Advanced energy efficient windows

Thomsen, Kirsten Engelund

Published in:
Guidelines - BRITA-IN-PuBS

Publication date:
2007

Document Version
Publisher's PDF, also known as Version of record

BRITA in PuBs

Advanced energy efficient windows

EU framework programme

eco buildings

Guidelines

2007

1 Introduction

01 Why use this technology

Windows should be paid special attention as they contribute a significant part of the total heat-loss coefficient of the building. Contrary to other parts of the thermal envelope the windows are not only heat loosers, but may gain heat in the day-time. Therefore there are possibilities for large energy savings.

In terms of energy, windows occupy a special position compared with other thermal envelope structures due to their many functions:
1) windows let daylight into the building and provide occupants with visual contact with their surroundings
2) windows protect against the outdoor climate
3) windows transmit solar energy that may contribute to a reduction of energy consumption, but which may also lead to unpleasant overheating.

In the following paragraphs the current use of windows is reviewed with an emphasis on energy, while special products like solar protection glazing and security glazing are not described. Then follows a chapter with some innovative window solutions.

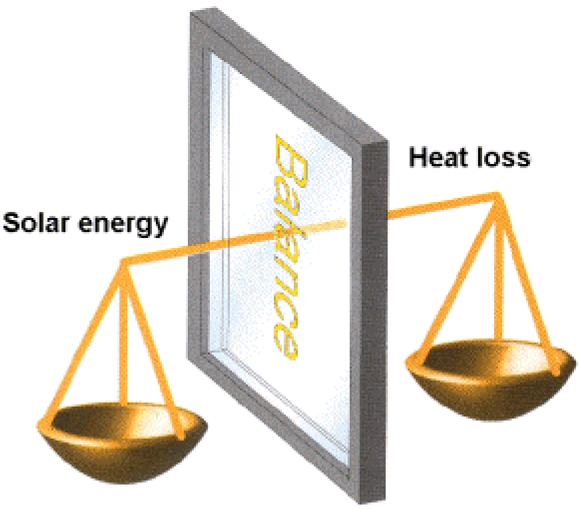

Figure 01. The energy balance of a window.

02 Requirements in regulations

In 2002 the European Parliament passed a directive on the energy performance of buildings, to be implemented by 4 January, 2006. The objective of this Directive is to promote improvement of the energy performance of buildings within the Community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness. This Directive lays down requirements as regards:

(a) the general framework for a methodology of calculation of the integrated energy performance of buildings;
(b) the application of minimum requirements to the energy performance of new buildings;
(c) the application of minimum requirements to the energy performance of large existing buildings that are subject to major renovation;
(d) energy certification of buildings; and
(e) regular inspection of boilers and of air-conditioning systems in buildings and in addition an assessment of the heating installation in which the boilers are more than 15 years old.

The energy performance of buildings should be calculated on the basis of a methodology that may be different at regional level. This includes, in addition to thermal insulation, other factors that play an increasingly important role such as heating and air-conditioning installations, application of renewable energy sources and design of the building. A common approach to this process, carried out by qualified and/or accredited experts, whose independence is to be guaranteed on the basis of objective criteria, will contribute to a level playing field as regards efforts made in Member States to save energy in the buildings sector, it will introduce transparency for prospective owners or users with regard to the energy performance in the Community's property market.

In the new Danish energy regulations for new buildings valid from 2006, the energy consumption will include energy for heating, hot water, cooling, ventilation and lighting. When the energy consumption is calculated, electricity consumption is multiplied by 2.5 to compensate for the inefficiency of the power production. This figure, which is multiplied on the electricity consumption, will vary across Europe.

So there are no special limits for windows, but there is a fixed limit for the transmission losses for the thermal envelope excluding windows and doors.

There are new requirements for windows when a building is renovated in a major way. If changing all the windows in one facade, the U-value must not exceed 1.5/1.8/2.0 W/m^{2}K depending on the type and shape of the windows.

2 Current practise

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 in Denmark this lead to the use of very small window areas at the expense of the daylight level, but concurrently with the development of improved insulating glazing, the size of typical window areas has again increased.

Sealed glazed units

Low-emissivity coatings

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 glass distance and an almost airtight and moisture-proof sealing of the cavity between the glass layers.

