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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2.1. Introduction

The building envelope (roof, external walls, windows, doors and floors) serves a number of functions but this chapter focuses on the thermal aspects, the insulation of the building. The climatic differences throughout Europe, for instance, are mirrored in the traditional buildings that range from uninsulated (usually quite heavy) constructions in the south (designed mainly for summer conditions) to fairly well insulated heavy or light constructions in the north, designed primarily to comply with winter conditions.

Improving the thermal properties of existing building envelope is, in many cases, one of the most logical solutions in order to reduce building energy consumption and in consequence this is one of the most important strategies in building retrofit.

In order to achieve good results in this area, the different aspects related to the energy performances of building envelope components and the technologies for their improvement, should be part of the designer's knowledge, in order to clearly define the most appropriate strategies.

The improvement of building envelope energy performance is often the result of an optimisation process and the choice of the correct strategies has to be the result of a general overview of all the necessary options for a building to be retrofitted, usually this will involve windows, doors, walls and roofs and an unbalanced design between different components, can lead to unsatisfactory results.

There are two key components to a super-insulated building shell: high levels of insulation with minimum thermal bridges and airtight constructions. High levels of insulation are accomplished by constructing a thicker than normal wall and filling it with an insulation material. However, by simply adding more insulation does not result in a conventional assembly turning into a high-performance assembly. The wall system and junctions between building components have to be carefully designed to be airtight and avoid thermal bridges or discontinuities. As more insulation is added, the thermal discontinuities become more important.

Cost effectiveness of building envelope intervention is a critical issue so it should be remembered, for example, that the first layer of insulation is the most effective and the law of diminishing returns dictates that each additional layer of insulation is less effective than the previous layer. On the other hand, the adoption of generally considered expensive solutions such as overcladding systems, can be considered a convenient strategy in a comprehensive retrofit scheme, including window and door replacement and the installation of new heating and ventilation systems

This chapter intends to be an overview of the technologies applicable in building envelope retrofit when looking at the different components. The readers will then find described some strategies in order to improve the energy performance of these components, by means of a correct use of the most recent technologies in the fields of windows, insulation, overcladding systems and doors.

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.

Gas fillings

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.

Edge sealing

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).

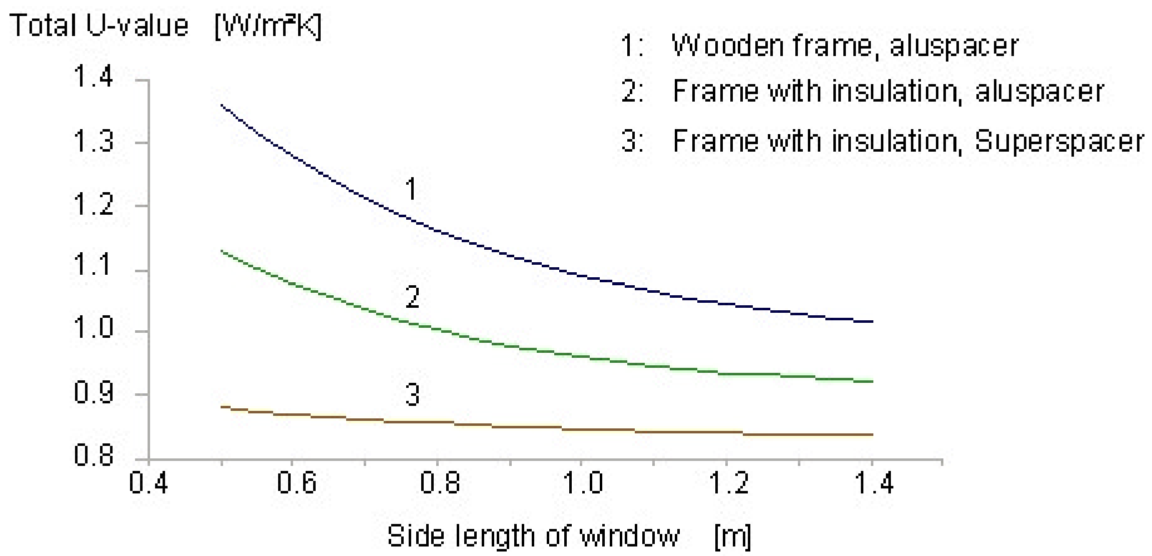


Figure 2.1. Total U-value calculated from a square window with triple glazed, coated and filled units (centre U-value = 0.85 W/(m^2 K)) as a function of the size of the window. Calculations are made with a traditional frame construction of wood (U = 1.6 W/(m^2 K)) and a wooden frame construction with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

<u>Superinsulating glazing</u>

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.

<u>Improved frame construction and g-value</u>

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.

