Verband Fenster + Fassade

Bundesverband Flachglas

Save more energy with new windows

September 2017 update of the study “In a new light: Energetic modernization of old windows”

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Contents

Foreword

Summary

1. Energetic properties of different window types
2. Modernization potential in Germany
3. Cost-effectiveness of new windows
4. Cost-effectiveness of investing in higher quality rather than replacing with the minimum standard
5. The additional benefits of new windows as a justification for the investment
6. Replacing windows makes sense

Appendix 1 Data on the German window market (1971–2016)
Appendix 2 Explanation of the calculations
Appendix 3 Literature

Foreword

This study of the German window market is the latest in a series of studies published regularly by the VFF since 2002.[1] It contains the latest statistical information from the association and updated calculations of the potential energy savings from replacing old windows in Germany's building stock.[2]

Since the previous study published in Juli 2011 solar gains from the use of transparent building materials are considered in the calculation of the potential for energy savings. Another is that the cost-effectiveness is no longer measured purely on a full cost basis but also based on the additional costs compared to replacement with the minimum quality standard.

As in previous editions, this study divides the existing window stock into types of window. This allows the true energetic quality of the current German window stock to be measured reliably.

The study calculates the cost of saving one kWh, which can then be compared to the cost of energy.

[1] *See VFF (2002), VFF-BF (2005), VFF-BF (2007), VFF-BF (2008), VFF-BF (2010), VFF-BF (2011) and VFF-BF (2014).*
[2] *The study was compiled / revised by Univ.-Prof. Dr.-Ing. Gerd Hauser, Technical University of Munich and Dr. Rolf-Michael Lüking in cooperation with the Window and Façade Association (Verband Fenster + Fassade, VFF) and the Federal Flat Glass Association (Bundesverband Flachglas, BF).*

Summary

Since its inception, the Federal Republic of Germany has witnessed four phases of window construction defined by economic developments and the changes in concepts for thermal insulation. From 1950 to 1978 the market was dominated by single-pane windows and double-glazed windows with two individual panes. The passing of the Insulation Act (Wärmeschutzverordnung, WSchVO) in 1978 meant that more insulation glass windows entered the market. From 1995 low-emissivity coated insulation glass (low-E) gained prominence. Windows with triple insulation glass (2 low-E coatings) were introduced in 2005 and their market share has been growing strongly since 2009.

Fig. 1 Total window stock in Germany

Window stock in Germany 2016		
		Million window units
Type 1	Single-pane windows	17
Type 2	Double-glazed windows	44
Type 3	Uncoated insulation glass windows	205
Type 4	Double-pane insulation glass windows (low-E)	289
Type 5	Triple-pane insulation glass windows (low-E)	55
Gesamt		**610**

Window unit stock (1 WU = 1.3 m x 1.3 m = 1.69 m²). Results rounded. Source: VFF, 2017

Type 1, single-pane windows, of which there are still around 17 million window units according to the VFF and BF, are particularly interesting targets for rapid replacement. Averaged over all construction years, type 1 windows have a very high thermal transmission coefficient (U-value) of 4.7 W/(m²K) or worse. In comparison, type 5 modern triple-pane low-E windows now achieve 1.1 W/(m²K) or less. Replacing single-pane windows would save around 491 kWh, or 49 m³ of natural gas, per window unit each year.[3]

The total energy saving potential through replacing single-pane windows is therefore around 8 billion kilowatt-hours and 1.9 million tonnes of CO_2 per year. Replacing old single-pane windows not only makes environmental sense, it is also very cost effective. The cost of the energy saved by replacing windows, when calculated in kWh, is already less than current energy prices. Partially this is the case for type 3 windows (uncoated insulation glass window) as well. Depending on the continued increase in the cost of energy, the replacement of windows of type 2 also becomes economically viable.
Window replacement costs that are higher than the energy savings achieved still represent an investment in the improvement of the building (for example improvements in comfort, sound-proofing or security; see chapter 5). New windows also increase the value of the property.

[3] *Calculation includes solar gain.*

1. Energetic properties of different window types

The energetic properties of a window are defined by its thermal transmission coefficient (U-value or U-factor) and its solar heat gain (solar factor or g-value). Over the past 50 years, the U-value of windows has improved by around 75%, as the table below illustrates. The lower the coefficient, the better, as heat losses are lower.

Fig. 2 Thermal transmission coefficient and solar factor of windows

ermal transmittance UW and solar factor of the building stock by window type			
Window type	Mainly installed	Average U_W-value in W/(m²K)	Average solar factor in %
1 Single-pane windows	until 1978	4,7	87
2 Double-glazed windows	until 1978	2,4	76
3 Windows with uncoated insulation glass	1978-1995	2,7	76
4 Double-pane insulation glass (low-E)	1995-2008	1,5	60
5 Triple-pane insulation glass (2 x low-E)	since 2005	1,1	50

The figures are averages for the stock from the respective years. The stock consists of windows with frames of different depths and with different insulating properties and of glazing with different thermal transmittance values and solar factors (see table in Appendix 1).
Source: VFF/BF

Modern insulating windows are made of three panes of insulation glass, two of which are coated (so-called low-E glazing). In conjunction with the advanced insulating and sealing technology of the frames, they achieve four times the insulation of single-pane windows. The coatings reduce the solar factor compared to old, poorly insulating glass, which is advantageous in summer but leads to reduced solar heat gain in the winter heating period.