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 air and is destroyed by mechanical impacts, which is the reason why soft coatings should always face a dry sealed cavity.

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 R&D has primarily been aimed at reducing heat transmission by radiation through low-emission (lowE) coatings 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) thereby reducing heat transmission caused by radiation.

The coatings influence the light transmittance and solar energy transmittance of glass because 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 range for visible light, while solar energy, in principle, refers to the whole wavelength range covered by solar radiation.

Gas fillings

The application of lowE coatings reduces heat transmission in connection with radiation by up to approximately 90 % and consequently the heat transmission and convection in the sealed cavity become dominant. 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, a U-value of 0.45 W/m^{2}K is obtained, but direct solar energy of only 0.29, by using a triple-glazed unit with 2 lowE coatings and krypton filling.

Edge sealing

The traditional 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 to 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, Canada and Germany are far ahead in the use of other types of spacers based on butyl and silicone foam. A metallized plastic film replaces the metal profile, 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 to use spacers of stainless steel with a material thickness of approximately 0.15 mm.

Frame constructions

Frame constructions are traditionally made of wood, which is easy to work with 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, e.g. by means of a disruption made of plastic, but the U-value is significantly higher than for wooden frames.

A combination in increasing use is the wooden window provided with an externally ventilated aluminium profile. This combines 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 the one of a traditional wooden construction. The U-values for typical frame constructions is approximately 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. 21).

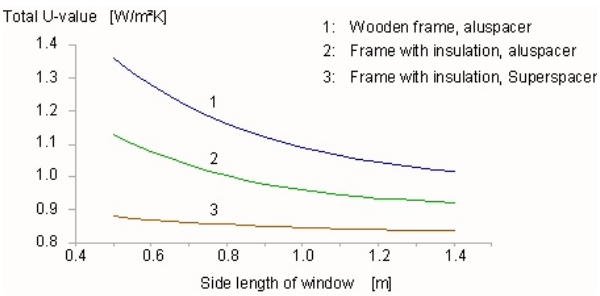

Figure 21. The total U-value of the window as a function of the size (length) of the window and the different insulation properties of the frame.

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, which might be advantageous for the dwelling. The two mechanisms are called the U-value and the g-value, respectively.

Table 21. Examples of window types and their U-and g-values.

Window type	U-value [W/m^{2}K]	g-value [-]
Double pane, low-e coated, aluminium frame	1.4	0.65
Double pane, low-e coated, wooden or plastic frame	1.2	0.65
Double pane, low-e coated, improved spacer, wooden or plastic frame	1.1	0.65
Triple pane, low-e coated, improved spacer, wooden or plastic frame	0.90	0.48
Triple pane, low-e coated, improved spacer, improved frame construction	0.80	0.48

In Denmark the U-value is calculated as an average 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 (according to ISO 10077-1 and ISO 10077-2).

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, conductivity and convection and thus contribute to covering the heat loss. Therefore the total solar transmittance is higher than the direct solar transmittance.

The new energy requirements for retrofit of windows in Germany and Denmark are 1.7 W/m^{2}K and 1.5 W/m^{2}K respectively.

3 Innovative solutions

Improvement in the energy performance of windows is an important element in energy conservation measures. It is needed to ensure that the correct solutions are applied when windows are replaced or improved.

Both industry and research make innovations to building components. The innovations listed in this section may not cover the whole area of new materials or applications, but should provide insight into what is ready (or very soon ready) to be applied in buildings to be renovated.

31 Alternative 1
Improved edge and frame construction

In addition to three-pane glazing for cold climates, the producers have spent development work on improved frames. Frames that include an insulation layer between wood or inside the plastic frame can reduce the frame-U-value down to 1.0 W/m^{2}K. Another recent development is the improved spacer. Today most window glazing manufacturers use 0.4 mm galvanised steel for spacers, but in a few cases insulating spacers are used. As a side effect this helps avoiding condensation on the interior side of the pane.

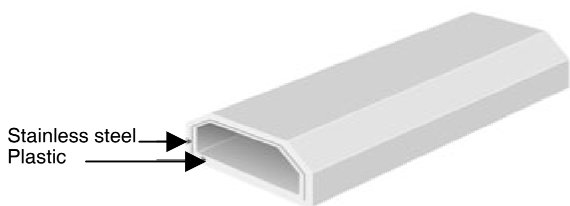

Figure 31. Advanced spacer of stainless steel and plastic.

