mm and a size critical for thermal expansion.
In the beginning, samples are used to determine water content, gas leakage and gas concentration.
After the ageing of the samples, the gas concentration, the leakage rate and the moisture penetration index are found

7.2.2 Scope

Principle of test
In order to create a differential temperature that may influence the joints in the glazing, the test specimen is exposed to a set of different climates on both sides. This is done for a specified time and varied in an accelerated and cyclic way.

All the tests will be completed with a solar control-glazing unit, using glass with a low g-value.

7.2.3 Test facility

The CliSim can be used to test solar facade components with a maximum size of 1.3 m x 3.0 m and maximum thickness of 0.2 m. The components can be mounted on a frame that can be moved into the test chamber of the facility. The test chamber is equipped with windows above, below and at the long sides of the component. The window above the component is made of a thin Teflon film and is used for exposing the component to solar and thermal radiation. The other windows are for inspection during the test.
A realistic situation for windows is to have an indoor climate facing one side and an outdoor climate facing the other side of the windows. Testing window components CliSim use an internal chamber. The internal chamber is made as an insulated box and is well ventilated to the climate in the laboratory. During the period with solar heat gain through the window, heat is removed by an external cooling devise.
PVC reinforced with steel profiles, ensuring good thermal insulation, makes a window frame at the outfacing surface of this box. Double sealing in the windows between frame and sash prevents the penetration of any air, dust or water.
In the CliSim facility the following climatic parameters can be simulated: variable air temperature, sky radiation, wind (air flow), driving rain at the front and perimeter of the component and solar radiation including UV-radiation. Se Figure 3.

A fan coil unit connected to the central cooling system operating at -20°C puts an upper limit on the air temperature in the climatic box. The wind is simulated by use of the fans in the fan coil unit blowing air along the outside facing surface of the component. An air velocity up to 3 m/s is accessible. Temperature change and ventilation of the internal chamber induce fluctuations of pressure difference across the unit.
The driving rain is simulated by a spaying system. 8 full cone nozzles are spraying 2.4 litre/m^2/min. on the outside facing surface. 16 nozzles are spraying at the perimeter of the component. The water is re-used by use of a pump, and the pressure can be adjusted to get the correct flow rate.
The use of an automatic controlling system enables, the solar facade component, in a cyclic way, to be exposed to the different climatic parameters at an extreme or moderate level and one at a time or in combinations. During the exposure of the component to the climatic parameters the function of the component can be tested.

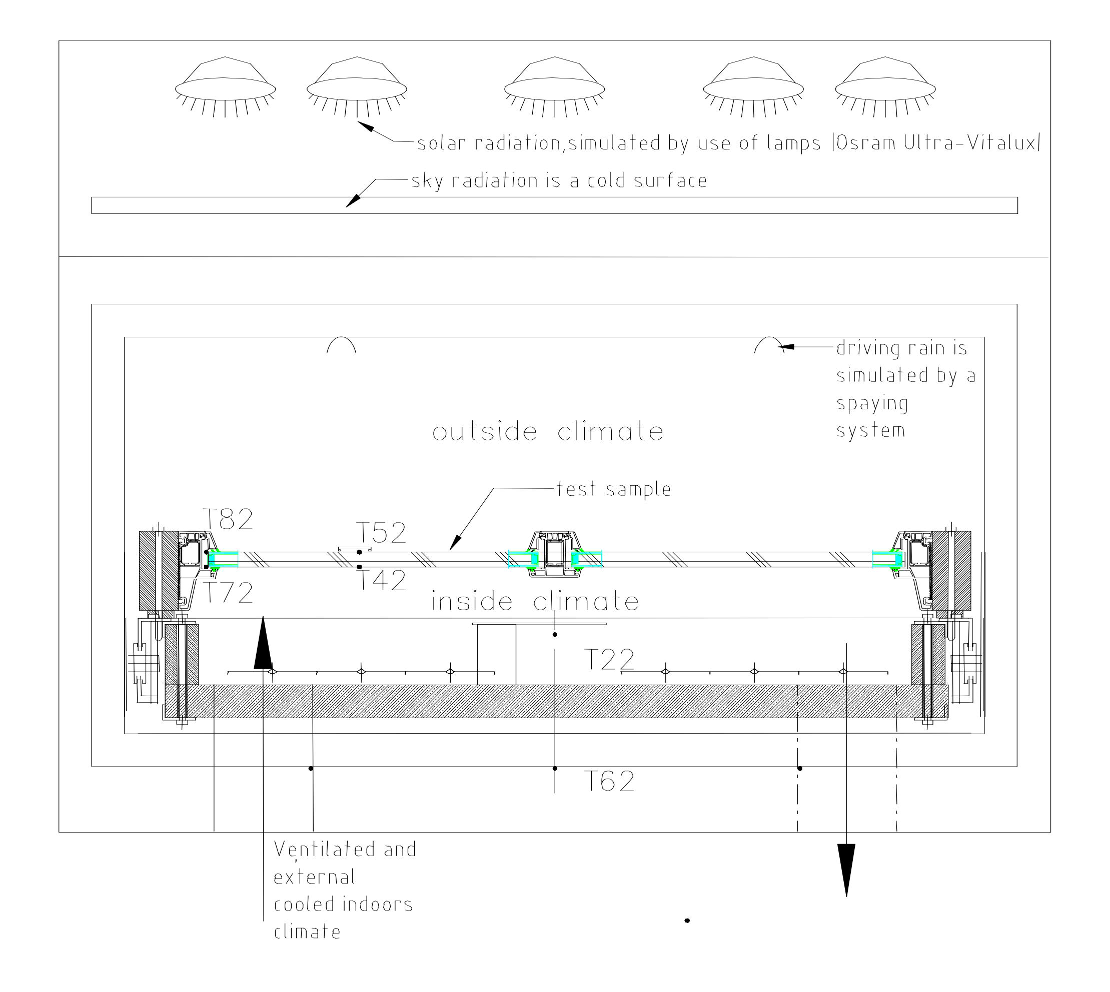

Fig. 4: Section of the CliSim simulator including parts simulating weather loads.

7.2.4 Test conditions

The test specimen shall be fixed in the test rig in a realistic way. IG units are mounted directly in a window frame.
A Insulated Glazing Unit has been applied to the test facility Clisim. The climate weather conditions have been monitored for the outside climate and the inside climate. The outside temperature t_1 is alternating with an amplitude of 8Cº around 15Cº, and the inside temperature t_2 is alternating with an amplitude of 3Cº around 19Cº, forced by the solar radiation or sky radiation cooling. See Table 6. The temperature of the panes depends on the structure of the sample and is monitored as well se Figure 5. The humidity in the two chambers is monitored se Figure 6.

Kommentar [a1]: Eller ”the IG unit is”

Kommentar [a2]: ”widow” betyder ”enke”!!

Table 6: monitored cycling parameters for Solar Control Units.

Test method	Test climate	Outside climate		Inside climate		Cycle/durability
Solar Control Units	With realistic temperature difference	Air temp. t_1 [Cº]	Rel. humidity rH_1 [%]	Air temp. t_2 [Cº]	Rel. humidity rH_1 [%]	
	High value	23	95	22	53	Cycling temperature for t_1 Sky radiation zero°C Solar radiation 800 W/m^2
	Low value	7	65	16	32	

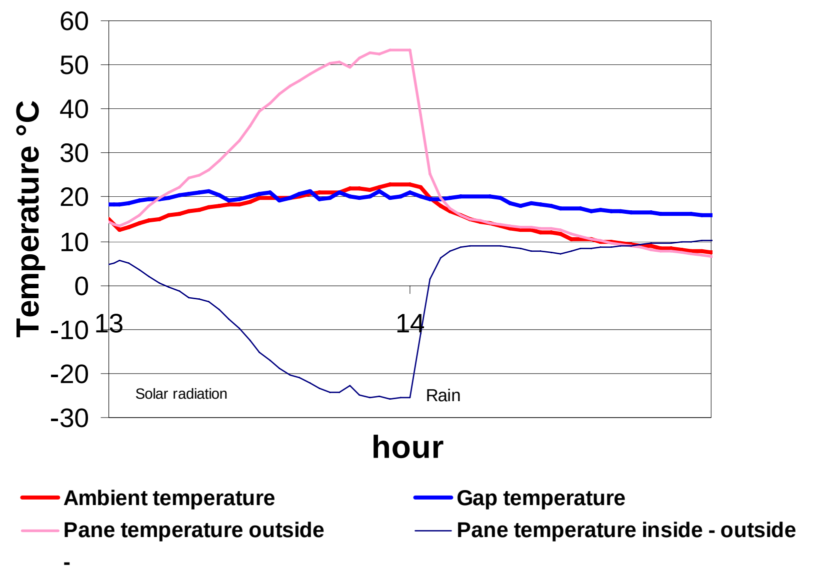

Fig. 5: Temperature variation in the climate cabinet with a cycling period of 2 hours.

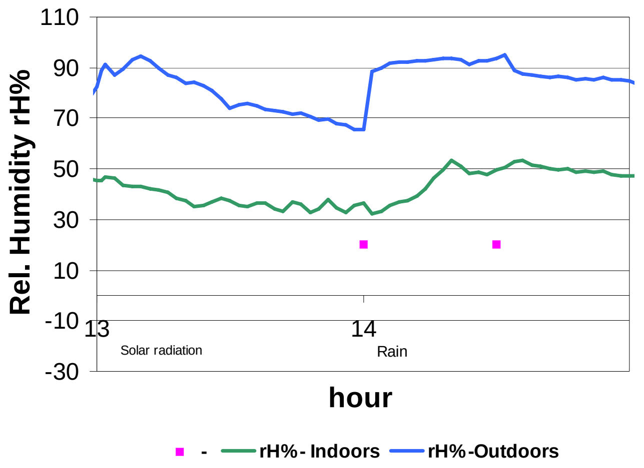

Fig. 6: Humidity variation in the climate cabinet with a cycling period of 2 hours.