The window stock consists of windows of various sizes, with frames of different depths and constructions. The insulating glass panes have various thermal transmittance values. The calculation of average U_W-values is therefore based on the thermal transmittance values of glass and frame, taking into account the proportions of different glass and frame types (see Appendix 1).

2. Modernization potential in Germany

Besides new construction, the potential for energy savings in existing building stock (residential and commercial) is of particular importance in the context of the current political environmental goals. Three-quarters of the residential housing stock dates from before 1979 (1st Insulation Act (WSchVO)).
This study examines the effects of replacing windows in the residential building stock from an economic point of view as well as in terms of energy savings and CO_2 reducti-

[4] *The units of the thermal transmittance coefficient are W/(m²K). In general, the lower the value, the better the window insulates.*

on. The calculations are based on a replacement of the window types described above by modern windows with triple-pane insulation glass, which have a U_W-value of 0.95 W/(m²K) and a solar factor of 62%.[5]

The potential energy savings are illustrated in detail in the following overview. It shows that replacing single-pane windows is particularly effective as the greatest savings can be achieved.

Fig. 3 Energy saving potential of windows, Germany 2017

Energy saving potential of windows in Germany	**Window types in the building stock**					**Units**
	triple-pane insulation glass	**double-pane insulation glass**	**uncoated insulation glass**	**Double-glazed windows**	**Single-pane windows**	
Window stock in window units WU (1 WU = 1.69 m²)	55	289	205	44	17	million WU
Mainly installed from...to...						
U_W-value to 1978 solar factor					4.7 87	W/(m²K) %
U_W-value to 1978 solar factor				2.4 76		W/(m²K) %
U_W-value 1978-1995 solar factor			2.7 76			W/(m²K) %
U_W-value 1995-2008 (double-pane) solar factor		1.3 -1.8 58 - 63				W/(m²K) %
U_W-value since 2005 (triple-pane) solar factor	0.8 -1.1 45 - 60					W/(m²K) %
With a degree day factor of 75 kKh and an annual usage factor of the heating system of 85% (e_G = 1.2), and including solar gains, **energy savings in kWh per WU (1.69 m²)** of:	Replacement not energetically viable		222	176	491	kWh/ (WU a)
Converted into in **m³ natural gas**			22	18	49	m³/ (WU a)
Energy saving potential in billion kWh			45	8	8	billion kWh
Converted into billion cubic metres natural gas			4.5	0.8	0.8	billion cubic metres natural gas/a
Converted into million tonnes CO_2			10.4	1.8	1.9	million tonnes CO_2/a

Source: Univ.-Prof. Dr.-Ing. Gerd Hauser, Technical University of Munich/Dr. Rolf-Michael Lüking.

[5] The U_W-value was chosen based on the requirements of the KfW for the subsidization of individual measures toward energy-saving renovations. In some cases, glass doors that allow access to the disabled do not achieve the given U_W-value.

3. Cost-effectiveness of new windows

The cost-effectiveness calculations are dynamic annuity calculations that establish the cost of energy savings per kWh, which can then be compared to the expected cost of energy. This comparison determines the cost-effectiveness of a measure: when the cost of the energy saved is lower than that of the energy that would have been purchased, the measure is cost effective.

The calculations result in a price per kilowatt-hour of energy saved (in €/kWh). Assumptions regarding the depreciation period of the investment as well as the interest rate and the rate of inflation are included in this calculation (see appendix 2 for the methodology).

The calculations are based on modern windows made of PVC, wood, wood-aluminium and aluminium, with common, average features and without extra options (e.g. locks, special safety features, electronic controls, window dividing bars etc.). The average market price of a new window was calculated from the weighted average, based on the market share in 2016, of the prices of all frame materials (PVC, wood, wood-aluminium and aluminium). Because aluminium is hardly used in residential buildings, a weighted average excluding aluminium was also calculated. The price calculation included installation costs (without removal and disposal) and VAT (currently 19% in Germany).

Figure 4 shows the average prices for a modern 1.3 m x 1.3 m triple-pane insulation glass window including installation and VAT[6] as well as the resulting cost of the energy saved.