The possibility of obtaining low U-values for the glazing has alted the focus on to reducing thermal bridging 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. In particular 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.

.

Figure 31b. Insulated frame.

32 Alternative 2
Improved g-value

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 to easily and quickly 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 to be 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.

33 Alternative 3
New glass fibre reinforced plastic (GRP) window

Figure 33. The new GRP window shown to the right alongside a window from the 1980s.

The frames of the window are made of modern GRP materials **(**glass-fibre reinforced plastic (GRP) introduced by Fiberline Composites in Kolding, Denmark**)** which insulate thermally, effectively reducing heat loss and minimising the problems of condensation and mould growth in dwellings. Fiberline employs a high-tech production process known as pultrusion and manufactures GRP profiles with high insulation properties for many different industries. The frames, mullions and transoms of the GRP window are noticeably narrower. This gives an elegant appearance and allows more light to enter a room. Furthermore they will weigh 25 % less than traditional windows; they will also benefit window installers' backs.

The window is part of a large development programme known as "Windows of the future for houses of the past" initiated by the Copenhagen-based urban renewal Company SBS on behalf of the Landowners' Investment Association. The idea is to kick-start the development of new and better types of windows devoid of thermal bridges, since many windows need to be replaced after a relatively short number of years due to either the use of wrong materials or poor workmanship or poor maintenance.

In Denmark, figures indicate that nearly half of the energy used for heating new buildings disappears through windows and doors that have poorly insulating frames and sills. The GRP material reduces the thermal bridges and insulates so well that the U-value of the total window structure is reduced to as low as 1.3 W(m^{2}K with a double pane, while the U value is 0.8 W/m^{2}K with a triple pane. This effectively anticipates new Danish building regulations for retrofit, which 1.5 W/m^{2}K.

Moreover, it is claimed that the window cannot rot. It has a very long service life and is well suited to the fluctuating weather conditions of Northern and Central European countries, and it requires only a little upkeep. Paint does not peel because it adheres well to the GRP material.

While the window still exists only as a prototype, Pro-Tec expects to have the finished product ready for the market by 2007.

34 Alternative 4
The VentVision window

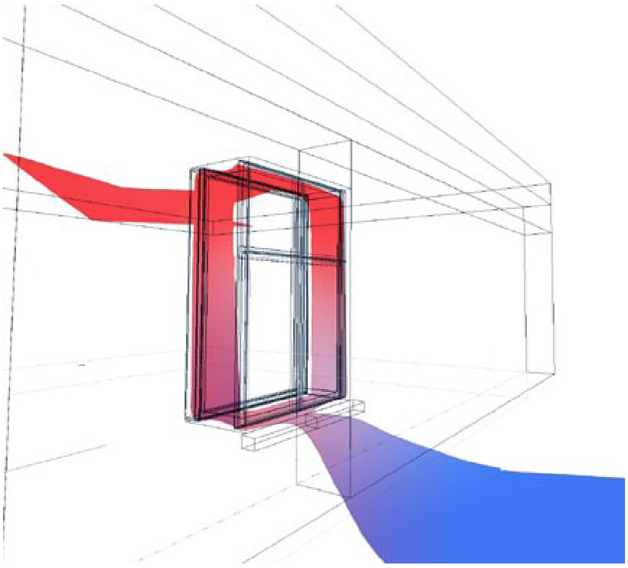

Figure 34. The VentVision window.

The VentVision window leads cold air in at its base and warms it in the hollow cavity inside the sill before releasing it into the house or flat. It is a joint R&D project focusing on ventilation and indoor climate results in a new generation of ”intelligent” windows. The window was developed in connection with the Danish project “Windows of the future for houses of the past” in 2004. The project aims to design quality windows that are well suited to older housing.

The frames of the window are made of modern GRP materials **(**glass-fibre-reinforced plastic) that insulate thermally, effectively reducing heat loss and minimising the problems of condensation and fungus in dwellings. Using the new materials has enabled the companies to create a window with narrow frames that complement older houses as well as contemporary homes. In addition the narrow frames allow more light to access rooms due to the increased surface area of the window pane. The window also has a built-in ventilation feature, which reduces allergy problems caused by house dust, while significantly improving indoor comfort.