8 Investigation of severe realistic exposure condition

8.1 Introduction

Product failures are frequently imposed by environmental condition. It is hardly ever possible to get field weather data of relevant reference products installed. Work is ongoing in Scotland [Garvin S. L., and Wilson J. (1998)], where long-term exposure experiments began in 1994 to monitor the conditions around double-glazing units in various types of window frames. Results presented until now are interim. There are a number of failure types. The most common one is condensation between the panes of the glass. In Switzerland inner-pane temperature on various types of IG-units, weather condition and the influence on indoor comfort have been monitored and calculated [Frank T. et al (1986),]. It is therefore important to have a correlation between the artificial weather data in the climate chamber and the realistic weather data outdoors. For different environmental regions it is possible to use available reference weather years to analyse the quantity of environmental load the product will experience. Cumulative percentage of combined outdoor temperature and global irradiance is statistically analysed from measured climatic data in Switzerland [Frank T. et al (1986)]. For a particular constellation of temperature and solar irradiation, this work gives the number of hours in the season counted between 8 a.m. and 6 p. m.

8.2 Objective

The goal for this item is to determine severe realistic exposure condition by statically analysing the reference year. Recognizing and counting cycles with high load factors in the reference year and comparing with the cycling frequency in the test protocol estimate an acceleration factor for the test.

8.3 Method

Analysing weather cycling during a reference year can be done by recording numbers of cycles where solar irradiance over a defined level is present and where any outdoor temperature has increased above a limit or decreased below a limit. A new record can only be sampled after the level of solar irradiance or absolute values of outdoor temperature have decreased to 10% of the defined level.

In the winter time the most critical situation is a low outdoor temperature combined with high solar irradiance and a window constructed with a low-e coating. Without sun the temperature difference between the outer pane and the inner pane can have a noteworthy size and should be counted as well. During the summer the most critical construction is a window with a solar control coating on the outer pane. It is necessary to make a distinction between the two applications, the one with the low-e coating and the one with the solar control coating. For the low-e application the severe exposure condition is a low outdoor temperature and a high inner pane temperature. In this case the recorded cycles are based on low outdoor temperatures and solar irradiance. For the solar control application the recorded cycles are based on high outdoor temperatures and solar irradiance. The coating material itself has an influence on the amplitude of the cycle at actual in-service conditions as well as in the accelerated test in the climate chamber.

8.4 Results

Solar irradiance and temperature are analysed for cycles in the reference year.

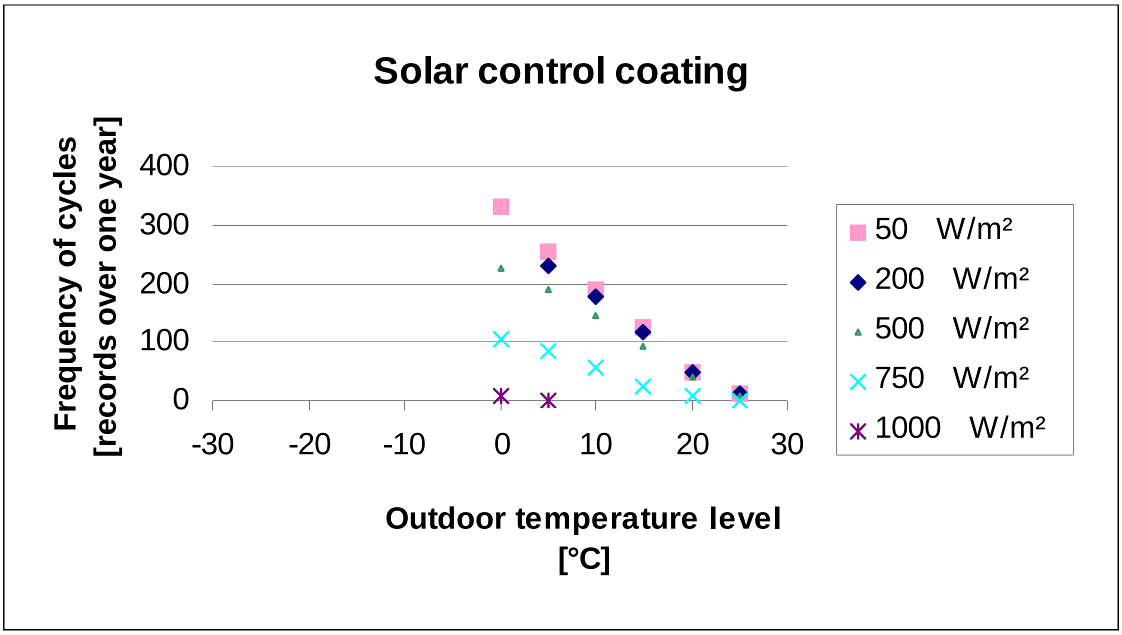

Fig. 7: Results from statistical analyses of a reference year.

From the reference year, the solar irradiance and the temperatures are recorded. At the x-axis, positive values of the outdoor temperature mean that the temperature has been above the value and negative values of the outdoor temperature mean that the temperature has been below the value. At the y-axis, spots show the occurrence of cycles with solar irradiance above zero, 50W, 200W, 500W, 750W and 1000W. Figure 7 considers the solar coating application where positive outdoor temperatures are the most severe condition.

As an example from Figure 7, 127 cycles are recorded matching conditions where the solar irradiance is above 50 W, and, in the same time, the ambient temperature is above 15°C.

Assuming that the influence on the material and the mechanism of degradation are to some extent proportional to the solar irradiance on the material, it is possible to cumulatively combine cycles with different levels of solar irradiance. Multiplying the levels of solar irradiance with the recorded occurrence of cycles for all ambient temperatures above zero °C, we get a number for the whole year of Watt-cycles/m². For the application of solar control coating this is 157 kW·cycles/m² and the number of cycles is 330. The average of solar irradiance for the cycles is then 478 W/m². In the climate chamber it is possible to have 12 cycles each day, resulting in 84 cycles in a week and 360 cycles in a month or 4320 cycles in a year. The irradiance in the climate chamber is 800 W/m², and in a year this results in 3456 kW·cycles/m². The acceleration factor resulting from solar irradiance is then 22 times.

The level of UV irradiance in the chamber is for UVA 33 W/m² and for UVB 2.5 W/m². At actual in service condition in Denmark, this will be 6% and 0.2% of total solar irradiance. The UVA then corresponds to 60 W/m² and the UVB corresponds to 2 W/m². Considering the UVB as the most severe exposure, the overall exposure of UV must be considered as in conformity with the total solar irradiance.

High humidity is analysed for cycles in the reference year.

Cycles with high humidity can be analysed from the reference year as well. In Table 7, the numbers of humid cycles are presented, considering a cycle to be a humid sequence followed by a decrease of humidity to 80% of the high humidity level considered. For a humidity cycle exceeding 97% relative humidity, we found 110 plus 31 cycles during a year. In the climatic chamber we have 4320 cycles a year. The acceleration factor is then 30 times.

Table 7: Analysed cycles of high humidity from the reference year. For solar control coating the humidity is combined with non freezing temperatures. for the low-e coating column the high humidity cycles are combined with sum-zero temperatures. the total number of cycles is the addition of the two columns.

Limit of rF	Solar control coating	Low-e coating	Total	cdl
%	Number of cycles	Number of cycles	Number of cycles	%
91	175	62	237	80
93	167	56	223	80
95	134	41	175	80
97	110	31	141	80
99	78	19	97	80

9 Accelerated ageing test procedures for durability of edge seal of Insulating Glass Units In Canada.

9.1 Introduction

Accelerated ageing of Insulating Glass Units is a means to test the durability and integrity of the seal(s) of these units by subjecting them to a number of cycles in a controlled environment. The amplitude and frequency of these cycles are determined by consensus among the experts and practitioners in the field and can be seen in Figure 8 and 9.

There are two basic accelerated ageing test procedures for the durability of edge seal of IG units, namely the [CAN/CGSB 12.8] standard in Canada, and [ASTM E773]- [E774] in the USA. During the past few years, efforts have been concerted to arrive at an acceptable test procedure that can be used in both countries. Three new ASTM standards were recently published: [ASTM E 2188-02], [E 2189-02] and [E 2190-02], which provide details about the test methods, procedures and performance requirements for the durability of edge seal of IG units.

This report provides the test results of a number of IG units tested according to the main part of the above standards. More details about the restrictions and the main objective of this study are given below.

9.2 Objective

The main objective of this study is to investigate the effect of IG units size on the edge seal durability when tested according to relevant parts of the new North American Harmonised test standard.

9.3 Test protocol

Testing was performed according to ASTM E 2188-02. However, because some of the IG units were larger in size than those specified in the ASTM standard, all units were not tested in the high humidity chamber or in the UV box for the UV Fogging test, ASTM E 2189-02. Therefore, the seven units in each set (six small units and one large unit) were only subjected to 65 days in the weather cycling apparatus.

For each unit, the dew point (frost point) was measured before and after the weather cycling test. The results were recorded to show the pass/fail criteria and conformance to the specified performance requirements in ASTM E 2190-02.

9.4 Test Apparatus

The weather cycling apparatus consists of a platform to mount IG units, where one side of each unit is exposed to the room environment and the other side is exposed to heating, cooling and water or mist spray. Figure 8 is a photo of the apparatus with units mounted. It is worth noting that the apparatus was modified to accommodate the large size units.

Fig. 8: IG units mounted in the weather cycling apparatus.

Samples

Four sets of IG unit samples were used in this study. Each set consisted of six units measuring 350±5 mm by 505±5 mm, and one unit 1000±5 mm by 1000±5 mm.
All samples were provided by Canadian manufacturers and represented new product lines within the manufacturer's portfolio. The designation given to the products and a brief description of the units is as follows in Table 8:

Table 8: brief descriptions of the units provided by Canadian manufacturers

Manufacturer/Client	Sealant	Spacer bar type
I	Continuous butyl	Corrugated aluminum
II	Continuous butyl	Corrugated plastic rib-tube
III	Polysulfide	Aluminum
IV	Continuous butyl	Embedded aluminum strip

All units were air filled, double glazed made of nominal 4 mm thick glass and 13 mm air gap. More details about the spacer bar design and other specifics about the sealants were not available due to the confidentiality agreement, and also because of the nature of the products (prototypes).

