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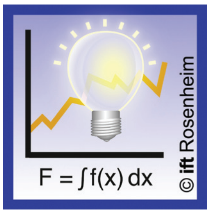
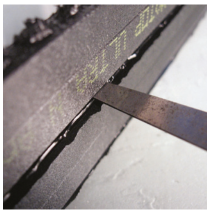
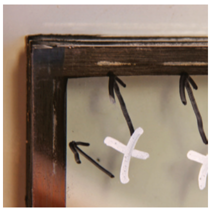
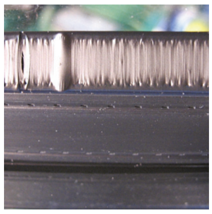
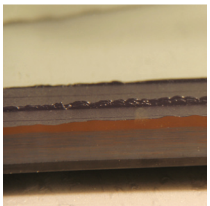
ift-RESEARCH REPORT
Short Report
October 2015

ROSENHEIM

The effect of the interpane spacing on the durability of highly insulating glass units




Short report

Subject	**The effect of the interpane spacing on the durability of highly insulating glass units**
Short title	Durability of IGUs
Sponsored by	Research Initiative „Zukunft Bau“ of the Federal Institute for Research on Building, Urban Affairs and Spatial Development (File reference: II 3-F20-12-1-156 / SWD-10.08.18.7-13.35) The responsibility for the content of this report lies with the authors.
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Rosenheim, October 2015

Contents

1 Motivation and aim of project

Transparent construction elements play a key role in improving the structural thermal protection of a building. A considerable reduction of the heat transfer coefficient can be achieved by the use of triple-pane insulating glass units. A double-pane unit with an interpane spacing of 16 mm, argon as fill gas and a low-e coating with an emissivity of 0.03 has a heat transfer coefficient of U_g = 1.1 W/(m^{2}K). An optimized triple-pane unit, however, can achieve U_g = 0.5 W/(m^{2}K), albeit with interpane spacings of 18 mm.

Conventional insulating glass units (IGUs) are hermetically sealed around the edges. Thus, whenever the external air pressure or the temperature in the cavity changes, the pressure in the cavity changes as well. This causes the panes to bulge inwards or out, inducing flexural stresses in them and loading the edge seal in tension or compression. These climatic loads increase with the size of the interpane gap and with the thickness of the glass panes. The effects of an increased climatic load on the glass are well known and can be estimated with established methods. This is different, however, for the edge seal. In particular, it is currently not known how an increased loading of the edge seal influences the durability of an IGU. Therefore, interpane spacings of 2 x12 mm are recommended for triple-pane IGUs at present. The drawback is a 40 % larger heat transfer coefficient than for an energetically optimized IGU.

It was the aim of this research project to study the effect of the edge load on the durability of triple-pane insulating glass units. The edge load was to be controlled by varying the size of the interpane spacing and the thickness of the glass panes. As it was known that the durability of an IGU depends very much on the quality of the manufacturing, which can vary considerably from manufacturer to manufacturer, a sufficiently high number of specimens had to be tested. Only then was it possible to gain statistically reliable results that would be valid for the IGU manufacturing industry as a whole.

2 Course of action

2.1 Specimens

IGU specimens of three different constructions were submitted to a moisture penetration test according to EN 1279-2. The chosen constructions differed in their interpane spacings and the thickness of the glass panes, so that different loads on the edge seal would be induced during the climate test. It was crucial to determine the absolute moisture uptake (in g) during the climate test because only the absolute value is a measure for the quality and tightness of the edge seal. The measurement of the gas leakage rate according to EN 1279-3 was not possible within the scope of this research project. The efforts in terms of time and cost would have been too great.

The following three IGU constructions, of dimensions 350 mm x 500 mm, were tested:

		Rel. maximum load on the edge seal *
Construction 1	4-12-4-12-4	100%
Construction 2	4-18-4-18-4	120%
Construction 3	6-18-4-18-6	160%

* Calculated with software Üko Professional 3S Vers. 9.1
Climatic loading based on EN 1279-2
The load on the edge seal is given as relative value with respect to construction 1.