2.3. Insulation materials and systems

2.3.1. Introduction

There are two key components to a super-insulated building shell: high levels of insulation with minimum thermal bridges, and airtight construction. High levels of insulation are accomplished by constructing a thicker than normal wall and filling it with an insulation material. However, simply adding more insulation does not turn a conventional assembly into a high-performance assembly. The wall system and junctions between building components have to be carefully designed to be airtight and avoid thermal bridges or discontinuities. As more insulation is added, the thermal discontinuities become more important. The building assemblies have to be designed so that all non-insulating building materials (including wood, steel and concrete) are thermally protected by insulation. The first layer of insulation is the most effective in reducing heat loss. The law of diminishing returns dictates that each additional layer of insulation is less effective than the previous layer. The amount of insulation used depends upon the severity of the climate. Mild climates require a wall U-value of 0.2 W/m^2K or less, whereas harsh climates might necessitate a value of below 0.13 W/m^2K.

2.3.2. Types of insulation materials

The insulating material which dominates most countries markets is mineral wool, but there are a number of other typical insulation materials available for example: aerated concrete, light clinker, cell glass, expanded polystyrene (EPS), extruded polystyrene (XPS), polyurethane, perlite, cellulose fibres, fibre boards and woodcrete. Increased interest in a building process that develops towards more eco-friendly insulation materials has resulted in a group of insulation materials with the common denominator 'alternative insulation materials'. These eco-friendly insulation materials can be agriculturally produced or produced via recycled products. A table below lists the raw materials and product types of the alternative products.

Straw is also used, not only as an insulation material, but also for construction of the carcass of a house. Globally approximately 1000 straw buildings have been built, most of them in the USA. Rot and mould is without doubt the weakest point of straw, so it is necessary to safeguard against water penetration.

Table 2.4. List of raw materials of alternative products and product types.

Products	Raw materials	Products types
Cellulose fibres	Paper granulate/cellulose fibres Borax (+boric acid) (Aluminium hydroxide)	Granulate Soft boards Hard boards
Cork	Natural or expanded cork granulate from the cork oak	Granulate Hard boards
Fibre boards	Wood chips and wood waste (Aluminium sulphate)	Soft boards Hard boards
Wood concrete boards	Wood chip Cement/magnesite	Hard boards
Flax fibres	Flax fibres Ammonium phosphate (boric salt) Polyester fibres	Soft boards Rolls
Sheep's wool	Cleansed sheep's wool Boric salt, insecticides (Polyester fibres)	Soft boards Rolls
Coconut fibres	Coir fibres (from the coconut shell) Fire retardant	Soft boards Hard boards
Cotton	Cotton Boric salt	Soft boards Rolls
Polyester fibres	Synthetic (recycled) Polyester fibres	Soft boards

The term 'dynamic insulation' describes insulation materials used as outdoor air filters. As a consequence of underpressure created in a building, the air passes though the insulation material and is heated by transmission loss. Dynamic insulation may be seen as a kind of heat exchanger and the more airtight? the house is, the greater the obtainable energy savings will be. The term 'evacuated insulation' is used as a common denominator for a group of insulation materials with the property in common that a vacuum between two surfaces helps improve the insulating property of an element. The surfaces are separated by filler, which serves additional purposes than to keep the membranes apart, such as a radiation barrier that reduces heat reduction through radiation compared with evacuated elements without a radiation barrier. Conversely, the filler contributes to conduction through the panel, which counteracts this effect. A number of evacuated insulating panels have been developed for refrigerating and cooling cabinets, and for refrigerating trucks and containers in the transportation trade. Compared with ordinary insulation materials, the advantage of evacuated insulation panels is improved overall insulating properties with less wall thickness. A considerable amount of research is going on in many places in the world, but information about advances is limited.
Moreover, mould-cast polystyrene blocks with holes to be filled out with cement are marketed, such as a product from New Zealand called “Formfour wall system”. Every block is made of EPS in with the measurements 1000 mmx250mmx300mm (l x w x h) and has 4 circular holes with a diameter of 160 mm. The product was developed for use in one and two-storey buildings. The term 'transparent insulation' is a material or a construction that has a green house effect like glass or better than glass. The material must have a high solar transmittance, but needs only to be clear as glass if used for windows. The insulating effect is normally caused by air gaps between the actual materials used. The materials can be divided into the following principal types: 1) Plane sheets and foils, 2) Corrugated foils and twin walled plates, 3) Honeyhomb and plastic foam, 4) Granular silica aerogel and 5) Monolithic silica aerogel. The transparent insulation is the basis for both passive and active use of solar energy for heating.

2.3.3. Post-insulation systems of the thermal envelope

A well-insulated thermal envelope without thermal bridges is a passive way to obtain a low heat demand and improved thermal comfort. A certain thickness of insulation gives the largest effect if applied externally, because the largest possible numbers of cold bridges are broken. Furthermore the importance of air tightness to the heat demand and to the durability of the constructions must not be underestimated. Very few insulation materials are airtight in themselves and their insulating effect is due to still air in small cavities and depends on them being built into airtight constructions. At the same time, air movement through a building construction will transport moisture in much higher contents than possible through diffusion. A higher moisture content in the construction has two major effects, a significantly lower thermal resistance and possible condensation in the colder parts of the construction.
Post-insulation may include many kinds of initiatives, all of which reduce energy consumption for heating, but also cooling loads may be reduced. In this chapter an overall outline is given of the different existing possibilities for post-insulation of the thermal envelope with the main emphasis on the facades (windows are discussed in main chapter 2.2 and overcladding systems in chapter 2.4) and pros and cons of the different methods are given. The existing constructions will of course set some limits eg the sizes of the cavities in the constructions as they may be filled on-site with sprayed foams or granulates.