9.5 Results

The initial dew point (frost point) was measured for each unit. Then the units were mounted in the weather cycling apparatus for 65 days. After the testing was completed, the final dew point was measured and recorded for each unit.

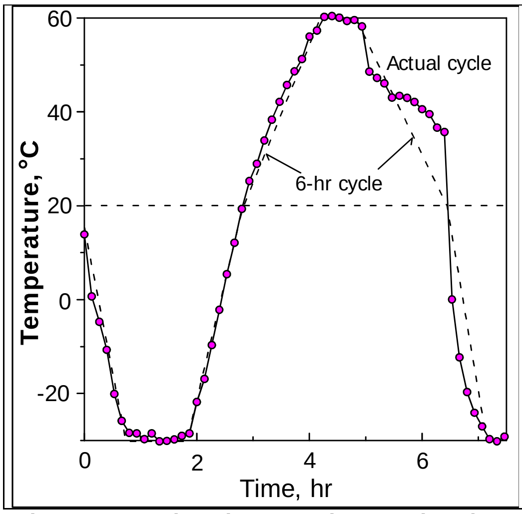

Fig. 9: Comparison between the actual cycle and the theoretical cycle

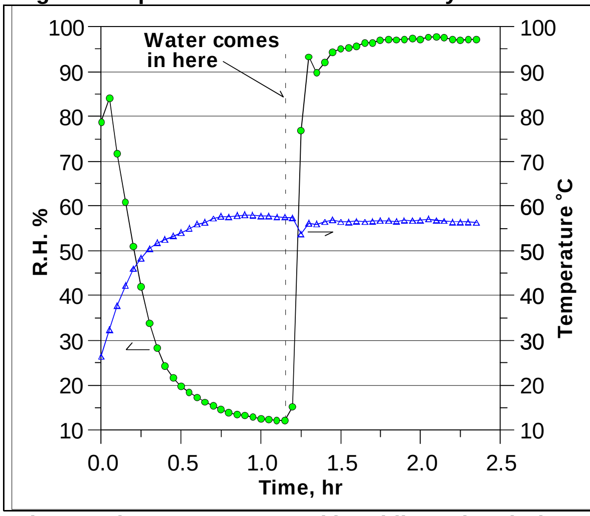

Fig. 10: Air temperatures and humidity ration during a typical cycle

Most of the units showed initial dew point lower than –40°C. The new standard does not require a certain value of the initial dew point due to the new designs and the possibility of later activation of the desiccant in the mastic tape of the spacer bars.

6 units (Client II) experienced major failure. This was discussed with the manufacturer who admitted a wrong corner key design at that stage, and consequently the failure was seen as a design related and not a test related failure. All other units passed the final dew point temperature measurement. The requirement is that at the end of the test the dew point has to be –40°C or lower.

9.6 Comments on the test results

Two sets show (Client I & II) experienced high degree of failure rate, particularly units in Client II. It was revealed by the manufacturer that this particular set had a flaw in the design of the corner keys, and it was corrected later on. New units are currently going through the 65 days weather cycling test.

9.7 Facility in Canada to study ASSEMBLES of Windows/Wall interface.

IRC's Building Envelope and Structure Program has a new test facility that can monitor and weigh a full-scale windows/wall assembly (2.4 m x 2.4 m), providing useful information about how the windows/wall interface perform regarding durability. See Figure 11.

The climatic chamber, which is unique in North America, is known as the Envelope Environmental Exposure Facility (EEEF). It can simulate interior and exterior climatic conditions over extended periods of time, controlling both temperatures (ranging from -47 to +48°C) on the 'weather' side of the facade and humidity levels (ranging from 10 to 100% RH). See Figure 9 and 10.

Fig. 11: Preparing a Full-Scale Wall Specimen For a Drying Experiment in the Envelope Environmental Exposure Facility (EEEF)

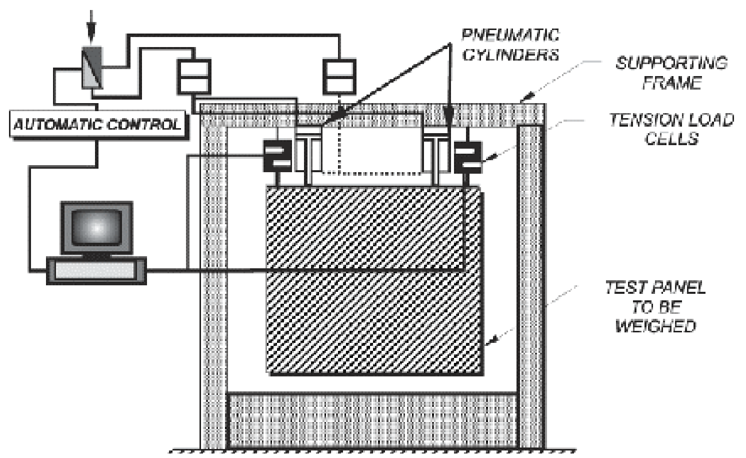

Fig. 12: Schematic of the EEEF's Wall Weighing System

The facility is useful to benchmark the thermal and moisture performance of window/walls in various climates, and to study drying behaviour at the interfaces between walls and windows.
Key information about the drying rate can be gathered and used to confirm the drying characteristics of the window/wall assembly predicted by a combined heat, air and moisture transfer model, hygIRC. These comparisons between experimental results and model predictions provide insight into how water re-distributes itself within the construction before drying out.

The facility features several innovations (see figure 12):
a weighing system that detects water evaporating from the wall by measuring the total wall weight with great precision (in grams) and tracking this weight over time;
a frame and gasket technique for sealing the wall specimens to the enclosure, without interfering with the weighing process;
state-of-the-art moisture meters for mapping differential drying on the face of the wall;
a complete data acquisition package to control and monitor experiments, and a comprehensive data analysis technique for interpreting the results.
The next stage of development for this facility will integrate the effects of rain, wind and some aspects of solar radiation.

10 Long-term performance of gas filling in insulating glass units

Argon and krypton gas fillings has been used in insulating glass units to improve the thermal resistance. The insulating gas is invisible and not possible to realize by eye. Some years ago it was not possible to detect the gas concentration in non-destructive methods and this was a reason to have doubts of the quality of the gas fillings. Nowadays there exists method to detect gas filling without breaking the unit and this will show the gas filling is permanent in normal high quality insulating glass units.
This chapter is mainly based on a published article [Hemmilä, Kari; Heimonen, Ismo 1999].

10.1 The insulating gases are part of atmospheric air.

Noble gases (argon, krypton and Xenon) are used in insulating glass units because of poorer heat transmittance properties compared to air. This property is used to improve the thermal insulation of glazing units. The biggest benefit is got in glazings having selective glass. The noble gases exit in atmospheric air. Table 9 presents the gases in air, concentration in air and physical properties of the gas. The typical insulating gases are having smaller heat conductivity and specific heat and bigger viscosity than air.

Table 9. The gases in atmospheric air and their properties [Lide, D., R., (1990 - 1991); Ryti, H., (1966)].

Gas	Sym-bol	Density [kg/m3]	Molecular weight [kg/kmol]	Concentration [% volume]	Heat conductivity [W/mK]	Specific heat [J/gK]	Viscosity [µPa s]
Nitrogen	N2	1,2506	28,013	78,084	0,0260	1,043	17,9
Oxygen	O2	1,429	31,999	20,946	0,0263	0,917	20,8
Carbon dioxide	CO2	1,965	44,010	0,033	0,0168	0,843	15,0
Argon	Ar	1,7837	39,948	0,934	0,0179	0,896	22,9
Neon	Ne	0,8999	20,183	0,001818	0,0498	1,030	32,1
Helium	He	0,1787	4,0026	0,000524	0,1567	5,192	20,0
Krypton	Kr	3,733	83,80	0,000114	0,0095	0,247	25,6
Xenon	Xe	5,887	131,30	0,0000087	0,0055	0,158	23,2
Hydrogen	H2	0,09	2,0159	0,00005	0,1869	14,277	9,0
Methane	CH4	0,716	16,043	0,0002	0,0341	2,218	11,2
Nitrous oxide	N2O	1,965	44,0128	0,00005	0,0174	0,874	15,0
Air, average		1,22	28,964		0,0262	1,007	18,6

Sulphur hexafluoride (SF6) has been used to improve the sound insulation of insulating glass unit. This gas is decreasing the thermal resistance and therefore the mixture of argon and sulphur hexafluoride has been used.

The noble gases are manufactured by distilling from liquefied air and for this reason, the gases having small fraction in air are more expensive. The rough estimation of the relative prices of gases is: argon 1, krypton 100 and Xenon 1000. The price of filling the insulating glass units is independent on the gas. Xenon is the best gas improving the thermal insulation, krypton is the second possible gas. In practice argon is economically viable gas filling.

10.2 The IG unit effecting on the quality of gas filling.

Before the filling process, the IG-unit is full of air, which is replaced by gas in automatic manufacturing line or manually after manufacturing line. In practice the concentration of the gas is less depending on size and shape of isuilating glass unit than on

- position of gas inlet and outlet during the filling
- gas flow velocity
- tightness of gas inlet device
- properties of gas inlet nozzle
- type of gas (density, viscosity)
- type of spacer bar

- position of gas detection sensor
- criteria to stop filling
- over-filling rate
- edge sealing
- mixing of remaining air from spacer bar to gas filling
- reaction of desiccant with gas filling
- delay between filling and closing the filling route
- delay between filling and secondary sealing process

The evaluation of the aspect effecting on the quality of gas filling manufactured by manual method has been done in research [Hemmilä, Kari; Heimonen, Ismo. (1999)]. In the experiments, the effects of gas flow velocity and position of gas inlet and outlet during the filling has been evaluated.