Twenty manufacturers supplied specimens of all three constructions. In this way, it should be possible to detect effects of the edge load on the moisture uptake as well as to gain an overview of the variation of results within the industry. Only rigid edge seal systems with pourable desiccants could be considered within the scope of this research project. Otherwise, it was left to the participating manufacturers to decide on the settings of system parameters like spacer type, amount of desiccant, sealant type (either PU or PS), edge seal geometry and dimensions. Polymeric spacers with a metallic diffusion barrier and PU as sealant were the preferred choices.

2.2 Execution

The initial moisture content (in % by weight) of four specimens was determined according to EN 1279-2, whereby the two interpane spaces were accounted for individually. It was assumed that the five specimens for the climatic ageing would have the same initial moisture content because they came from the same production batch.

After the climatic ageing, the moisture content (in g) of the five aged specimens was measured. Again, the two interpane spaces were accounted for individually. Special care was taken to gather all the desiccant in a spacer. (For the determination of the initial moisture content (in % by weight) it was not critical if by accident a little desiccant remained in the spacer as this would not influence the result.)

The moisture content (in g) of an interpane space after ageing is the sum of the initial moisture content and the moisture uptake during ageing. Conversely, the moisture uptake during ageing can be calculated from the moisture content after ageing and the initial moisture content.

2.3 Individual results

Figure 1 shows, as an example, the readings and results of the specimens from one manufacturer, as they can be found for all participating manufacturers in the annex to the main report.