Fig. 4 Cost of energy saved by window replacement (full cost calculation)

<table>
<tr><th colspan="8">Replacement with a window with triple-pane insulation glass
(U_w = 0.95 $W/(m^2K)$ and solar factor = 62%)</th></tr>
<tr><td colspan="3"></td><td colspan="5">Window types in building stock</td></tr>
<tr><td>Frame material</td><td>Market share in %</td><td>Price per window in €</td><td>with triple-pane insulation glass</td><td>with double-pane insulation glass</td><td>with uncoated insulation glass</td><td>Double-glazed windows</td><td>Single-pane windows</td></tr>
<tr><td></td><td></td><td></td><td colspan="5">Cost of energy saved in €/kWh</td></tr>
<tr><td>Wood</td><td>15.0</td><td>638,-</td><td colspan="2" rowspan="6">Replacement not energetically viable</td><td>0.075</td><td>0.095</td><td>0.034</td></tr>
<tr><td>Wood-aluminium</td><td>9.2</td><td>789,-</td><td>0.093</td><td>0.118</td><td>0.042</td></tr>
<tr><td>PVC</td><td>57.8</td><td>479,-</td><td>0.057</td><td>0.071</td><td>0.026</td></tr>
<tr><td>Aluminium</td><td>18.0</td><td>926,-</td><td>0.110</td><td>0.138</td><td>0.049</td></tr>
<tr><td>Weighted average residential windows excluding aluminium</td><td>82.0</td><td>543,-</td><td>0.064</td><td>0.081</td><td>0.029</td></tr>
<tr><td>Weighted average for all window types</td><td>100.0</td><td>612,-</td><td>0.072</td><td>0.091</td><td>0.033</td></tr>
</table>

Source: VFF, average market prices for windows, end 2016,
Univ.-Prof. Dr.-Ing. Gerd Hauser, Technical University of Munich/Dr. Rolf-Michael Lüking.

[6] *Average prices rounded to full euros.*

Replacing old windows of type 1 (single-pane) clearly makes economic sense, as the cost of energy purchased, around 0.070 €/kWh, is already (September 2017) above the cost of the energy savings for all common frame materials.Partially this is the case for type 3 windows (uncoated insulation glass window) as well. Future energy cost developments are usually represented in several scenarios, assuming, for example, annual cost increases of one, two or five percent. In the scenarios with higher cost increases, and assuming a lifetime of 48 years, the replacement of type 2 and 3 window stocks is always economically viable. If other measures are to be carried out on the building shell anyway, such as improving the exterior insulation, it therefore makes sense to also modernize double-glazed windows or replace insulation glass windows without low-E coatings.

However, scenarios that assume such a constant increase in energy costs over such a long period need to be evaluated critically. In a report for the BMVBS[7] (Federal Ministry for Traffic, Building and Urban Development) Dr Feist points out that a price limit will probably be reached when renewable energies achieve price parity [with energy from fossil fuels]. The current study leaves it to the reader to compare the presented cost of a kilowatt-hour of energy saved with possible or expected future energy prices.

4. Cost-effectiveness of investing in higher quality rather than replacing with the minimum standard

So far, the full cost of replacing windows has been presented. A further point of interest is the economic viability of investing in the described high-quality modern windows (U_W-value 0.95 (W/(m²K); solar factor 62%) instead of in a minimum standard window that is being replaced not for energy-saving purposes but for functional reasons (breakage, malfunction, wear and tear). For comparison, the window standard set as the minimum requirement by the Energy Saving Act of 2016: U_W-value 1.3 W/(m²K) is used (in practice this means a double-pane insulation glass window with a solar factor of 60%).

The market price for such a standard window measuring 1.3 x 1.3 m including installation and VAT was calculated as described above and a weighted average price taking into account the market share of the various frame materials was determined.[8]

In replacements for functional reasons, if one opts to invest in a high-quality modern window (U_W-value 0.95 (W/(m²K); solar factor 62%) instead of in the minimum requirement window, the extra cost per window measuring 1.3 m x 1.3 m lies between € 76 and € 82, including installation and VAT, depending on the frame material.

The extra cost for a kilowatt-hour of energy saved is then between 0.033 and 0.036 €/kWh, as shown in figure 5. This is far bellow the level of the current (September 2017) price of energy (around 0.070 €/kWh). In the case of window replacement that is due to take place anyway, deciding to invest in the described high-quality modern windows therefore makes economic sense.

[7] Dr. Feist (2007), p. 20 et seq.
[8] Average prices rounded to full euros, as of end-2016.