10.3 The long-term performance is effected by edge seal materials

The long-term performance and permanency of gas filling in the insulating glass units depends on the edge seal properties. The important properties effecting on the durability are:

- adhesion of edge seal materials to glass and spacer
- elasticity and strength of seal materials
- ageing of seal materials
- dimensions (thickness, width) of seal material layers
- rate of diffusion through the seal materials
- rate of diffusion through the spacer materials
- gas pressure in glazing unit
- amount of desiccant in spacer

In the modern double sealed IG-unit (figure 13), the diffusion tightness is guaranteed by plastic sealant between spacer and glass. The polyisobutyl (PIB) is a typical material. The thickness of the material layer is some tents of millimeter and height 3 … 5 mm. The diffusion tightness is guaranteed by low diffusion of the material. The outer elastic sealant in edge is typically polysulfide, but silicone and polyurethane are also used. The function of the outer seal is to keep the glazing package as a unit, give tightness for diffusion and enable the movements due to temperature and pressure. The desiccant inside the spacer prevent the humidity diffusing through the edge seal to condensate inside the glazing unit.

The diffusion through the edge seal depends on the partial pressures of the gases inside and outside the glazing unit. The vapour is typically trying to diffuse from surrounding air into the glazing unit and filling gases diffuse out from the IG unit. The direction depends on the partial pressures of the gases. The partial pressures tends to equalize. The diffusion of the insulating gases is typically very small. The rate of diffusion is not constant and it depends on the temperature, type of gas and type and aging of seal materials. The vapour diffusion for different materials at temperature of 20 … 80 °C is presented in [Wolf, A. T. (1992)]. Figure 14 shows the dependency of the diffusion on the temperature. The increase of the temperature from 20 °C to 60 °C increases the diffusion 5...9 times higher.

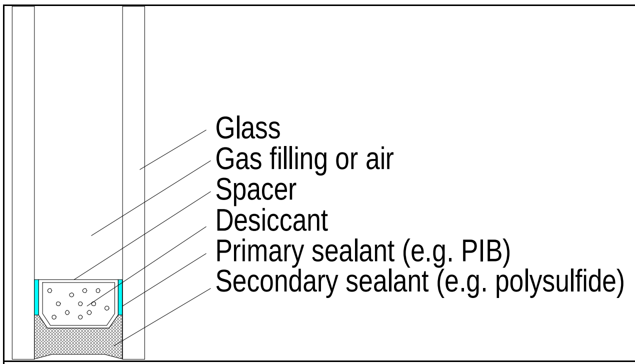

Fig. 13: Structure of the edge of double glazed unit.

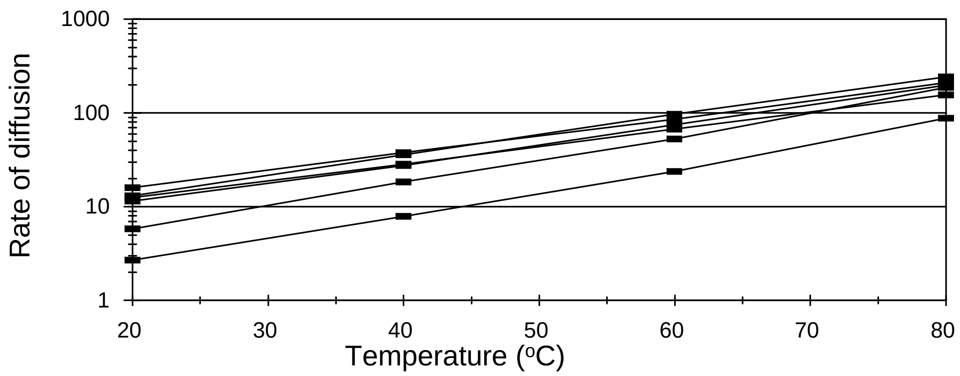

Fig. 14: The influence of the temperature on the vapour diffusion for different materials.

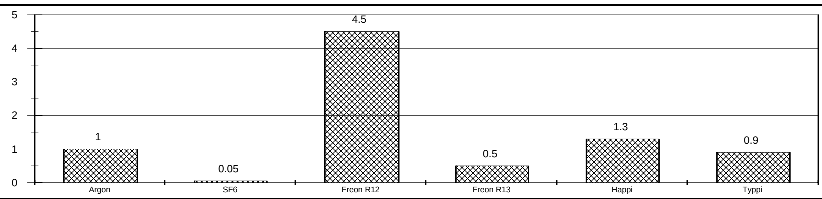

Fig. 15: The relative diffusion rate of gases through polysulfide sealant [Unger, G., (1991)].

Figure 15 shows the relative diffusion of gases through polysulfide. The diffusion rate is influenced by ageing of material due to evaporation of solvents and softeners, oxidation and UV-radiation. The evaluation of the ageing and influence on the diffusion is difficult to evaluate in real climatic conditions.

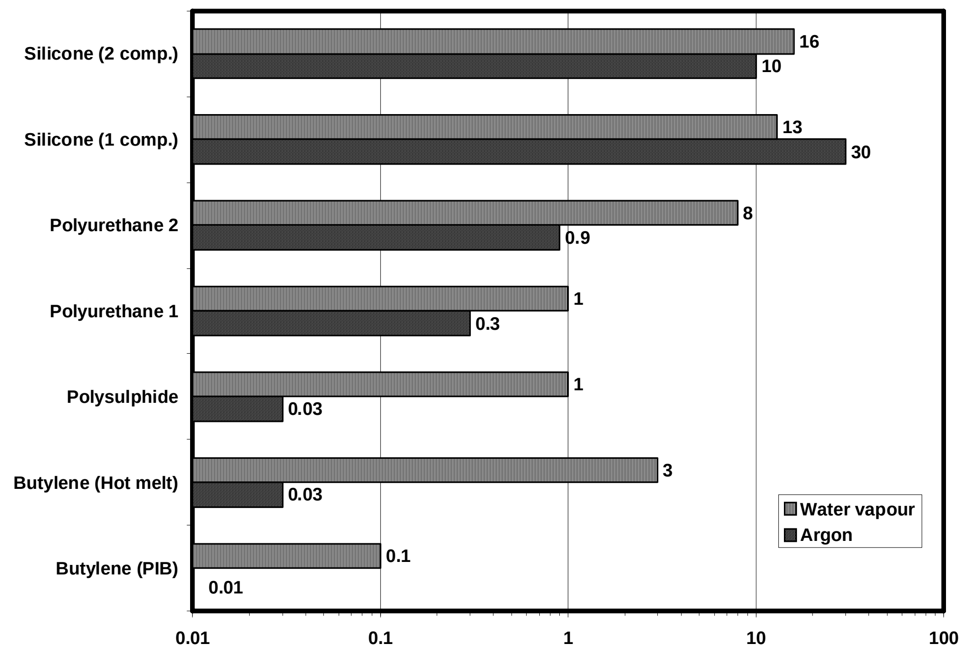

Fig. 16: The relative diffusion rate of water vapour and argon through the typical edge seal materials [Unger, G., (1991); Chemetall Gmbh.]

The results of experimental aging for seal materials has been reported in [Wolf, A. T. (1992); Unger, G., (1991); Feldmeler, F. & Schmid, J., (1992); Owens, R., (1990); Chemetall Gmbh.]. The accelerated aging and normal ageing in 2 years has been done. The two-phase sealing with PIB and polysulfide was realized as a good solution in edge seal. The concentration of argon decreases 0,4 - 2 % in a year. The rate of diffusion for same type of material supplied by different manufacturers have some differences.

The requirement for the leakage rate has been presented in the European measurement standard [prEN 1279-3, (1997)]. The leakage rate must be less than 1 % during a year under the test conditions. The tests are performed for the insulating glass unit of size 350 mm * 500 mm. In this case the edge length compared to total area is bigger than in average glazing unit. In appendix B in standard the tested leakage rates has been compared to leakage of glazings in real windows in buildings. The comparative measurements showed that during 10 year the leakage of real building windows was about 1/10 of the rates in laboratory measurements. The diffusion decreases when the difference in concentration is decreasing. The ageing of edge seal materials is also effecting on the diffusion rate.

10.4 The effect of the gas concentration on window U-value

The effect of the gas concentration on window U-value is presented in figure 17. The window type is Finnish type of triple glazed operable window with two sashes. In practice, the concentration of argon or krypton is never ideal and there exists some air in gas gap. In case the concentration after the manufacturing is 90 % and the leakage is 1 % in a year, the concentration after 20 years is 74 %. During the same period, the U-value increases 0,03 W/m^2K with krypton and 0,02 W/m^2K with argon.

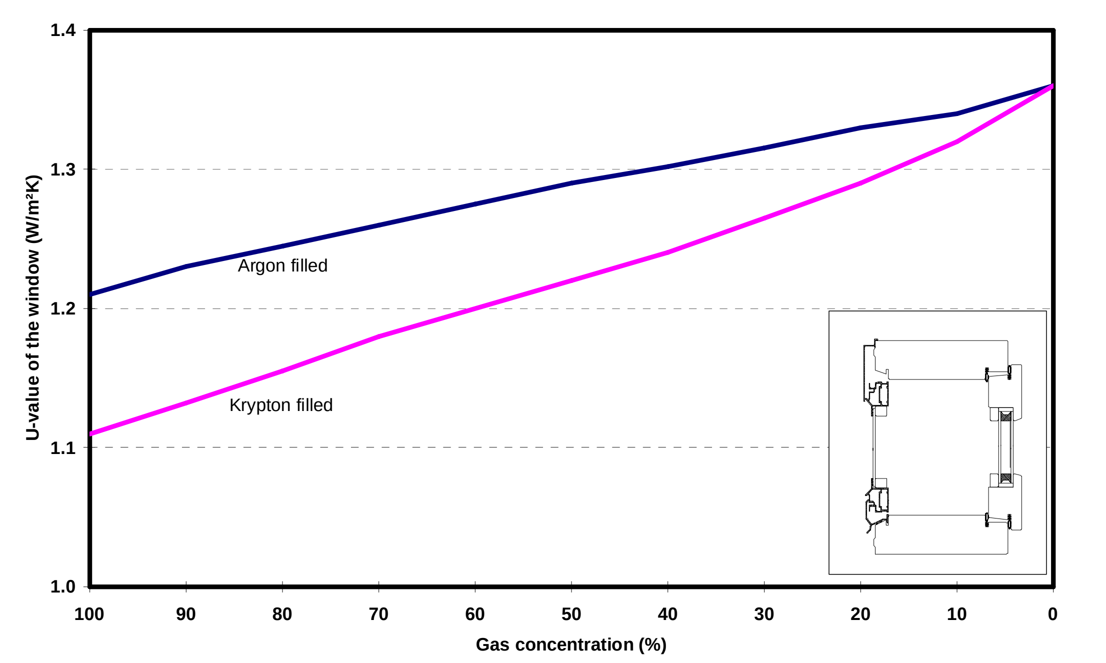

Fig. 17: The effect of the gas concentration in IGU on window U-value. The window size is 1,2 m * 1,2 m. The low-emissivity coated glass (ε=0,04) is used in IGU. The width of the gas gap is 12 mm.