Hersteller	5		Abstandhalter:		Kunststoff / metallische Diffusionssperre					
			Sekundärdichtstoff:		PS					
			Tc	in %	22					
	Lieferzustand				**Gealtert**				"Z"	
				"Ti"	"m fe"	"m tr"			Zubeladung	Feucht.
	TM	TM		Anfangs-	TM	TM	"B"	"Tf"	durch	aufn.faktor
	entnommen	getrocknet	Beladung	beladung	entnommen	getrocknet	Beladung	Beladung	Alterung	I
	in g	in g	in g	in %	in g	in g	in g	in %	in g	in %
36 mm	27,362	26,932	0,430	1,6	30,061	28,883	1,178	4,08	0,73	12,3
4-12-4-12-4	27,116	26,707	0,409	1,5	29,617	28,331	1,286	4,5	0,84	14,5
	28,260	27,832	0,428	1,5	30,008	28,748	1,260	4,4	0,81	13,8
	27,850	27,429	0,421	1,5	29,083	27,839	1,244	4,5	0,81	14,2
	28,754	28,283	0,471	1,7	29,413	28,035	1,378	4,9	0,94	16,4
	26,126	25,731	0,395	1,5	27,827	26,689	1,138	4,3	0,72	13,2
	28,237	27,802	0,435	1,6	28,619	27,409	1,210	4,4	0,78	13,9
	28,171	27,733	0,438	1,6	29,550	28,578	0,972	3,4	0,52	9,0
					29,925	28,605	1,320	4,6	0,87	14,9
					29,748	28,631	1,117	3,90	0,67	11,4
Mittel	**27,7**	**27,3**	**0,4**	**1,6**	**29,4**	**28,2**	**1,2**	**4,3**	**0,77**	**13,4**
Stabw	**0,8**	**0,8**	**0,0**	**0,0**	**0,7**	**0,7**	**0,1**	**0,4**	**0,12**	**2,1**
Median	**28,0**	**27,6**	**0,4**	**1,6**	**29,6**	**28,5**	**1,2**	**4,4**	**0,79**	**13,9**
					$T_{i,av}$					
48 mm	39,910	39,307	0,603	1,5	46,074	43,060	3,014	7,0	2,36	26,8
4-18-4-18-4	41,324	40,721	0,603	1,5	44,527	42,670	1,857	4,4	1,21	13,8
	41,533	40,909	0,624	1,5	44,377	41,867	2,510	6,0	1,87	21,9
	40,749	40,158	0,591	1,5	45,531	43,980	1,551	3,5	0,88	9,8
	39,550	38,936	0,614	1,6	45,754	42,902	2,852	6,6	2,20	25,0
	40,853	40,248	0,605	1,5	43,955	42,153	1,802	4,3	1,16	13,5
	42,522	41,873	0,649	1,5	44,937	42,922	2,015	4,7	1,36	15,5
	40,854	40,242	0,612	1,5	42,993	41,309	1,684	4,1	1,06	12,5
Mittel	**40,9**	**40,3**	**0,6**	**1,5**	**44,8**	**42,6**	**2,2**	**5,1**	**1,51**	**17,3**
Stabw	**0,9**	**0,9**	**0,0**	**0,0**	**1,0**	**0,8**	**0,6**	**1,3**	**0,56**	**6,3**
Median	**40,9**	**40,2**	**0,6**	**1,5**	**44,7**	**42,8**	**1,9**	**4,5**	**1,29**	**14,7**
52 mm	43,479	42,822	0,657	1,5	44,653	41,600	3,053	7,3	2,43	28,5
6-18-4-18-6	43,793	43,150	0,643	1,5	43,922	41,041	2,881	7,0	2,27	26,9
	43,028	42,397	0,631	1,5	45,614	42,903	2,711	6,3	2,07	23,5
	41,500	40,883	0,617	1,5	44,323	41,635	2,688	6,5	2,07	24,2
	44,242	43,593	0,649	1,5	44,776	42,239	2,537	6,0	1,91	22,0
	42,973	42,347	0,626	1,5	44,915	42,629	2,286	5,4	1,65	18,9
	42,165	41,544	0,621	1,5	44,269	42,151	2,118	5,0	1,49	17,2
	41,928	41,314	0,614	1,5	44,592	41,699	2,893	6,9	2,27	26,5
					42,837	40,059	2,778	6,9	2,18	26,5
					43,384	41,704	1,680	4,0	1,06	12,3
Mittel	**42,9**	**42,3**	**0,6**	**1,5**	**44,3**	**41,8**	**2,6**	**6,1**	**1,94**	**22,7**
Stabw	**1,0**	**0,9**	**0,0**	**0,0**	**0,8**	**0,8**	**0,4**	**1,1**	**0,42**	**5,1**
Median	**43,0**	**42,4**	**0,6**	**1,5**	**44,5**	**41,7**	**2,7**	**6,4**	**2,07**	**23,9**

Figure 1 An example of the readings and results of the specimens from one manufacturer

2.4 Moisture uptake due to ageing

Figure 2 presents the moisture uptakes caused by ageing according to EN 1279-2 for each manufacturer. In Figure 3, the moisture uptakes are normalized for each manufacturer individually with respect to its construction 1. Thereby, a general effect of the edge load on the moisture uptake should become more evident.

