IEA ECBCS Annex 36: Retrofitting in Educational Buildings –
Energy Concept Adviser for Technical Retrofit Measures

SUBTASK A
Overview of Retrofitting Measures

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December 2003

Chapter 2

Building Envelope

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2.2. Windows

2.2.1. Introduction

In the following paragraphs the present state of windows is reviewed with emphasis on energy conditions, while special products like solar protection glazing and security glazing are not described. Finally, topical research areas are outlined.
In terms of energy, windows occupy a special position compared with other thermal envelope structures this is due to their many functions: 1) Windows let daylight into the building and provide residents with visual contact with their surroundings, 2) Windows protect against the outdoor climate and 3) Windows transmit solar energy that may contribute to a reduction of energy consumption, but which may also lead to unpleasant overheating.
Windows are still the least insulating part of the thermal envelope with a heat loss coefficient, a U-value, which is typically 4-10 times higher than that of other thermal envelope elements. At one time this led to the use of very small window areas at the expense of the natural daylight level, but concurrently with development of improved insulating glazing**,** the size of typical window areas has increased again.
In the following sections the present state of windows is reviewed with emphasis on energy conditions, while special products like solar protection glazing and security glazing are not described. The final section in this area outlines topical research areas.

2.2.2. Sealed units

<u>Low-emissivity coatings</u>
Sealed glazed units are built up of two or more layers of glass that are joined together at the edge with a spacer that ensures the desired distance between the panes of glass and an almost airtight and moisture proof sealing of the cavity between the glass layers.
Heat transmission in a sealed glazed unit occurs by means of conduction and convection in the cavity and by radiation from the warm glass to the cold glass. In an ordinary double-glazed unit heat transmission by radiation accounts for approximately 2/3 of the total heat transmission between glass layers**.** Therefore research and development (R&D) has primarily been aimed at reducing heat transmission by radiation through low-emission (lowE) coating on one or more glass surfaces. A lowE coating consists of a very thin metallic film that is almost 100% transparent to solar radiation (short-wave radiation). However, the film will radiate only very little heat (long-wave radiation) therefore reducing heat transmission caused by radiation.
Two different kinds of coating exist: 'hard' and 'soft' coatings which are two different methods of applying the coating. The hard coatings are added during production of the glass and are resistant to exterior impacts (thus the name 'hard'), but soft coatings are applied to the finished glass in a vacuum chamber. The latter type of coating is attacked by ordinary humid, atmospheric, conditions in air and is destroyed by mechanical impacts, which is the reason why soft coatings should always face a dry sealed cavity.
The coatings influence the light transmittance and solar energy transmittance of glass as a major amount of short wave radiation is absorbed. This means that the coated glass is heated through solar radiation more than ordinary glass. Therefore lowE coatings should not be applied on layers in between multi-glazed units, as the temperature of the glass can become very high and lead to thermal fractures in the pane. Sunlight refers to the wavelength of the area for visible light while solar energy, in principle, refers to the whole wavelength area covered by solar radiation.

Table 2.1. Typical values for a sealed, argon-filled double-glazed unit coated on the inner pane, depending on the type of coating. Glass distance is 15 mm.

Type of coating	Emissivity	Solar transmission	Solar heat gain	Centre U-value
Hard	0.35	0.73	0.66	1.9
	0.12	0.76	0.64	1.4
Soft	0.09	0.77	0.54	1.3
	0.04	0.75	0.47	1.1

Table 2.1 shows that it is impossible with hard coating to obtain emissivity as low as when using soft coatings. On the other hand the transmittance of light and solar energy is higher.

<u>Gas fillings</u>

The application of lowE coatings reduces heat transmission in connection with radiation by up to approximately 90% and thereby the heat transmission and convection in the sealed cavity become dominate. Heat transmission and convection depend on the glass distance and gas.

By combining several layers of glass, lowE coatings and insulating gases it is possible to construct glazing with a very low U-value, but for every layer of glass and every coating, light transmittance and solar energy transmittance is significantly reduced. For example, by using a triple-glazed unit with 2 lowE coatings and krypton filling a U-value of 0.45 W/(m^2 K) is obtained, but a direct solar energy of only 0.29.

<u>Edge sealing</u>

Traditional the spacer, a part of the edge sealing of the pane, consists of a metal profile of 0.4 mm aluminium or galvanised steel, separated from the glass surfaces only by an approximately 0.3 mm butyl joint. Metal is completely diffusion-resistant against gas and water vapour, while diffusion through the butyl joint is reduced to an almost negligible level owing to the very small cross-section area of the joint and the high diffusion resistance of the butyl mass.