10.5 The detection of gas concentration

The detection methods of gas filling type and concentration has been studied in reference /9/. Some years ago it was not possible to detect gas filling without breaking the unit. The gas sample was taken from the unit and content of the sample was analysed. The taking of the sample was damaging the edge sealing. A new method has been developed for detecting the gas without breaking the unit.

The GasGlass works by igniting a high voltage spark inside the IG. The color of the spark immediately tells what gas concentration is inside the IG. The unique part of the GasGlass is the possibility to ignite the spark into the IG from one side and thus enabling measurements on almost any windows. The GasGlass meter is manufactured by Finnish Sparklike Ltd (http://www.sparklike.com/).

10.6 The gas filling is cost-effective in cold climate

In case the gas filling is decreasing the window U-value by 0,15 W/m2K in Helsinki area (heating degree days 4366 Kd) and the price of the heating energy is 0,03 EUR/kWh (district heating), the yearly saving due to gas filling is: 24 * 4366 * 0,15 * 0,03 / 1000 EUR/m2 = 0,47 EUR/m2. In case of Sodankylä (located in the northern Finland) and direct electricity as heating energy, the yearly saving is more than 1,5 EUR/m2. In case the estimated extra price of gas filling is 1 to 2 EUR/m2, the gas filling is very cost-effective.

11 Accelerated ageing test for insulated glazing units with large interpane separation in Germany

11.1 Introduction

The integration of solar shading devices between the glass panes of an IG unit has advantages not only regarding architectural requirements. Environmental loads on the shading device as wind, rain and dirt can be excluded if the component is included in hermetic sealed interpane separation. Due to the assembling in the interpane separation, it is necessary to increase the air gap in order that the movable parts of the shading devices can not touch glass surfaces. The increased air volume causes higher internal pressure. This leads to increased loads on the edge sealant and increased deflection of the glass panes.

The question is now, how the higher loads on the edge sealant affect the durability of the IG-units especially the edge sealant. Moisture penetration and gas leakage rate can be considered as one of the most important properties to asses the service life time of such a product. The durability of the product is not only defined by gas leakage and moisture penetration. Mechanical properties of the IG unit and the integrated shading devices should be considered too. This topic is not addressed in this report.

At the moment experience with DIN EN1279 and large interpane separation are not existing. According to the German Standard DIN 1286 the same specimen size is required as in DIN EN 1279. It is a national regulation that its possibility to change the specimen size to a quadratic format 500 x 500 mm² for the testing according DIN 1286 when significant difference in the interpane separation to standard IG unit is present.

This report provide test results for different IG units tested according to European Standard DIN EN 1279-3 and DIN EN 1279-2 and a calculation to determine the internal pressure and loads on the edge sealant for two different sizes of specimen.

11.2 Edge Sealant with large interpane separation

11.3 Objective

The main objective of this investigation is to asses the durability of the edge seal according increased requirements of IG units with large interpane separation and to get experience when tested according to the European Standard DIN EN 1279-2 and DIN EN 1279-3. For standard IG-units the DIN EN 1279 is an adequate test procedure therefore we believe, the specimen with large interpane separation should be chosen so, that the resultant loads should be similar to the loads of a standard IG unit. Therefore, it is a question how appropriate is the specimen size of the European Standard to asses IG units with large interpane separation. Do we need a specimen size of 500 x 500 mm² for IG-units with large interpane separation?

11.4 Requirements on IG units

For standard IG units the requirements are well known. However, the investigated systems have essential difference to a standard IG unit and therefore different degradation factors.

Difference from standard IG unit
increased volume due to large interpane separation
increased temperatures due to solar absorption on integrated components

penetration of edge sealant for cables to control electric motors
material compatibility of integrated components to sealant material.
fogging of UV radiation on integrated material

Summery of boundary conditions and influencing variables for degradation factor.
Geometry of IG unit
Construction of IG unit (stiffness of glass panes)
Encased gas volume
Operative temperature
Absorption of desiccant
Place of use
Air pressure and temperature during production (Place of production)
Partial pressure
Wind loads

11.5 Test procedure

Testing was performed according to DIN EN 1279-2 May 2002 (Long term test method and requirement for moisture penetration) and according to DIN EN 1279-3 (Long term test method and requirement for gas leakage rate and for gas concentration tolerance). The size of the test specimen for the test according DIN EN 1279-3 was increased to the geometry of 500 x 500 mm² due to the experience at the ift that this dimension is better suited for large interpane separation. Fig. 18 shows the climatic condition in test cabin for DIN EN 1279-3 Test.

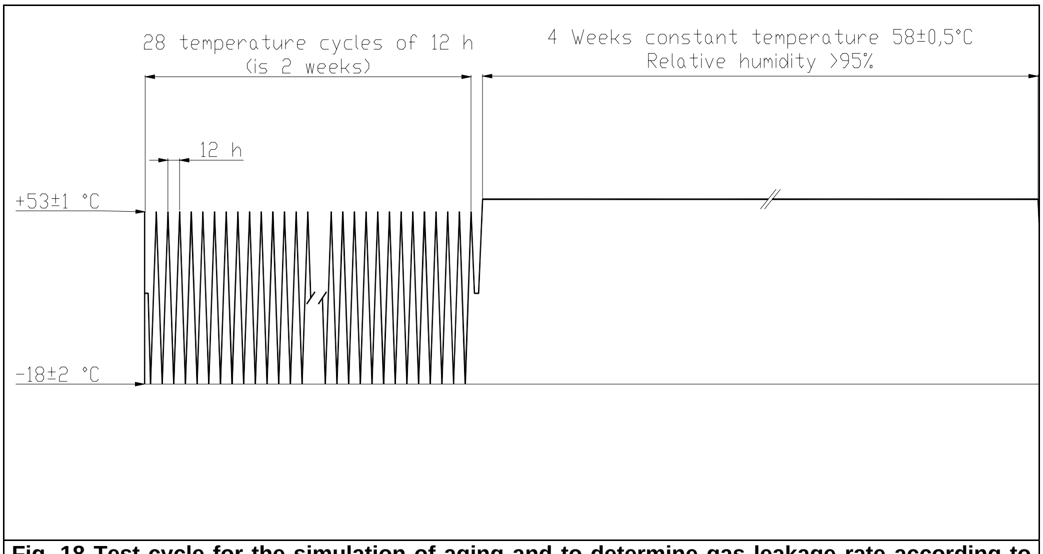

Fig. 18 Test cycle for the simulation of aging and to determine gas leakage rate according to DIN EN 1279-3

Table 10 Comparison of climatic cycles of DIN EN 1279-2 and DIN EN 1279-3

Standard	DIN EN 1279-2	DIN EN 1279-3
Geometry	350 x 500 mm²	500 x 500 mm²
Climatic cycles	56 cycles a 12h +53 ± 1°C bis –18 ± 2°C	28 cycles a 12h +53 ± 1°C bis –18 ± 2°C
Constant temperature	+58 ± 0,5°C for 7 weeks relative humidity ≥ 95%	+58 ± 0,5°C for 4 weeks relative humidity ≥ 95%

A set of 11 specimens are randomly divided in
4 specimens to determine the initial moisture content of desiccant (Ti),
5 specimens to determine the final moisture content of desiccant (Tf)
1 specimen as spare unit after climatic exposure and 1 specimen as spare unit with out climatic exposure. The moisture penetration index Iav is defined as the average of the results of 5 specimen

$$I = \frac{T_f - T_{i,av}}{T_{c,av} - T_{i,av}}$$

T_f = final moisture content of desiccant

$T_{i,\,av}$ = Average initial moisture content of desiccant

$T_{c,\,av}$ = Average standard moisture adsorption capacity of desiccant

In accordance with DIN EN 1279-3 a set of 4 specimen with the dimension 500 x 500 mm² are exposed to climatic cycles as shown in Fig. 52. The final gas concentration was measured and the gas leakage rate was determined after climatic exposure for 2 specimens according to the following formula:

$$L_i = 87{,}6 \cdot 10^6 \frac{m_i}{c_i \cdot V_{\text{int}} \cdot \rho_{o,i}} \cdot \frac{T}{T_0} \cdot \frac{P_0}{P}$$

L_i = Gas leakage rat in % a^{-1}

m_i = mass of gas that leaked from a gas filled unit

c_i = gas concentration

V_{int} = internal volume of test specimen

$\rho_{0,I}$ = density of gas

T = temperature at which unit was sealed

T_0 = temperature at which ρ_0 was determined

Following tables 11 to 12 show the selection of specimens for accelerated aging test provided by different German manufacturers. All specimen represent a typical product of the manufacturers product range. The specimens were designed with all penetrations of electric cables, clamping devices for integrated shading. Specimens for DIN EN 1279-3 test are argon filled.