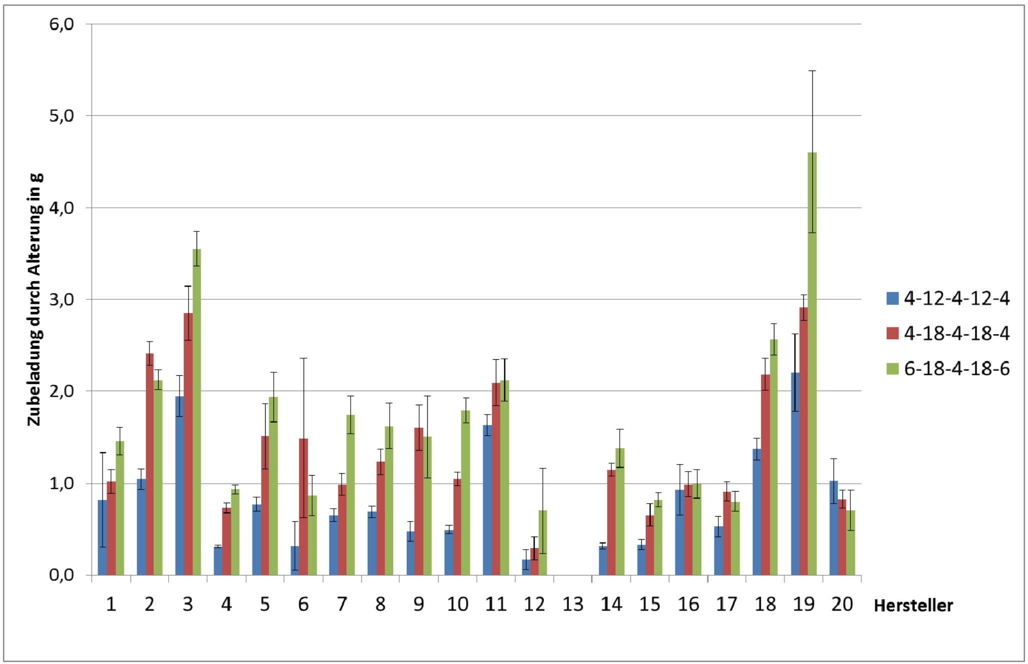

Figure 2 Average moisture uptake during ageing with 95 % confidence intervals

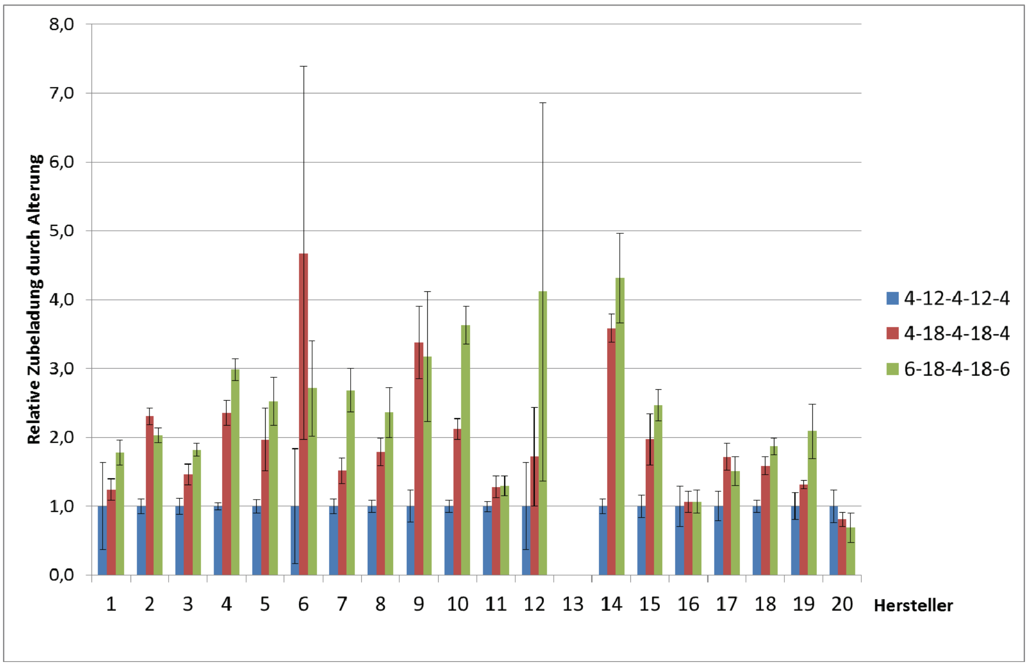

Figure 3 Average relative moisture uptake during ageing, normalized for each manufacturer individually with respect to its construction 1; with 95 % confidence intervals

The differences between the manufacturers are considerable. The moisture uptake of construction 1 (4/12/4/12/4) is most often clearly below that of the other two constructions. The difference between construction 2 (4/18/4/18/4) and 3 (6/18/4/18/6) is not that obvious although the moisture uptake of construction 3 tends to be higher than that of construction 2. A linear relationship between edge load and moisture uptake, however, is not recognizable. The increase in moisture uptake from construction 2 to construction 3 is smaller than could be expected from the calculated values for the edge load.