Because of the metal profile, the edge sealing forms a pronounced thermal bridge in relation to the rest of the pane. The thermal bridge is important for surface temperatures at distances of approximately 0.10 m, calculated from the pane edge, to the pane centre. The importance of the thermal bridge for the total U-value of the pane depends on the shape and size of the pane, but typically it gives a U-value for the whole pane that is 5-10% higher than the U-value at the centre of the pane.

USA and Canada are far ahead in the use of other types of spacers based on butyl and silicone foam. The metal profile is replaced by a metallized plastic film thereby reducing the thermal bridge significantly. These new types of spacers have not become popular in Denmark, primarily because of the price, but also because they require introduction of new production technology. However, a few manufacturers offer to supply windows with insulating spacers in the glazed units - typically in cases, where there is an increased risk of condensation. Another possibility of reducing the thermal bridge is by using spacers of stainless steel with a material thickness of approximately 0.15 mm. This type of spacer will not require introduction of new technology and will lead to a reduction of the thermal bridge that approaches the level of non-metals.

2.2.3. Frame constructions

Frame constructions are traditionally made of wood, which is easy to work and has a relatively low thermal conductivity. Wooden windows still make up the major part of the market, but high maintenance costs have brought about the development of plastic and aluminium windows with minimal maintenance costs. Plastic windows insulate less than wooden windows partly because of an inserted metal profile, which is necessary for reasons of strength. For aluminium windows, the exterior and the interior parts of the construction are required to be thermally separated, eg by means of a disruption made of plastic, but the U-value is significantly higher than for wooden windows.

A combination in ever-wider use is the wooden window provided with an externally ventilated aluminium profile combining the low maintenance costs with the good insulating properties of wooden windows.

New frame constructions have been developed that are made of unbroken insulating material such as PU foam covered with aluminium. The insulating properties of the construction are somewhat better than those of a traditional wooden construction, but a commercially accessible frame construction that significantly improves the insulating properties is not yet available.

The U-values for typical frame constructions is approx. 1.4 - 2.0 W/(m^2 K) and are significantly higher than the centre U-value of the most frequently used double-glazed, coated and filled units. As the frame construction often constitutes a large part of the total window area, the higher U-value has a noticeable effect on the U-value of the whole window.

In connection with Danish participation in IEA Task 13 Solar Heating and Cooling Programme - Advanced Solar Low Energy Houses detailed analyses of the total U-value as a function of size and insulating properties of the frame area were performed (fig. 2.1).

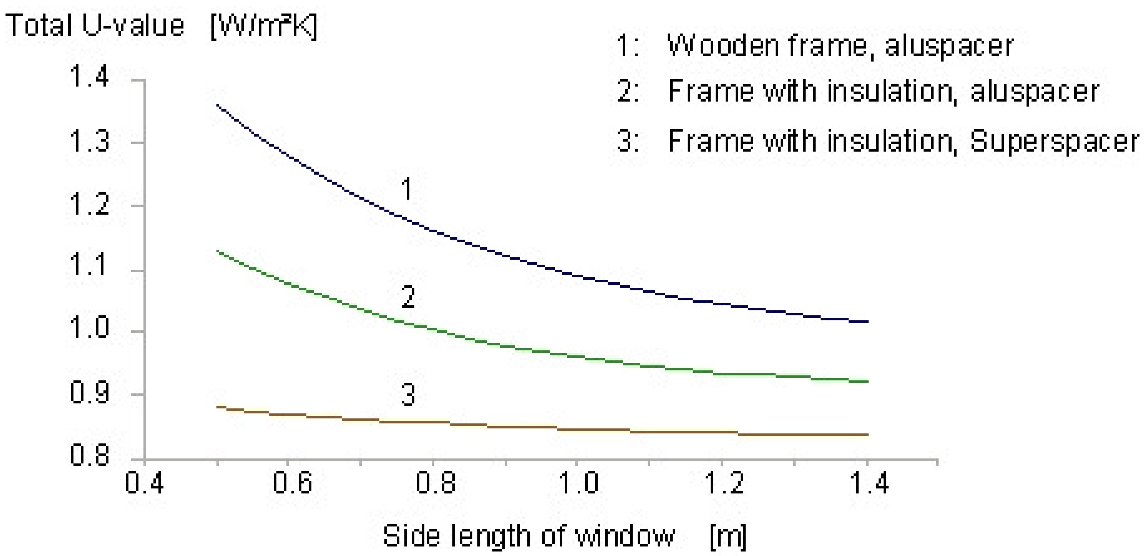

Figure 2.1. Total U-value calculated from a square window with triple glazed, coated and filled units (centre U-value = 0.85 W/(m^2 K)) as a function of the size of the window. Calculations are made with a traditional frame construction of wood (U = 1.6 W/(m^2 K)) and a wooden frame construction with a built-in insulating layer (U = 0.8 W/(m^2 K)) and two different spacers.