Table 11 Selected specimens for DIN EN 1279-3 test

Specimen	No.	Dimension mm		IGU	primary seal	secondary seal	spacer
1 EN 3	4	500	500	5/16/5/16/5	Butyl	PU	Stainless steel
2 EN 3	4	500	500	5/16/4/16/5	Butyl	Polysulfide	TPS
3 EN 3	4	500	500	4/27/4	Butyl	Polysulfide	Alu
4 EN 3	4	500	500	5/27/4	Butyl	PU	Alu
5 EN 3	4	500	500	5/27/5	Butyl	PU	Alu
6 EN 3	4	500	500	5/32/5	Butyl	PU	Alu
7 EN 3	4	500	500	5/27/5	Butyl	PU	Alu
8 EN 3	4	500	500	6/24/6	Butyl	Polysulfide	Alu
9 EN 3	4	500	500	6/27/6	Butyl	Polysulfide	Plastic

Table 12: Selected specimen for DIN EN 1279-2 test

Specimen	No.	Dimension mm		IGU	primary seal	secondary seal	spacer
1 EN 2	11	350	500	5/32/5	Butyl	PU	galvanized steel
2 EN 2	11	350	500	5/16/5/16/5	Butyl	PU	Stainless steel
3 EN 2	11	350	500	5/16/4/16/5	Butyl	Polysulfide	TPS
4 EN 2	11	350	500	5/16/4/16/5	Butyl	PU	TPS
5 EN 2	11	350	500	4/27/4	Butyl	Polysulfide	Alu
6 EN 2	11	350	500	5/27/5	Butyl	PU	Alu
7 EN 2	11	350	500	5/27/5	Butyl	PU	Alu
8 EN 2	11	350	500	5/32/5	Butyl	PU	Alu
9 EN 2	11	350	500	5/27/5	Butyl	PU	Alu
10 EN 2	11	350	500	6/24/6	Butyl	Polysulfide	Alu
11 EN 2	11	350	500	6/27/6	Butyl	Polysulfide	Plastic

11.6 Results

Fig. 19 shows the moisture penetration index I_{av} in %. Two systems experiences major failure due to design related and material related issues (see Fig. 55 and Fig. 56.) All other units show a moister penetration index lower than 20 %. The standard requires a average moister penetration index lower than 20 % and a maximum index for a single specimen of 25 %.

Table 13: Results of moisture penetration Test

Specimen	Design	primary seal	secondary seal	spacer	I_{av} in %	Ti_{av} in %	Tf_{av} in %
1 EN 2	5/32/5	Butyl	PU	galvanized steel	12,5	7,9	9,4
2 EN 2	5/16/5/16/5	Butyl	PU	Stainless steel	5,6	2,0	3,0
3 EN 2	5/16/4/16/5	Butyl	Polysulfide	TPS	3,3	0,2	0,2
4 EN 2	5/16/4/16/5	Butyl	PU	TPS	0,9	0,2	0,2
5 EN 2	4/27/4	Butyl	Polysulfide	Alu	6,5	6,5	3,4
6 EN 2	5/27/5	Butyl	PU	Alu	6,2	2,3	3,4
7 EN 2	5/27/5	Butyl	PU	Alu	5,6	1,8	2,8
8 EN 2	5/32/5	Butyl	PU	Alu	6,9	2,9	4,1
9 EN 2	5/27/5	Butyl	PU	Alu	9,1	2,7	4,3
10 EN 2	6/24/6	Butyl	Polysulfide	Alu	34,6	2,2	8,3
11 EN 2	6/27/6	Butyl	Polysulfide	Plastic	121,5	2,3	23,8

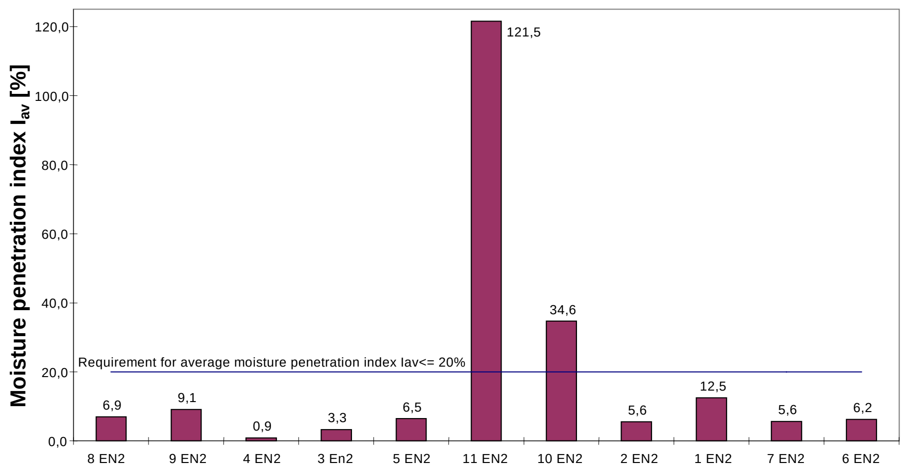

Fig. 19: Moisture penetration index I_{av}

The gas leakage rate was determined for 9 different systems according to DIN EN 1279-3. For each system, 2 specimens were measured. The values of 3 systems meet the requirements Li<1,0 %·a-1 of DIN EN 1279-3. 6 Systems exceed the requirements of the standard. The highest gas leakage rates were measured for the system 8 EN 3 and 9 EN 3. As shown in Fig. 55 and Fig. 56 these Systems have substantial defects in the construction and used components. The failure of the other systems can be attributed to initial production defects (see chapter Visually detected defects of specimen).

Table 14: Results of DIN EN 1379-3 test

Specimen	Design	Gas leakage rate % a^{-1}	Final gas concentration in %
1 EN3-1	5/16/5/16/4	0,5	90
1 EN3-2	5/16/5/16/5	0,7	92
2 EN3-1	5/16/4/16/5	0,3	94
3 EN3-1	4/27/4	0,4	87
3 EN3-2	4/27/5	0,4	66
4 EN3-1	5/27/4	4,6	77
4 EN3-2	5/27/5	1,9	91
5 EN3-1	5/27/5	2,3	88
5 EN3-2	5/27/5	2,9	89
6 EN3-1	5/32/5	5,2	88
6 EN3-2	5/32/5	3,7	91
7 EN3-1	5/27/5	4,2	90
7 EN3-2	5/27/5	4,1	92
8 EN3-1	6/24/6	27,8	86
9 EN3-1	6/27/6	91,9	76

Fig. 20 shows a corner key design of an edge sealant. It can be seen that the electric cable is fixed with an aluminium adhesive tape. This leads to a insufficient bonding of the secondary sealant with the spacer. Fig. 21 shows a component defect of the spacer design. The spacer has longish cracks. In addition, the adhesion between spacer and secondary sealant is reduced.

Fig. 20: 8 EN 3 adhesive tape

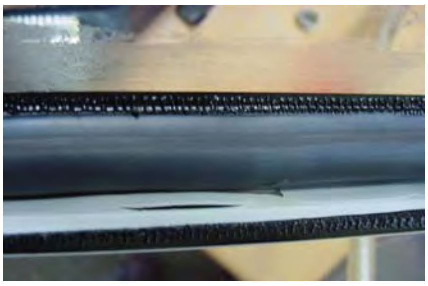

Fig. 21: 1:9 EN 3

The widening of the edge sealant was measured to observe a correlation between expansion of the edge sealant and gas leakage rate.

Table 15: Widening of edge sealant

Specimen	Design	Thickness of IG unit				widening of edge sealant	
		initial	final	initial	final	difference	
		corner	corner	center	center	corner	center
		mm	mm	mm	mm	mm	mm
1 EN 2	5/32/5	41,8	42,1	41,6	42,1	0,29	0,54
2 EN 2	5/16/5/16/5	47,3	48,0	47,3	48,2	0,71	0,89
5 EN 2	4/27/4	35,7	36,5	35,6	36,8	0,80	1,16
3 EN 3	4/27/4	35,7	35,8	35,6	36,7	0,17	1,04
6 EN 2	5/27/5	37,3	37,3	37,6	38,0	0,02	0,40
4 EN 3	5/27/5	37,3	37,3	37,6	37,7	0,05	0,12
7 EN 2	5/27/5	37,5	37,5	37,6	37,9	0,04	0,39
5 EN 3	5/27/5	37,5	37,7	37,6	37,7	0,11	0,20
8 EN 2	5/32/5	42,1	42,6	42,1	43,2	0,47	1,12
6 EN 3	5/32/5	42,1	42,5	42,1	42,6	0,39	0,52
9 EN 2	5/27/5	37,1	37,5	36,9	37,8	0,40	0,85
7 EN 3	5/27/5	37,1	37,4	36,9	37,4	0,34	0,48
10 EN2	6/24/6	36,3	36,2	36,9	37,6	0,56	1,40
8 EN 3	6/24/6	36,3	36,2	37,2	38,0	0,82	1,78
						0,37	0,78

Figure 22 shows the widening of the edge sealant after climatic exposure.

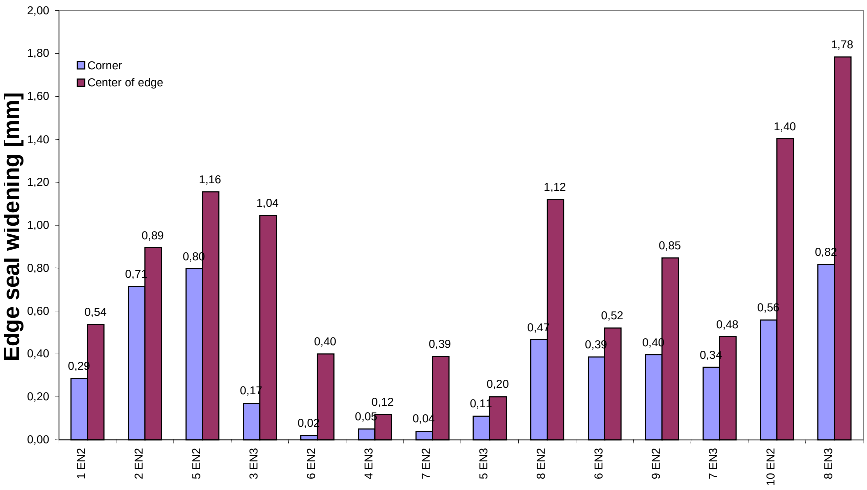

Fig. 22: Widening of the edge sealant after climatic cycles according to DIN EN 1279-2 and –3, measured in the middle of the edge and at the corner of the specimen

The widening of the edge sealant is in that case not a significant indicator that systems are within the limits of DIN EN 1279. It can not be seen that there is a correlation between widening of the edge sealant and gas leakage rate. For example, the widening of 3 EN3 is relatively high although the specimen passed the test for gas leakage rate. Otherwise 4 EN3 and 5 EN3 has a relatively slight widening the specimen failed through the test DIN EN 1279-3. It can be located, that the expansion in the middle of the edge sealant is higher than in the corner area. The material properties of the secondary sealant are an essential parameter of the widening of the edge sealant.