Another VentVision innovation is its heat exchanger, which is integrated in the window sill. Cold air enters the sill under the ledge and is lead through the cavity within the sill where the air is warmed before it enters the room. This function pre-warms outside air and reduces traffic noise, thus providing occupants with a better indoor climate in comparison with standard windows.

The Landowners’ Investment Association initiated the project, and the new window is expected to be on the market within one to two years’ time.

35 Alternative 5
Superinsulating glazing

Besides the traditional three-pane glazing for cold climates two different types of superinsulating glazing can be mentioned. They are in the process of being developed or further improved:

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 to prevent the outer atmospheric pressure from causing 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 are approximately 0.3 W/m^{2}K, but because of the spacers the real centre U-value will be about 0.5 W/m^{2}K. The g-value will be 0.6 because of the two coatings. The edge sealing causes a significant thermal bridge along the perimeter of the pane. The sealing must be very air tight.

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 approximately 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 approximately 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.

36 Alternative 6
The ACC Window

A good example of a new innovative building element is the Norwegian window. To help a small Norwegian enterprise to penetrate the marked, two new types of elements will be integrated for testing and demonstration purposes. The elements have to be further developed and prototypes must be constructed and tested. The ACC Window is a wooden window with a sealed glazing unit of one solar absorbing glass and one glass with low emissive coating. The sash may be turned 180 degrees in the frame. The advantage of this is increased solar gains during the heating season with the solar absorbing glass facing inwards, and reduction of unwanted solar gains in the cooling season when the absorbing glass is facing outwards.

As an example the ACC Window Company suggests reduced U-value from 1.41 W/m²K, to 1.3 W/m²K. Such a reduction will reduce the energy consumption in Oslo by 3.8 %. The calculations show that looking at the total economy it will be better to use the ACC window than a normal energy-efficient sealed units plus cooling.

4 Advantages/disadvantages

By using advanced energy efficient windows there are both advantages and disadvantages. The advantages are not only energy savings, but also covering financial and environmental issues. A big problem can be exterior condensation on well-insulated glazing (U-values from 1.00 W/m²K and below).

5 Costs

51 Investment costs

In Denmark the Energy Authority, glass industry, glaziers' trade organisation and Vinduesproducenternes Samarbejds Organisation (VSO) (window manufacturer's co-operation organisation) have entered into an agreement on the phasing-out of traditional sealed units and promotion of energy-efficient window solutions. Consequently, energy-efficient sealed units have become standard products and a campaign to promote their sales and those of other energy-efficient window solutions has been launched. This means that the prices for energy-efficient windows in e.g. Denmark are now the same as those for traditional sealed units.

An example of investment costs is the economic evaluation and forecast by using monolithic silica aerogel sheets (from the EU project HILIT+). The actual production of both the monolithic silica aerogel sheets and the actual glazing assembling are at the moment a highly labour intensive process leading to an actual cost at this level of approximately 930 € per m^2 final glazing. However, if a large scale production is foreseen with a 10 m^3 autoclave and full automation the costs are evaluated to drop to approximately 277 € per m^2.

52 Energy-saving potential

Taking as an example monolithic silica aerogel sheets (from the EU project HILIT+). The final glazing has a total solar energy transmittance above 85 and a U-value of 0.7 W/m^{2}K for about 14 mm aerogel thickness, which for a 20 mm thickness corresponds to a U-value of approximately 0.5 W/m^{2}K. No other known glazing exhibits such an excellent combination of solar transmittance and heat loss coefficient. The annual energy savings forecast by using monolithic silica aerogel sheets compared to triple low energy glazing is in the range of 10 – 20 % depending on type of building.

6 Maintenance and service

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.

7 Best practise example

The following built example shows the application of high-efficient windows when retrofitting a nursery home in Stuttgart. The nursery home is one of the case studies in the BRITA In PuBs project. The renovation is finished by the end of 2006. After that a monitoring period is planned.

Figure 71. Nursery Home Filderhof in Stuttgart, Germany.

Figure 72. The high-efficient window.