Fig. 5 Cost of energy saved compared to a minimum-standard window

Replacement with a window with triple-pane insulation glass (U_w = 0.95 W/(m²K) and solar factor = 62%) instead of with a window according to the minimum requirements of the Energy Saving Act (EnEv) (U_w = 1.3 W/(m²K), solar factor = 60%)					
Frame material	Market share in %	Price per modern window in €	Price per window according to EnEV minimum standards in €	Price difference in €	Cost of extra energy saved in €/kWh
Wood	15.0	638,-	556,-	82,-	0.036
Wood-aluminium	9.2	789,-	711,-	78,-	0.034
PVC	57.8	479,-	403,-	76,-	0.033
Aluminium	18.0	926,-	846,-	80,-	0.035
Weighted average residential windows excluding aluminium	82.0	543,-	466,-	77,-	0.034
Weighted average for all window types	100.0	612,-	534,-	78,-	0.034

5. The additional benefits of new windows as a justification for the investment

It can be seen that the replacement of single-pane windows and, in parts, of uncoated insulation glass windows with high-quality modern windows is cost-effective regard-less of assumptions about future developments in the price of energy. The same holds true for investing more in high-quality windows during planned renovations rather than using windows meeting the minimum requirements of the Energy Saving Act. In both cases, the cost of a kilowatt-hour of saved energy is below the level of the current cost of a kilowatt-hour of energy (around 0.070 €/kWh).

Whether the replacement of existing type 2 windows (double-glazed windows) is also cost-effective depends on assumptions made about future energy costs, as explained above.

This calculation of cost-effectiveness above is limited to the energetic properties of new windows. But high-quality modern windows also achieve a number of other modernizing effects compared to old, existing windows, for example improvements in...

- Comfort (through higher surface temperatures of better insulated glass surfaces[9])
- Ease of operation
- Ease of care (e.g. surfaces)
- Safety
- Sound-proofing

If these effects were quantified, they would certainly improve the cost-effectiveness of window replacement. Such quantification is possible, although it would require making debatable assumptions.

[9] *See BF (2009), p. 14*

Without quantification the cost of the energy savings that exceeds the cost of purchased energy can be viewed as an investment in the improvement of the property. Further motives for replacement are increasing the value of the real estate or its rental value.

6. Replacing windows makes sense

The replacement of old, single-pane windows, while essential from the point of view of environmental politics, is becoming increasingly important for every owner of a house, an apartment or commercial real estate for economic reasons.

For windows dating from before 1995 with frames and seals still in good condition, replacing the uncoated insulating glass with modern low-E insulation glass is an interesting option. Generally the replacement will be with double-pane insulation glass because the mounting slots in the existing frames are not wide enough for triple-pane insulation glass.

The various attractive subsidies provided by the German federal government – for instance the KfW-CO_2 building renovation programme – are very helpful when renovating a building for energetic reasons. Increasing and expanding such incentives, in particular tax deductions for renovations for energetic purposes, would help to achieve the necessary savings in energy use and the environmental protection aims.