11.7 Visually detected defects of specimens

The specimen are visually inspected to evaluate the production quality and to asses the effect of quality to durability of the IG units. Possible defects and the frequency of the appearance is reported. 64 Specimen were inspected in total 80 defects were detected. For each defect, examples are given in Fig. 23 to Fig. 30.

Table 16: detected defects

Defect	number of defect	frequency of defects	Figure
Corner processing	37	46 %	9; 10
Insufficient butyl on spacer	16	20 %	11; 12
Delamination on primary seal	9	11 %	13; 14
Air gaps in secondary seal	9	11 %	17
Air gaps in primary seal	4	5 %	16
Butyl on coating	4	5 %	
Delamination secondary seal	1	1 %	15
Sum	80	100%	

A typical example for an insufficient corner processing is shown in figure 23 (direct connection between secondary sealant and cavity).

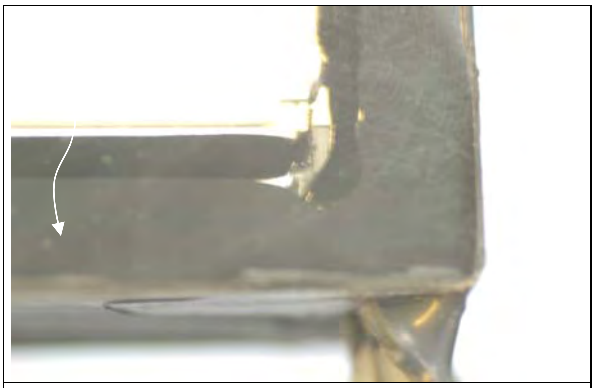

Fig. 23: insufficient corner processing

11.8 Calculation of internal loads on edge sealant

The basic physical principles to calculate the internal loads of an IG unit are based on the combination of the theory of surface structure of plates and shell with the basic gas laws. The climatic load of an IG unit originates from thermal expansion of the enclosed air and changes of the external air pressure. Both effects lead to pressure difference between external atmosphere and enclosed gas. The calculation of internal loads of IGU with large interpane separation is calculated with the calculation model and the computer program ISOBEL developed by Prof. F. Feldmeier. For detailed information on the calculation model, see the literature.

The assumption for the calculation are single axes supported bearings of the glass panes. The approximation leads to adequate results for deflection of the glass panes, load of edge sealant and internal pressure. A more detailed evaluation leads to very complex mathematical correlations and can only be solved by computer aided finite element programs.

For triple glazing, it can be assumed that the performance is similar to a double glazing unit under the following requirements:

Symmetric design of triple glazing unit:

- The thickness of the two external glass panes must be the same as the double glazing unit (DGU)
- The interpane separation between the glass panes must be the same as the DGU
- Same geometry as DGU
- The total enclosed gas volume (sum of both cavity of the triple glazing unit) must be the same as the DGU

Another approximation for one cavity of a symmetric triple glazing units (TGU) can be the assumption, that the performance is similar to an asymmetric double glazing. For the calculation the following requirements must be applied:

- Symmetric design of triple glazing unit
- One pane must be rigid
- Second pane must have the same thickness
- The gas volume must be the volume of one cavity of the TGU
- The geometry must be the same

A triple glazing unit has the double length of primary sealant compared to a double glazing unit with the same size. The internal loads are similar to a double glazing unit as long the triple glazing unit is symmetric, has the same thickness of glass and the enclosed gas volume is the same. The effect of the enlarged sealant area is still unknown.

The objective of the calculation was to evaluate the effect of different specimen sizes and the use of different pane thickness.

Table 17: Boundary conditions for calculation

	Place of production	Place of use
Air pressure	1013 hPa	1013 hPa
Temperature	20	58*
Relative humidity	-	30 %
Altitude	500 m	500 m
Water vapour pressure	0	0
Wind		0 kN/m²

* Temperature according to DIN EN 1279

Fig. 31 shows the development of the load on the edge sealant for two different aspect ratios (long edge to short edge of specimen) and for a glass thickness of 5 mm. The chosen aspect ratios are e = 1 for a quadratic format and e = 0,7 for a rectangular format e.g. 350 x 500 mm²

It can be seen that the load for a specimen with the format 500 x 500 mm² and a interpane separation of 40 mm (1) is approximately the same as for an specimen with 40 mm interpane separation and 350 x 500 mm² format (2). One compares the results for the specimen with 16 mm interpane separation, the load of edge sealant for the format 500 x 500 mm² (3) is significant lower than for the specimen 350 x 500 mm² (4). This indicates that, with increasing interpane separation the effect of the more flexible pane due to the quadratic format affects less the load of the edge sealant. With increasing interpane separation the difference between the formats 500 x 500 mm² and 350 x 500 mm² are approaching.

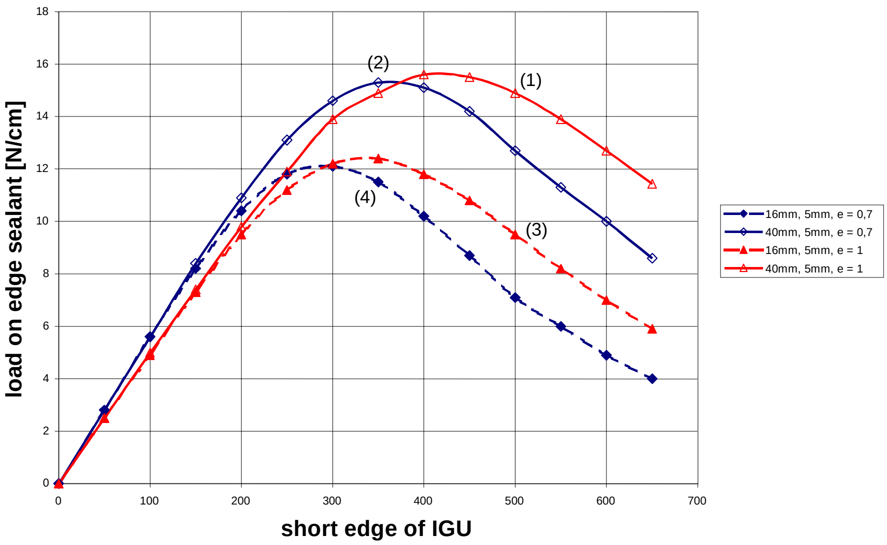

Fig. 31: Load on edge sealant against short edge of IGU for the aspect ratio 0,7 and 1,0 for 5 mm glass panes and interpane separation of 16 mm and 40 mm

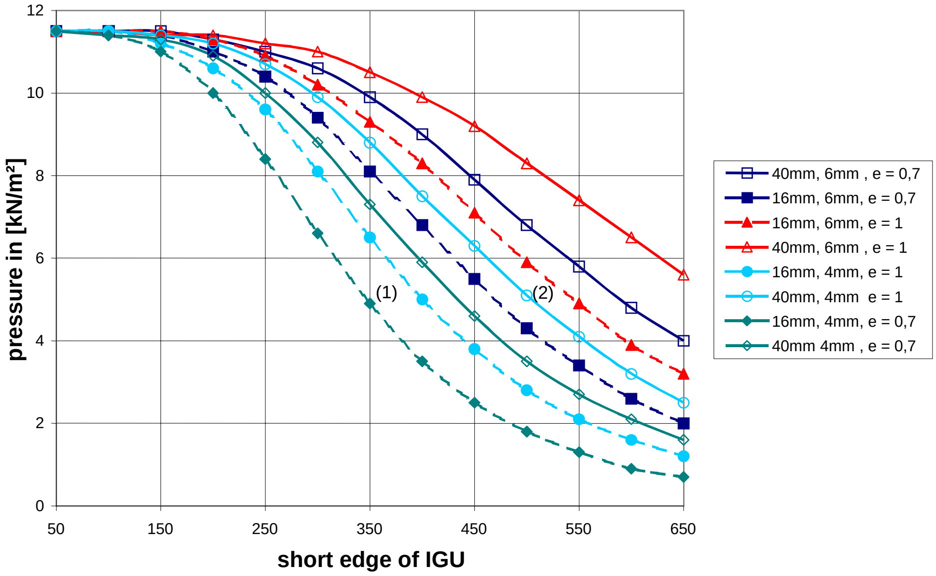

Fig. 32: Internal pressure for aspect ratio of 0,7 and 1,0, thickness of glass panes of 4 mm and 6 mm and for interpane separation of 16 mm and 40 mm

Table 18: Internal pressure kN/m²

pane thickness	6 mm				4 mm			
interpane separation	16	40	16	40	16	40	16	40
aspect ratio length of short edge [mm]	1	1	0,7	0,7	1	1	0,7	0,7
50	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5
100	11,5	11,5	11,5	11,5	11,5	11,5	11,4	11,4
150	11,5	11,4	11,4	11,5	11,2	11,4	11,0	11,3
200	11,3	11,4	11,0	11,3	10,6	11,2	10,0	10,9
250	10,9	11,2	10,4	11,0	9,6	10,7	8,4	10,0
300	10,2	11,0	9,4	10,6	8,1	9,9	6,6	8,8
350	9,3	10,5	8,1	9,9	6,5	8,8	4,9	7,3
400	8,3	9,9	6,8	9,0	5,0	7,5	3,5	5,9
450	7,1	9,2	5,5	7,9	3,8	6,3	2,5	4,6
500	5,9	8,3	4,3	6,8	2,8	5,1	1,8	3,5
550	4,9	7,4	3,4	5,8	2,1	4,1	1,3	2,7
600	3,9	6,5	2,6	4,8	1,6	3,2	0,9	2,1
650	3,2	5,6	2,0	4,0	1,2	2,5	0,7	1,6

Fig. 32 shows the internal pressure for aspect ratio of 0,7 and 1,0, thickness of glass panes of 4 mm and 6 mm and for interpane separation of 16 mm and 40 mm. If one assumes, that the pressure of a standard IG-unit with 16 mm interpane separation and 4 mm glass with the format 350 x 500 mm² (1) is the reference value it can be seen, that similar pressure is achieved for the dimension 500 x 500 mm² and 4 mm glass (2).