The nursery home is retrofitted with Saint-Gobain windows, SGG Climatop ultra N (3-glazed units with thermal efficient spacer). The centre U-value for the glass is 0.8 W/m^{2}K. The total U-value for a 1230 mm x 1480 mm window is 0.99 W/m^{2}K. The final glazing has a total solar energy transmittance of 46 %.

There has been replaced approx 160 m^2 window area with a price of 482 €/ m^2.

8 Calculation tools

In most countries there are a set of guidelines concerning windows. Furthermore a lot of different programmes for calculating the U-values for windows exist.

The BuildingCalc program can be downloaded for free as either a Matlab or a stand alone Windows version from (Denmark):
http://www.byg.dtu.dk/Centre/BFI/Om%20BFI/Medarbejdere/trn.aspx

A program from Pilkington can be found (Denmark):
http://www.pilkington.com/europe/denmark/danish/building+products/glas04.htm

Saint-Gobain Glass has also made a program called CALUWIN (Switzerland):
http://www.designbuild-network.com/contractors/joinery/giesbrecht/giesbrecht3.html

For calculation of frame construction a program called Therm can be found (USA):
http://windows.lbl.gov/software/therm/therm.html

For calculation of windows U- and g-values can be mentioned WINDOW from Lawrence Berkeley (USA):
http://windows.lbl.gov/software/window/window.html

WIS is a uniform, multi-purpose, European based software tool designed to determine the thermal and solar characteristics of window systems (glazing, frames, solar shading devices, etc.) and window components -WIS 3.0 (The Netherlands):
http://windat.ucd.ie/wis/html/index.html

In Denmark the Danish trade organisations have entered into a voluntary energy-labelling scheme for windows, and labelling schemes will be introduced for windows and internal double-glazing. The schemes will categorise products on a scale from A to C. The companies and products subject to the scheme will be regularly checked and companies will have to state the energy properties of their products.
Certification of windows in Denmark: (voluntary labelling):
http://www.energimarkning.dk

9 References

91 Compilation

This guideline is written as a part of the project BRITA in PuBs – Bringing retrofit innovation to application in public buildings, EU 6th Framework programme Eco-building (TREN/04/FP6EN/S.07.31038/503135).

The author is Kirsten Engelund Thomsen from the Danish Building Research Institute SBi, Denmark. The professional editing was closed in May 2007.

92 Literature

[1] DS/EN ISO 10077-1 and DS/EN ISO 10077-2: Termisk ydeevne for vinduer og døre (Thermal performance of windows and doors), Danish Standards.

[2] K.I.Jensen, J.M. Schultz & F.H.Kristiansen (Denmark): "Development of windows based on highly insulating aerogel glazings”. Article in Journal of Non-Crystalline Solids 350 (2004), page 351-357.

[3] Highly Insulating and LIght Transmitting Aerogel Glazing for Super Insulating Windows- HILIT+. Edited by Karsten I. Jensen, Finn H. Kristiansen and Jørgen M. Schultz, Department of civil engineering (BYG•DTU), Technical University of Denmark, 2005. http://www.byg.dtu.dk/Sektioner/BFI/Publikationer.aspx?lg=showcommon&id=185121

[4] Toke Rammer Nielsen (Denmark): “Simple tool to evaluate energy demand and indoor environment in the early stages of building design”. Article in Solar Energy 23 August 2004.

[5] Saint-Gobain-Glass homepage (United Kingdom): http://uk.saint-gobain-glass.com/b2c/default.asp

[6] REFRAME homepage (project co-ordinator is Esbensen Consulting Engineers, Denmark): http://www.eu-reframe.net/public/default.htm

[7] Glass-fibre reinforced plastic (GRP), Denmark: http://www.fiberline.com

[8] The window with frame parts made of a modern GRP with excellent insulation properties is the result of a research and development project carried out by the Danish window manufacturers Pro-Tec Vinduer A/S and designed in close cooperation with the Danish architects Friis & Moltke A/S. http://www.protecwindows.com

[9] During 2004, a group of Danish companies have cooperated in creating VentVision – the “intelligent” window. The companies are KHR arkitekter A/S, the Danish Building Research Institute SBi, Birch & Krogboe A/S, Glas I Aps, Jægersprisvinduet A/S and the manufacturers of GRP profiles, Fiberline Composites A/S.

10 Disclaimer