2.5 Visual inspection of specimens

After the climatic ageing, some specimens were inspected in detail (visually, butterfly test) in the hope of finding reasons for conspicuously high values of moisture uptake.

An insufficient butyl covering of the spacer was observed quite often (Figure 4), especially in the corners where the spacer had widened during the bending process (Figure 5).

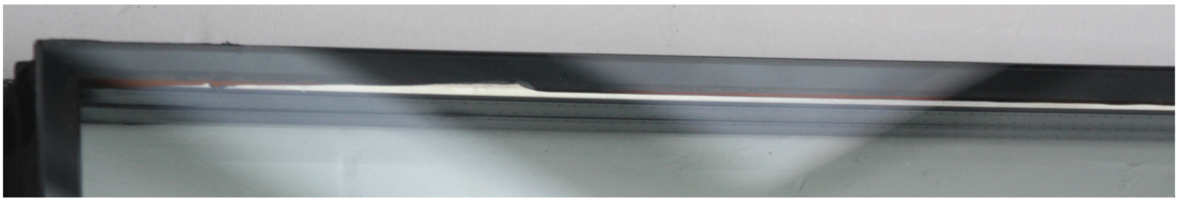

Figure 4 Insufficient butyl covering on a spacer

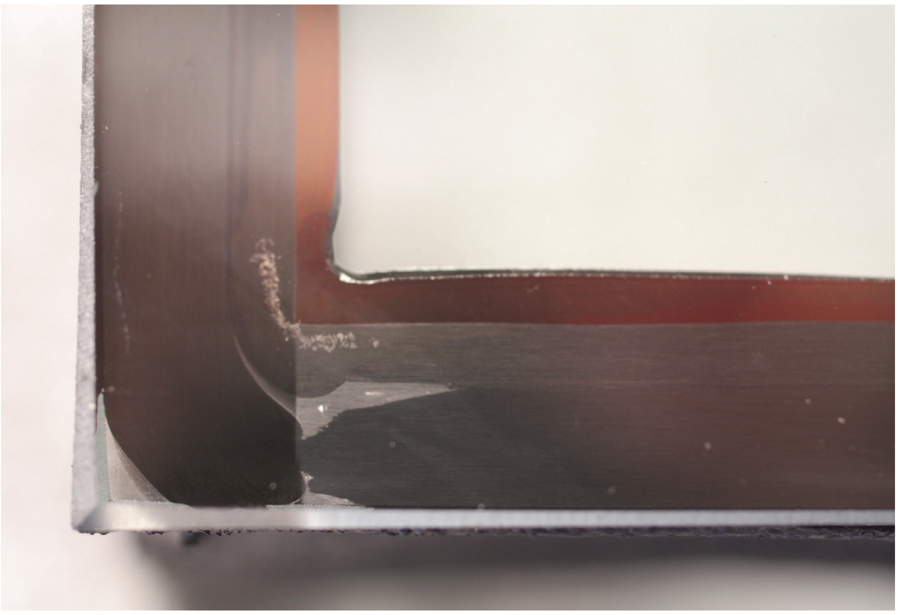

Figure 5 Insufficient butyl covering at the corner where the spacer has been widened by bending; air pockets (grey) in secondary sealant at the start/end point of the automatic sealing process

The stringing of butyl during a butterfly test is a good indicator of the quality of adhesion of butyl on glass and butyl on the spacer, respectively (Figure 6 to Figure 8). In the butterfly test, first, the bond between an outer glass pane and the sealing edge of an IGU is severed with a knife on three sides (short-long-short). The glass pane is then lifted like a hinged lid, and the stringing of butyl can be observed on the inside of the specimen at the fourth side. If the adhesion is not very good, it is likely that paths exist for moisture to penetrate into the interpane space and for fill gas to escape from it. The durability of the IGU would be compromised. The same is true if, during the climatic ageing, cohesive failure occurs in the butyl. There would be no stringing during the butterfly test and facing butyl surfaces would appear smooth.