Windows produced in Germany* U-value, as of 09-2017			1971	1972	1973	1974	1975	1976	1977
Window market production figures									
Wood	In millions of units,		5,6	6,8	7,0	7,6	7,0	6,7	6,4
PVC	1 unit = 1.69 m^2		1,0	1,3	1,7	2,0	2,5	3,0	3,6
Aluminium			5,7	6,3	6,1	6,0	5,5	4,9	5,1
Wood-aluminium			0,0	0,0	0,0	0,0	0,0	0,0	0,0
Total market			**12,3**	**14,4**	**14,8**	**15,6**	**15,0**	**14,6**	**15,1**
*Source: VFF (totals rounded)									
Market share of glass types									
Single-pane glass		U_g = 5.8 W/(m^{2}K)	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%
Double-glazed windows		U_g = 2.8 W/(m^{2}K)	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%
Insulation glass 4/12/4 (uncoated)		U_g = 2.8 W/(m^{2}K)							
2-pane insulation glass 1st generation		U_g = 1.4 W/(m^{2}K)							
2-pane insulation glass 2nd generation		U_g = 1.2 W/(m^{2}K)							
2-pane insulation glass 3rd generation		U_g = 1.1 W/(m^{2}K)							
3-pane insulation glass		$U_g \leq$ 0.8 W/(m^{2}K)							
Glass types in m^2 (millions)									
Single-pane glass			4,4	5,1	5,3	5,5	5,3	5,2	5,4
Double-glazed windows			10,2	11,9	12,3	12,9	12,4	12,1	12,5
Insulation glass 4/12/4 (uncoated)			0,0	0,0	0,0	0,0	0,0	0,0	0,0
2-pane insulation glass 1st generation			0,0	0,0	0,0	0,0	0,0	0,0	0,0
2-pane insulation glass 2nd generation			0,0	0,0	0,0	0,0	0,0	0,0	0,0
2-pane insulation glass 3rd generation									
3-pane insulation glass									
Proportion of windows with "warm edge" technology (Psi-value of 0.06 W/mK)									
	Av. U_g-value	**W/(m^{2}K)**	**3,7**	**3,7**	**3,7**	**3,7**	**3,7**	**3,7**	**3,7**
U-value for frame types									
Wood single-pane window (hardwood)		U_f = 1.9 W/(m^{2}K)	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%
Wood single-pane window (softwood)		U_f = 1.5 W/(m^{2}K)	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Wood double-glazed window (hardwood)		U_f = 1.4 W/(m^{2}K)	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%
Wood single-pane window (type 1)		U_f = 1.1 W/(m^{2}K)							
Wood single-pane window (type 2)		$U_f \leq$ 1.0 W/(m^{2}K)							
	Av. U_f-value	**W/(m^{2}K)**	**1,6**	**1,6**	**1,6**	**1,6**	**1,6**	**1,6**	**1,6**
PVC window 2 chambers		U_f = 2.2 W/(m^{2}K)	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
PVC window 3 chambers		U_f = 1.8 W/(m^{2}K)							
PVC window multi-chambers (type 1)		U_f = 1.4 W/(m^{2}K)							
PVC window multi-chambers (type 2)		U_f = 1.1 W/(m^{2}K)							
PVC window multi-chambers (type 3)		$U_f \leq$ 1.0 W/(m^{2}K)							
	Av. U_f-value	**W/(m^{2}K)**	**2,2**	**2,2**	**2,2**	**2,2**	**2,2**	**2,2**	**2,2**
Aluminium window frame material group 3		U_f = 7.0 W/(m^{2}K)	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
Aluminium window frame material group 2.3		U_f = 5.0 W/(m^{2}K)							
Aluminium window frame material group 2.2		U_f = 3.8 W/(m^{2}K)							
Aluminium window frame material group 2.1		U_f = 3.0 W/(m^{2}K)							
Aluminium window frame material group 1		U_f = 2.2 W/(m^{2}K)							
Aluminium window today (type 1)		U_f = 1.9 W/(m^{2}K)							
Aluminium window today (type 2)		U_f = 1.4 W/(m^{2}K)							
Aluminium window today (type 3)		U_f = 1.1 W/(m^{2}K)							
Aluminium window today (type 4)		$U_f \leq$ 1.0 W/(m^{2}K)							
	Av. U_f-value	**W/(m^{2}K)**	**7,0**	**7,0**	**7,0**	**7,0**	**7,0**	**7,0**	**7,0**