An alternative to using improved insulating frame constructions is a minimising of frame dimensions which will lead to lower total U-value for the window if the frame U-value is not changed, but it will also lead to a larger transparent area resulting in added light and solar heat gain in the dwelling.

2.2.4. U-value / g-value

As previously mentioned, the heat loss coefficient of a window is significantly higher than that of other thermal envelope constructions, but at the same time the window allows solar energy to pass through which might be advantageous for the dwelling. The two properties are named the U-value and the g-value, respectively.
In Denmark the U-value is calculated as the weighting of the area of the U-values of the glazed unit and the U-value of the frame construction plus an additional value for the thermal bridge conditions along the perimeter of the glazed unit. This additional value is calculated as the product of the circumference of the pane and the linear transmission coefficient Ψ_g that expresses the extra heat loss per metre edge.
The g-value is a measure of how much of the solar energy that penetrates the exterior of the window and is transmitted to the space behind. This is called total solar energy transmittance. Total solar transmittance contributes with: 1) Direct solar transmittance, and 2) Indirect solar transmittance. The indirect contribution originates from the heating of the glass panes because solar energy is absorbed in the glass and from possible coatings. Part of the absorbed heat will be transmitted to the space behind by means of radiation and convection and thus contributes to covering the heat loss. Therefore the total solar transmittance is higher than the direct solar transmittance.
The concept 'g-value' is used both for glazing and for the finished window and it is important to know which of the two the g-value is referring to. The g-value for a window will typically be much smaller than for the glazing as the frame area does not transmit solar energy, see table 2.2.
For well-insulated glazing, the narrow and less insulating frame construction means that the total U-value is lower than in traditional and better insulating wooden frames because of its larger glass area.

Table 2.2. Examples of various combinations of frame construction and types of panes and their significance for the total U-value and g-value. The exterior measurements are 1 x 1 m^2. The linear transmission coefficient is 0.6 W/(m K).

Frame height	Frame area	Glass area	Pane circumference	Centre U-value	Frame U-value	Total U-value	g-value pane	g-value window
mm	m^2	m^2	m	$W/(m^2 K)$	$W/(m^2 K)$	$W/(m^2 K)$	-	-
110	0.39	0.61	3.12	1.4	1.6	1.66	0.64	0.39
110	0.39	0.61	3.12	1.1	1.6	1.48	0.59	0.36
110	0.39	0.61	3.12	0.45	1.6	1.09	0.39	0.24
55	0.21	0.79	3.56	1.4	2.0	1.74	0.64	0.51
55	0.21	0.79	3.56	1.1	2.0	1.5	0.59	0.47
55	0.21	0.79	3.56	0.45	2.0	0.99	0.39	0.31

However, it is not clear how the U- and g-values should be weighted in relation to each other, as other conditions may be used for determining for the actual choice of glass construction for example the orientation of the window, shading conditions, the thermal mass of the building, internal heat load. In each case an assessment/calculation should be made to find the optimum choice of window in terms of energy.

2.2.5. An overview of existing window solutions

Windows are built up of a number of components (glass type, gas filling, spacer, frame) that can be combined so that in each case the window meets the requirements made to insulating properties, daylight conditions, solar shading, noise reduction etc

Table 2.3 lists typical values for panes for windows. The table includes some solar protection glazing to illustrate the possibilities for limiting solar heat gain.

Well-insulated pane types, ie panes with a centre U-value of less than approximately 1 W/(m^2 K)), present an aesthetic problem of condensation on the exterior of the pane. Condensation is primarily present on clear, silent nights but will start to disappear late in the morning or towards noon. Time will show how much this will influence the user's opinion of well-insulated windows.

Today most window glazing manufacturers use 0.4 mm galvanised steel for spacers but in a few cases insulating spacers are used, primarily to avoid condensation on the interior of the pane, while the energy aspect rarely leads to the use of improved spacers.

In the field of frames practically no developments have occurred towards improving insulating constructions, this is due to the main efforts of the manufacturer’s focus on a reduction of maintenance costs. Narrow frame constructions are marketed with a frame height of approximately half of what is found in traditional windows. In contrast the U-value is a considerably higher but this is partly compensated for by a smaller frame area.