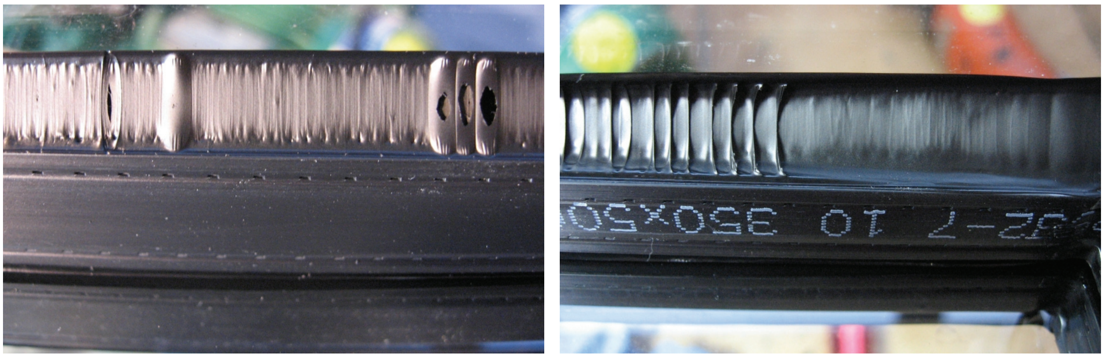

Figure 6 Example of butyl stringing in butterfly test: good adhesion – formation of a closed curtain of strings

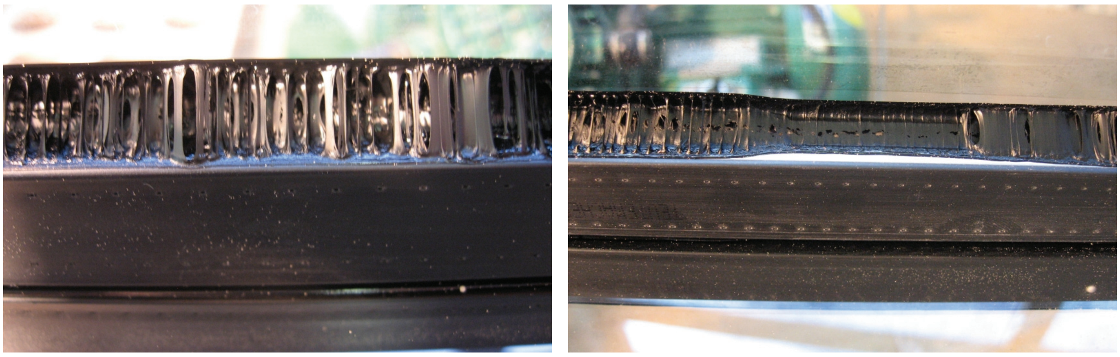

Figure 7 Example of stringing in butterfly test: patches with bad adhesion between butyl and spacer are visible