Wood-metal window (type 1)		U_f = 1.7 W/(m^{2}K)	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
Wood-metal window (type 2)		U_f = 1.3 W/(m^{2}K)							
Wood-metal window (type 3)		U_f = 1.1 W/(m^{2}K)							
Wood-metal window (type 4)		$U_f \leq$ 1.0 W/(m^{2}K)							
	Av. U_f-value	**W/(m^{2}K)**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**
All window frame materials	**Av. U_f-value**	**W/(m^{2}K)**	**4,1**	**4,0**	**3,9**	**3,7**	**3,7**	**3,5**	**3,5**
Average U_w-value all windows acc. to table		**W/(m^{2}K)**	**3,8**	**3,8**	**3,8**	**3,7**	**3,7**	**3,6**	**3,7**
Average U_w-value 1971 – 1978							**3,7**		
Average U_w-value 1979 – 1994									
Average U_w-value 1995 - 2001									
Average U_w-value 2001 - 2007									
Average U_w-value 2008 - 2016	**(current state of technology)**								

Calculation of the Uw-value according to DIN EN ISO 10 077 Part 1
Calculation of the glass quantity according to DIN EN ISO 14351-1

1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
6,3	7,0	7,1	6,2	5,5	5,3	5,5	5,2	5,1	5,3	5,4	6,6	7,3	7,3	7,6	8,0
4,2	5,5	6,3	5,7	5,2	5,0	4,9	5,1	5,4	5,5	5,3	5,7	6,6	8,5	9,3	10,0
4,8	5,0	4,7	3,2	2,7	2,3	2,3	2,1	2,7	3,1	3,5	3,8	4,2	4,4	4,7	4,8
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,2	0,2	1,0	0,4	0,5	0,7	0,6
15,3	**17,5**	**18,1**	**15,1**	**13,4**	**12,6**	**12,7**	**12,4**	**13,3**	**14,1**	**14,4**	**17,1**	**18,5**	**20,7**	**22,3**	**23,4**
20,0%	0,0%														
70,0%	5,0%														
10,0%	95,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	90,0%	89,0%	88,0%	83,0%
												10,0%	11,0%	12,0%	17,0%
3,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12,7	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1,8	19,7	21,4	17,9	15,9	14,9	15,0	14,7	15,7	16,7	17,0	20,2	19,7	21,8	23,2	23,0
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	2,2	2,7	3,2	4,7
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3,4	**2,8**	**2,8**	**2,8**	**2,8**	**2,8**	**2,8**	**2,8**	**2,8**	**2,8**	**2,8**	**2,8**	**2,7**	**2,6**	**2,6**	**2,6**
30,0%	95,0%	100,0%	80,0%	80,0%	80,0%	80,0%	80,0%	80,0%	80,0%	80,0%	80,0%	80,0%	80,0%	60,0%	60,0%
0,0%	0,0%	0,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	40,0%	40,0%
70,0%	5,0%														
1,6	**1,9**	**1,9**	**1,8**	**1,8**	**1,8**	**1,8**	**1,8**	**1,8**	**1,8**	**1,8**	**1,8**	**1,8**	**1,8**	**1,7**	**1,7**
100,0%	100,0%	100,0%	100,0%	100,0%	90,0%	80,0%	70,0%	60,0%	50,0%	40,0%	30,0%	20,0%	10,0%		
					10,0%	20,0%	30,0%	40,0%	50,0%	60,0%	70,0%	80,0%	90,0%	95,0%	90,0%
														5,0%	10,0%
2,2	**2,2**	**2,2**	**2,2**	**2,2**	**2,2**	**2,1**	**2,1**	**2,0**	**2,0**	**2,0**	**1,9**	**1,9**	**1,8**	**1,8**	**1,8**
100,0%	90,0%														
	10,0%	100,0%	100,0%	90,0%	70,0%	50,0%	30,0%	10,0%							
				10,0%	30,0%	50,0%	70,0%	90,0%							
									100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
7,0	**6,8**	**5,0**	**5,0**	**4,9**	**4,6**	**4,4**	**4,2**	**3,9**	**3,0**	**3,0**	**3,0**	**3,0**	**3,0**	**3,0**	**3,0**
100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
1,7	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**
3,4	**3,4**	**2,8**	**2,6**	**2,6**	**2,5**	**2,4**	**2,3**	**2,3**	**2,1**	**2,2**	**2,1**	**2,1**	**2,1**	**2,0**	**2,0**
3,4	**3,0**	**3,0**	**3,0**	**2,9**	**2,9**	**2,9**	**2,9**	**2,9**	**2,8**	**2,8**	**2,8**	**2,7**	**2,7**	**2,6**	**2,6**
							2,8								