Fig. 33 shows the development of the load on the edge sealant against the interpane separation. For standard IG units e.g. 16 mm the test format of DIN EN 1279 causes loads of approximately 8,3 N/cm if 4 mm glass panes are used. It can be seen that the load is only remaining below of 8.3 N/cm for the specimen with 4 mm glass and the quadratic format. The range of loads for a IG-unit with large interpane separation can only be reduced to comparable value of a standard IG-unit if 4 mm glass combined with the format of 500 x 500 mm² is used. The stiffness of the glass panes is the biggest actuating variables for the load on the edge sealant. With increased interpane separation, the enlarged volume in combination with very stiff glass panes (e.g. 6 mm) leads to extremely high loads.

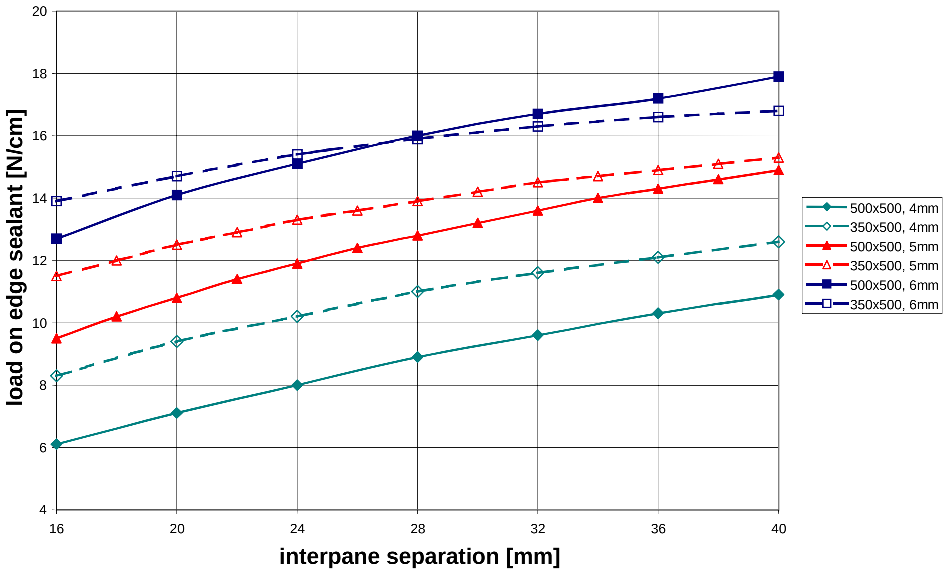

Fig. 33: Load on edge sealant against interpane separation for DGU with 4 mm, 5 mm and 6 mm glass panes, with a specimen size 350 x 500 mm² and 500 x 500 mm²

Table 19: Load on edge sealant in kN/m² for different interpane separation, format of specimen and glass thickness.

Glass thickness	Format	interpane separation in [mm]						
in [mm]	in [mm²]	16	20	24	28	32	36	40
4	500 x 500	6,1	7,1	8,0	8,9	9,6	10,3	10,9
4	350 x 500	8,3	9,4	10,2	11	11,6	12,1	12,6
5	500 x 500	9,5	10,8	11,9	12,8	13,6	14,3	14,9
5	350 x 500	11,5	12,5	13,3	13,9	14,5	14,9	15,3
6	500 x 500	12,7	14,1	15,1	16	16,7	17,2	17,9
6	350 x 500	13,9	14,7	15,4	15,9	16,3	16,6	16,8

11.9 Conclusions

The general understanding was, that a change in the specimen size from 350 x 500 mm² to the quadratic format 500 x 500 mm² will reduce the internal loads in such a way that the IG units with large interpane separation can meet the requirement of DIN EN 1279. By measuring the moisture penetration with the format required in the standard it is shown that the pumping of IG unit due to climatic load is not a significant degradation factor to the failure mode of moisture penetration. The specimens who failed in DIN EN 1279-2 had serious material and construction defects.

The result of DIN EN 1279-3 test shows that the effect of using a larger quadratic format does not significantly reduce the internal loads. That indicates that the movement of the edge sealant is a significant degradation factor for gas leakage. This statement must be restricted if the poor production quality is considered. From testing result is not clear whether the measured gas leakage rate is assigned to initial defects or to the degradation due to the climatic loads. The result showed that the specimen with 4 mm glass performed much better then specimen with 5 mm and 6 mm glass. This indicates that the selection of glass thickness has a essential effect on the performance of the tested specimen.

Calculations of the internal loads were carried out to verify the effect of different specimen sizes and glass thickness. The calculation showed that the effect of the rigidity of the glass panes plays a major role for the resultant loads on the edge sealant for the considered specimen sizes 350 x 500 and 500 x 500 mm². The lowest load for the tested specimens is achieved by the design with 4 mm glass and the quadratic format. A change to thicker glass panes e.g 6 mm leads to 64% higher loads on the edge sealant when the format 500 x 500 mm and the interpane separation of 40 mm is used. The effect of specimen size is much lower depending on glass thickness and interpane separation. Using 4 mm glass a variation from 500 x 500 mm² to 350 x 500 mm² leads to load increase between 16% to 36%.

The final conclusion of the calculation is, that the effect of specimen size and thickness of glass has to be considered in combination. The major advantage can be achieved by selecting thin glass panes. The risk of glass fracture due to the climatic loads in the chamber should be pre calculated and its usually necessary using tempered glass. With exceeding dimension in practical use of an IG unit, the climatic loads will be relatively low compared to the wind loads.

It must be considered that the resultant loads during the test does not exceed a certain value were the ultimate strength of the material will be exceeded. For standard IG-units the DIN EN 1279 is an adequate test procedure therefore we believe, the specimen with large interpane separation should be chosen so, that the resultant loads should be similar to the loads of a standard IG unit. That can be achieved by using the quadratic specimen size 500 x 500 mm² in combination with 4 mm tempered glass. From the tests to EN 1279 it can be concluded that these units are less fault tolerant than a standard 16 mm IG unit. For this reason manufacturers must control quality very accurately. The normal quality standard of an IG unit might not be sufficient.

12 Closing Remarks

From testing result and observations from installed windows it is, at this state, not possible to draw final conclusions on the effect from sample size on the durability and reliability of the new types of insulated glazing units. The tests conducted on the four sets in Canada indicate that the size of the unit does not have a strong impact on the longevity of the edge seal. Analyses in America give an impression that there is an effect of glass size showing increase in failure occurrence for larger dimension of the window especially with the failure mode condensation.

Temperature fluctuations produce variations in pressure within the air gap and exert mechanical stresses on the edge seal. Those stresses are strongest for small units.

The temperature difference between the outer and inner glass pane of the IG unit can be substantial. In Europe 30°C could be realistic. Investigations of the temperature-exerted deformations show large dilatations factors for the edge seal. These large elongations in the primary seal could be serious. This depends on the speed of the movement and under what temperature condition this movement occurs and how many cycles it take until failure occurs. The frequency of high intensities of solar irradiation on windows is different from summer to winter, highest loads in winter situation and highest frequent in summer situations. The worst-case situation is also depending on the type of IG unit. The winter situation is worst for an IG unit with low e-coating and the summer situation is worst for the IG unit with a solar control coating.

The shear and peel stresses caused by the differential movement between spacer and glass may cause delamination (loss of adhesion) for large glazing units. Both causes give premature failure of the primary seal once its fatigue resistance is exceeded.

Wind load exerted stresses are strongest for larger units and also the temperature-exerted deformations resulting in large dilatations are larger for larger units. It is apparent that realistic deformations of the sealing in IG units as a result of elongation of the materials are large compared to deformations from deflection of the cover caused by pressure fluctuations in the air gap. This is contrary to general judgment claiming that the standard size used in existing durability test is the most critical size. IG units edge seal systems that minimise differential thermal movement, tend to perform significantly better in terms of gas loss rates than systems with high thermal movements, this can be seen from test results performed on systems with stainless steel spacers and systems with aluminium spacers, some spacer system designs have even taken this into account by making systems that could accommodate some movement within the spacer itself.

What we have clarified is that the elongations of the materials may cause higher stresses than allowable and therefore the “elongation at break” will be one of the determining parameters for the sealant material. A preferable elongation capability is 200%. This is not sufficient for non-metallic spacers, polycarbonate as spacer material shows that the elongation is 369%.

Experience is presented from a new method for detecting the gas filling type and concentration without breaking the unit. In normal high quality insulating glass units the permanence of gas filling have a good quality.

Higher loads on the edge sealant, as a result of integration of solar shading devices between the glass panes of an IG, affect the durability of the IG-units especially the edge sealant. The result of DIN EN 1279-3 test shows that the effect of using a larger quadratic format does not significantly reduce the internal loads. That indicates that the movement of the edge sealant is a significant degradation factor for gas leakage. This

statement must be restricted if the poor production quality is considered. From testing result is not clear whether the measured gas leakage rate is assigned to initial defects or to the degradation due to the climatic loads. The result showed that the specimen with 4 mm glass performed much better then specimen with 5 mm and 6 mm glass. This indicates that the selection of glass thickness has a essential effect on the performance of the tested specimen.
It must be considered that the resultant loads during the test does not exceed a certain value were the ultimate strength of the material will be exceeded. For standard IG-units the DIN EN 1279 is an adequate test procedure therefore we believe, the specimen with large interpane separation should be chosen so, that the resultant loads should be similar to the loads of a standard IG unit. That can be achieved by using the quadratic specimen size 500 x 500 mm² in combination with 4 mm tempered glass. From the tests to EN 1279 it can be concluded that these units are less fault tolerant than a standard 16 mm IG unit. For this reason manufacturers must control quality very accurately. The normal quality standard of an IG unit might not be sufficient.

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