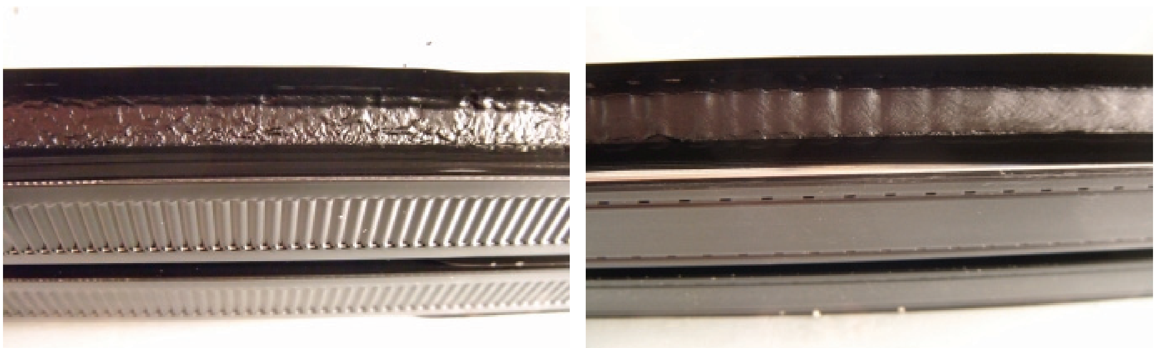

Figure 8 Cohesive failure in the butyl – no stringing

3 Results

The results can be summarized as follows:

- A higher load on the edge seal causes a higher moisture uptake.
- A linear relationship between the edge load and the moisture uptake could not be detected. The specimens of construction 2 clearly show a higher moisture uptake than those of construction 1. However, the difference in moisture uptake between construction 3 and construction 2 is not as clear as could be expected from the calculated values for the edge load.
- The influence of the manufacturing quality on the moisture uptake is at least as strong as that of the edge load, and it confounds the results.
- From the preceding point follows: process control and product assurance become more important with increasing loading of the edge seal, i.e. for triple-pane IGUs with large interpane spacings and thick glass panes.
- The moisture penetration index I (expressed as a fraction or percentage of the water adsorption capacity of an IGU) is not a sufficient criterion to judge the quality of an edge seal because, beside the actual manufacturing quality, it depends on the amount of desiccant in the spacer.

Further, it has to be noted:

- The conclusions from this study of the moisture penetration are not directly transferrable to the gas leakage of IGUs.
- It is not clear whether the insights gained in this study on systems with rigid edge seals are applicable to flexible edge seal systems with integrated desiccants.
- IGUs that are long and narrow (with a short side < 65 cm) carry the highest risk of glass failure under climatic loads. The highest loading of the edge seal, however, occurs always in square-shaped IGUs (with a length of 40–60 cm).

The results and conclusions of this research project should be considered together with those from the project “DuraSeal” (TU Darmstadt, 2015). One of the key aims of this project was to gain an overview of the variation of results from manufacturer to manufacturer. In “DuraSeal”, these variations were excluded because the same manufacturer built all the specimens. Instead, factors like spacer type, amount of butyl, type of secondary sealant, width of secondary seal etc. were varied deliberately, with the aim of establishing functional relationships between the factor settings and the resulting durability of the IGU. Perhaps the results from “DuraSeal” cannot be transferred directly to designs other than those used in the project, but some of the insights will probably be useful for the improvement of IGU manufacturing processes in general.

Furthermore, within the framework of the external quality monitoring (RAL), more triple-pane IGUs should be submitted for durability testing according to EN 1279 (instead of the double-glazed units prescribed by the standard). In the long term, this would build a good source of data for triple-pane IGUs, which could help to improve process quality.

Two more subject areas can be considered for a continuation of this work:

- The influence of the edge load on the gas leakage rate (EN 1279-3) in triple-pane IGUs: The gas content in the interpane space and the gas leakage rate have a considerable effect on the thermal insulation of an IGU and the rate of its decline during normal service life. Gas leakage rate measurements, however, are very time-consuming and expensive.
- The influence of the edge load on the durability of triple-pane IGUs with flexible spacers and integrated desiccants: These systems have a growing proportion of the market. The effort to determine the degree of moisture penetration according to EN 1279-2 (by means of Karl-Fischer titration) is much larger than that for rigid spacer systems with pourable desiccants (by about a factor of 8). Therefore, the number of specimens would probably have to be reduced in comparison to this project. The effort to determine the gas leakage rate would be the same as for rigid systems with pourable desiccants.

4 Acknowledgements

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Note: The listing is in alphabetical order. The manufacturer's numbers (Hersteller-Nr.) used in sections 2.3 and 2.4 of this report have been allocated randomly.

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