* *Figures up to 1990 for West Germany*

Windows produced in Germany* U-value, as of 09-2017		1994	1995	1996	1997	1998	1999	2000
Window market production figures								
Wood	In millions of units,	7,6	7,4	6,8	6,5	5,9	5,4	4,6
PVC	1 unit = 1.69 m²	11,7	12,3	12,1	12,6	12,1	12,1	10,7
Aluminium		5,2	5,2	5,1	4,4	3,9	3,5	3,5
Wood-aluminium		0,7	0,7	0,8	0,8	0,8	0,8	0,8
Total market		**25,2**	**25,5**	**24,7**	**24,3**	**22,6**	**21,8**	**19,5**
*Source: VFF (totals rounded)								
Market share of glass types								
Single-pane glass	$U_g = 5.8$ W/(m²K)							
Double-glazed windows	$U_g = 2.8$ W/(m²K)							
Insulation glass 4/12/4 (uncoated)	$U_g = 2.8$ W/(m²K)	66,0%	41,0%	20,0%	17,0%	15,0%	9,0%	5,0%
2-pane insulation glass 1st generation	$U_g = 1.4$ W/(m²K)	34,0%	59,0%	80,0%	83,0%	85,0%	45,0%	30,0%
2-pane insulation glass 2nd generation	$U_g = 1.2$ W/(m²K)						46,0%	65,0%
2-pane insulation glass 3rd generation	$U_g = 1.1$ W/(m²K)							
3-pane insulation glass	$U_g \leq 0.8$ W/(m²K)							
Glass types in m² (millions)								
Single-pane glass		0,0	0,0	0,0	0,0	0,0	0,0	0,0
Double-glazed windows		0,0	0,0	0,0	0,0	0,0	0,0	0,0
Insulation glass 4/12/4 (uncoated)		19,7	12,4	5,8	4,9	4,0	2,3	1,2
2-pane insulation glass 1st generation		10,1	17,8	23,4	23,9	22,7	11,6	6,9
2-pane insulation glass 2nd generation		0,0	0,0	0,0	0,0	0,0	11,9	15,0
2-pane insulation glass 3rd generation								
3-pane insulation glass								
Proportion of windows with "warm edge" technology (Psi-value of 0.06 W/mK)								
	Av. U_g-value W/(m²K)	**2,3**	**2,0**	**1,7**	**1,6**	**1,6**	**1,4**	**1,3**
U-value for frame types								
Wood single-pane window (hardwood)	$U_f = 1.9$ W/(m²K)	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	40,0%
Wood single-pane window (softwood)	$U_f = 1.5$ W/(m²K)	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	60,0%
Wood double-glazed window (hardwood)	$U_f = 1.4$ W/(m²K)							
Wood single-pane window (type 1)	$U_f = 1.1$ W/(m²K)							
Wood single-pane window (type 2)	$U_f \leq 1.0$ W/(m²K)							
	Av. U_f-value W/(m²K)	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**
PVC window 2 chambers	$U_f = 2.2$ W/(m²K)							
PVC window 3 chambers	$U_f = 1.8$ W/(m²K)	85,0%	80,0%	70,0%	60,0%	50,0%	40,0%	30,0%
PVC window multi-chambers (type 1)	$U_f = 1.4$ W/(m²K)	15,0%	20,0%	30,0%	40,0%	50,0%	60,0%	70,0%
PVC window multi-chambers (type 2)	$U_f = 1.1$ W/(m²K)							
PVC window multi-chambers (type 3)	$U_f \leq 1.0$ W/(m²K)							
	Av. U_f-value W/(m²K)	**1,7**	**1,7**	**1,7**	**1,6**	**1,6**	**1,6**	**1,5**
Aluminium window frame material group 3	$U_f = 7.0$ W/(m²K)							
Aluminium window frame material group 2.3	$U_f = 5.0$ W/(m²K)							
Aluminium window frame material group 2.2	$U_f = 3.8$ W/(m²K)							
Aluminium window frame material group 2.1	$U_f = 3.0$ W/(m²K)	100,0%	100,0%	95,0%	90,0%	85,0%	80,0%	70,0%
Aluminium window frame material group 1	$U_f = 2.2$ W/(m²K)		0,0%	5,0%	10,0%	15,0%	20,0%	30,0%
Aluminium window today (type 1)	$U_f = 1.9$ W/(m²K)							
Aluminium window today (type 2)	$U_f = 1.4$ W/(m²K)							
Aluminium window today (type 3)	$U_f = 1.1$ W/(m²K)							
Aluminium window today (type 4)	$U_f \leq 1.0$ W/(m²K)							
	Av. U_f-value W/(m²K)	**3,0**	**3,0**	**3,0**	**2,9**	**2,9**	**2,8**	**2,8**
Wood-metal window (type 1)	$U_f = 1.7$ W/(m²K)	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
Wood-metal window (type 2)	$U_f = 1.3$ W/(m²K)							
Wood-metal window (type 3)	$U_f = 1.1$ W/(m²K)							
Wood-metal window (type 4)	$U_f \leq 1.0$ W/(m²K)							
	Av. U_f-value W/(m²K)	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**
All window frame materials	**Av. U_f-value W/(m²K)**	**2,0**	**2,0**	**2,0**	**1,9**	**1,9**	**1,8**	**1,8**
Average U_w-value all windows acc. to table	**W/(m²K)**	**2,4**	**2,2**	**2,0**	**1,9**	**1,9**	**1,7**	**1,7**
Average U_w-value 1971 – 1978								
Average U_w-value 1979 – 1994								
Average U_w-value 1995 - 2001						**1,9**		
Average U_w-value 2001 - 2007								
Average U_w-value 2008 - 2016	**(current state of technology)**							