Table 2.3. Overview of the most typical values for commercially available types of window panes. The window pane is described by 4-15-*4, for example, which indicates a double glazed unit with a glass thickness of 4 mm and a glass distance of 15 mm and a coating on the inner glass.

Description	Emissivity	Centre U-value			Light transmission	g-value
		Air	Argon	Krypton		
	-	W/(m^2 K)	W/(m^2 K)	W/(m^2 K)	-	-
4-12-4	-	2.9	2.7	2.6	0.82	0.76
4-12-*4	0.09	1.8	1.4	1.2	0.77	0.66
4-15-*4	0.12	1.7	1.4	1.4	0.75	0.71
4-15-*4	0.09	1.6	1.3	1.2	0.77	0.66
4-15-*4	0.04	1.4	1.1	1.0	0.75	0.59
4-12-4-12-*4	0.09	1.4	1.1	0.9	0.70	0.59
*4-12-4-12-*4	0.09	1.0	0.8	0.6	0.66	0.48
*4-12-4-12-*4	0.04	0.9	0.7	0.4	0.62	0.40
*4-12-4 solar shading	0.09	1.8	1.4	1.2	0.56	0.46
*4-12-4 solar shading	0.04	1.6	1.3	1.0	0.65	0.44

2.2.6. Research and development

In Denmark research concerning window centres has concentrated on the development of new superinsulating glazing, improved insulation of frame constructions and increased g-value of the windows.

Superinsulating glazing

1. Vacuum glazing is a double sealed unit where the sealed cavity is evacuated to a pressure below 10^{-7} atm causing all heat transmission and convection to stop. In order that the outer atmospheric pressure does not cause the glazed unit to collapse, a number of small supports are evenly distributed between the two glass layers. The supports are visible at close range.
   The vacuum pane is very thin, the glass distance is only approximately 0.2 mm, which makes this pane suitable for replacement by single window panes. The theoretical centre U-values is approx. 0.3 W/(m^2 K), but because of the spacers the real centre U-value will also be about 0.5 W/(m^2 K). The g-value will be 0.6 because of the two coatings. The edge sealing must be 100% air tight; which causes a significant thermal bridge along the perimeter of the pane.

2. Aerogel units are double-glazed sealed units where the cavity between the layers is filled with monolithic silica aerogel and evacuated under a pressure of approx. 10^{-3} atm. Aerogel is a porous material with open pores making up 90% of its volume. The fine pore structure breaks the transmission and convection in the air at an almost vacuum while at the same time making the material impenetrable to heat radiation. Aerogel has a pressure strength that can withstand the load from the outer atmospheric pressure thus preventing the pane from collapsing.

The pane thickness can be randomly chosen but with a glass distance of 20 mm a U-value of 0.4 W/(m^2 K) can be achieved for the pane. The great advantage of an aerogel pane is the high g-value of approx. 0.7. The aerogel pane has not been developed to be at a level that makes it suitable for use in ordinary windows as the aerogel material is translucent. The edge sealing can be made without any noticeable thermal bridge, by means of a special plastic film that has sufficient diffusion resistance to moisture and gas diffusion so that the pane can maintain the vacuum approximately 25 years.

Improved frame construction and g-value

The possibility of obtaining low U-values for the glazing has centred focus on obtaining a reduced thermal bridge effect of the edge sealing and the frame construction. Possible design solutions with regard to the edge sealing are already available by using insulating spacers, and research has therefore concentrated on frame construction. Particularly the development of narrow constructions has a high priority, as the insulating pane will fill in a larger part of the window area. This will also give a larger transparent area to compensate for the often-lower g-value of well-insulated panes.

Other topical research areas are improvement of the g-value of the pane and use of so-called non-ferrous glass where the absorption of sunlight and solar energy in the glass can be reduced by approximately 5%. The use of non-ferrous glass will also mean less colouring of the light. Moreover the glass is surface-treated with an antireflection treatment so that a smaller part of the sunlight is reflected from the surfaces of the pane. Both methods will lead to a significant improvement of the g-value.

In addition methods are being developed in order easily and quickly to assess what combination of the U- and g-values will be optimal in a given situation in terms of energy.

The problem of exterior condensation on well insulated glazing is assessed as a general problem that impedes widespread use of better insulated windows and a more detailed determination of conditions leading to condensation is being worked on as well as the possibilities of reducing this problem.

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