** Figures up to 1990 for West Germany*

2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
3,5	3,5	2,8	2,8	2,3	2,5	2,1	2,0	2,1	2,1	2,1	2,1	2,1	2,0	2,0	2,1
8,6	8,1	7,2	7,2	6,5	7,2	6,4	6,4	6,8	7,1	7,4	7,5	7,6	7,7	7,7	8,0
3,1	2,6	2,6	2,4	2,2	2,3	2,4	2,5	2,4	2,4	2,4	2,4	2,4	2,4	2,4	2,5
0,7	0,6	0,6	0,6	0,6	0,6	0,7	0,8	0,8	0,8	0,9	1,0	1,1	1,2	1,2	1,2
16,0	**14,7**	**13,2**	**13,1**	**11,6**	**12,6**	**11,6**	**11,7**	**12,1**	**12,5**	**12,9**	**13,0**	**13,1**	**13,4**	**13,4**	**13,8**
5,0%	4,0%														
20,0%	6,0%														
75,0%	90,0%	100,0%	90,0%	75,0%	26,0%	10,0%									
			10,0%	20,0%	65,0%	80,0%	85,0%	75,0%	60,0%	55,0%	50,0%	45,0%	44,0%	42,0%	41,0%
				5,0%	9,0%	10,0%	15,0%	25,0%	40,0%	45,0%	50,0%	55,0%	56,0%	58,0%	59,0%
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,9	0,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3,8	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
14,2	15,7	15,7	13,9	10,3	3,9	1,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
			1,5	2,7	9,7	11,0	11,8	10,7	8,9	8,4	7,7	7,0	7,0	6,7	6,7
				0,7	1,3	1,4	2,1	3,6	5,9	6,9	7,7	8,5	8,9	9,2	9,6
						3%	8%	16%	30%	40%	50%	55%	58%	62%	63%
1,3	**1,3**	**1,2**	**1,2**	**1,2**	**1,1**	**1,1**	**1,0**	**1,0**	**0,9**	**0,9**	**0,9**	**0,9**	**0,9**	**0,9**	**0,9**
40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	30,0%	25,0%	10,0%						
60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	65,0%	60,0%	74,0%	84,0%	84,0%	84,0%	80,0%	76,0%	74,0%
													4,0%	8,0%	10,0%
							5,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%
								5,0%	6,0%	6,0%	6,0%	6,0%	6,0%	6,0%	6,0%
1,7	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,6**	**1,5**	**1,5**	**1,4**	**1,4**	**1,4**	**1,4**	**1,4**	**1,4**
20,0%	10,0%	5,0%	5,0%												
80,0%	90,0%	95,0%	95,0%	100,0%	100,0%	100,0%	95,0%	88,0%	60,0%	55,0%	51,0%	48,0%	46,0%	45,0%	44,0%
							5,0%	8,0%	32,0%	35,0%	40,0%	41,0%	45,0%	46,0%	47,0%
								4,0%	8,0%	8,0%	9,0%	9,0%	9,0%	9,0%	9,0%
1,5	**1,4**	**1,4**	**1,4**	**1,4**	**1,4**	**1,4**	**1,4**	**1,4**	**1,3**	**1,2**	**1,2**	**1,2**	**1,2**	**1,2**	**1,2**
65,0%	45,0%	30,0%	15,0%												
35,0%	50,0%	55,0%	65,0%	50,0%	30,0%	30,0%	24,0%	14,0%							
	5,0%	15,0%	20,0%	50,0%	70,0%	70,0%	70,0%	70,0%	70,0%	50,0%	40,0%	10,0%	5,0%		
							5,0%	10,0%	22,0%	39,0%	46,0%	74,0%	82,0%	84,0%	84,0%
							1,0%	5,0%	7,0%	10,0%	13,0%	15,0%	12,0%	15,0%	15,0%
								1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%
2,7	**2,5**	**2,4**	**2,3**	**2,1**	**2,0**	**2,0**	**1,9**	**1,8**	**1,7**	**1,6**	**1,6**	**1,4**	**1,4**	**1,4**	**1,4**
100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	86,0%	69,0%	38,0%	25,0%	15,0%				
							10,0%	20,0%	44,0%	53,0%	59,0%	70,0%	68,0%	67,0%	66,0%
							4,0%	8,0%	12,0%	15,0%	18,0%	20,0%	22,0%	23,0%	24,0%
								3,0%	6,0%	7,0%	9,0%	10,0%	10,0%	10,0%	10,0%
1,7	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,7**	**1,6**	**1,5**	**1,4**	**1,3**	**1,3**	**1,2**	**1,2**	**1,2**	**1,2**
1,8	**1,7**	**1,7**	**1,6**	**1,6**	**1,6**	**1,6**	**1,6**	**1,5**	**1,4**	**1,3**	**1,3**	**1,3**	**1,3**	**1,3**	**1,3**
1,7	**1,6**	**1,5**	**1,5**	**1,5**	**1,4**	**1,4**	**1,4**	**1,3**	**1,3**	**1,2**	**1,2**	**1,2**	**1,2**	**1,2**	**1,2**
			1,5												
									1,3					**1,2**	

Explanation of the calculations

a) Assumptions on heating period and total solar radiation

- Heating period according to DIN 4108-2; degree-day factor 75 kKh (assumption for a partially renovated building: current values of the specific CO_2 emissions of the considered energy sources according to GEMIS 4.5)
- Calculation methodology: heating period balance method according to EnEV 2007: annual heating requirement: $Q_h = F_{GT} * (H_T + H_V) - \eta_{HP}(Q_s + Q_i)$ [kWh/a]
- The useful heat gains (Q_s) from solar radiation are dependent on window orientation and are derived from the total solar radiation (Is,HP) during the heating period, taking into account reduction factors such as the frame (30% of the window) and dirt and shading per m² window surface $Q_s = 0.567 * I_{s,HP}$
- Degree of use of heat gain $\eta_{HP} = 0.9$
- Average value of total solar radiation in the heating period per square metre of window surface facing north, south, east and west: $I_{s,HP,average} = 306$ kWh/(m²a)

b) Assumptions about heating systems

- Equipped with low-temperature or condensing boilers: ratio of primary energy to domestic energy consumption 1.20
- The reduction of heating requirements due to window replacement yields a reduction in heating energy needs as follows:
  $\Delta Q_E = 1.2 * \Delta Q_h = 1.2 * (F_{GT} * \Delta U_W - \Delta g * \eta_{HP} * Q_s)$ [kWh/(m2window surface a)]
- energy source for heating: natural gas with a specific CO_2 emission of 0.228 kg/(kWh) GEMIS 4.95

c) Basis of the cost-effectiveness calculation

- The cost of energy saved (P_{Ein} in €/kWh) s derived from the energy saved (ΔQ_E) and the annuity costs (K) of the investment: $P_{Ein} = K/\Delta Q_E$
- The annuity costs of the measure are the product of the annuity factor a and the investment costs I: K = a * I
- The annuity factor a depends on the real interest rate p and the lifetime n of the investment according to this formula: $a = p/(1-(1+p)^{-n})$
- Nominal interest rate $p_N = 2.5$ %
- Rate of inflation i = 1.5 %
- Lifetime n = 48 years
- Resulting effective interest rate p = 0.99 %

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