2.3.4. Internal post-insulation of facades

Internal post-insulation is usually done by mounting lathes on the inside of an existing construction. Insulation material is placed between the lathes and gypsum boards or wood finishes covers? the insulation. The lathes can be made of wood or sometimes a metal profile is used, but in all circumstances the lathes will form a thermal bridge. Dividing the total insulation thickness into two layers can reduce the thermal bridge effect. Letting the lathes of each layer lie perpendicular to each other reduces the thermal bridge to the area where the lathes cross. Internal post-insulation requires a vapour barrier to be mounted on the warm side of the insulation in order to prevent diffusion of moisture to the construction. It is often placed between the finishing internal cladding and the insulation material, but the vapour barriers can be placed approximately a third of the total insulation thickness from the warm side in the case of extensive post-insulation. This leaves the vapour barrier well protected and also leaves room for installation of electrical switches etc without rupturing the vapour barrier.
There are many disadvantages connected with post-insulation. In terms of moisture, internal post-insulation may involve a risk of defects in the construction caused by moisture, as the resulting moisture resistance of the vapour barrier, including any leakage at joint or ductways of installations, is required to be significantly higher than that of the original construction. Internal post-insulation will reduce the thermal bridge effect around the floors and joints between internal partitioning walls and exterior walls only to a limited degree. Post-insulation will moreover reduce the active thermal mass of the room, thus increasing the risk of overheating due to solar radiation. Apart from thermal and moisture disadvantages, internal post-insulation means that the room cannot be used as long as work is in progress and that the inner measurements of the room will be reduced. These many disadvantages are the reasons why internal post-insulation is not commonly used.

2.3.5. External post-insulation of facades

A number of insulation initiatives for facades can be considered external to post-insulation: Mounting of insulation layers on top of existing construction, replacement of windows, solar walls, ventilated solar walls and combinations of the above. Within each group several variations exist of how to carry out post-insulation in practice.
It is assumed that the original wall construction is solid or that cavity wall insulation has already been done in the case of cavity wall structures.

2.3.5.1. Mounting an extra external insulation layer

Extra insulation layers can be mounted on the existing facade without a ventilated layer of air if it is ensured that the external insulation cladding allows water to penetrate the constructions behind. At the same time the cladding must be sufficiently diffusion open to allow moisture diffusing into the construction from the indoor air to be drained off. Alternatively the external post-insulation can be placed with a ventilated layer of air between the insulation material and the finishing facade cladding. In this way moisture diffusing into the construction can be ventilated out.
Post-insulation without a ventilated layer of air is typically done by mounting the insulation material directly on the original facade by means of an adhesive and mechanical fastening such as through-going dowels. On the outside the insulation finishes with a reinforced layer of plaster. This way a surface without joints is achieved which provides the necessary wind and water tightness. In principle the insulation thickness can be freely chosen, but in practice it will depend on the shearing stiffness of the fastening and the insulation material, as in principle there is no support for the insulation material.
The ventilated solution is executed by mounting a profile system fastened to the original facade. The profile system can be built up of wooden lathes or metal profiles and serves to fasten the finishing facade cladding and as a means of fastening the insulation material. The insulation is placed between the mounted profiles and is fastened to the existing wall construction by means of through-going dowels. In some cases fastening is done by means of the metal profile directly. The fastening is to ensure close contact between insulation material and the wall surface behind. Moreover it contributes to maintaining the desired width of the gap between the surface of the insulation material and the finishing cover. The surface of the insulation material, orientated towards the ventilated layer of air, must be diffusion open but windproof and waterproof. This might be achieved either through the properties of the selected insulation material or by mounting a windproof cover. The insulation thickness depends on the strength of the selected profile system, as the system has to transfer the shear strength from the facade cladding to the construction behind. Both types of post-insulation requires special details around windows, doors and projections adapted to each building. If the external post-insulation is combined with replacement of windows, the windows should be pulled forward so that they are level with the post-insulation.
The existing facade should be reasonably smooth and able to absorb the loads from the mounted post-insulation systems. The unventilated solution focuses on the weight of the insulation material and the facade plaster that will result in a load equally distributed over the facade and which originates from bonding and anchoring with dowels. The ventilated solution is different as the weight of the insulation is equally distributed over the facade while the weight of the finishing facade cladding is distributed via the profile system, i.e. in more concentrated areas.

External post-insulation with a diffusion open layer of plaster or with a ventilated layer of air causes moisture problems and moreover it will lead to drying out of the original wall construction. External post-insulation is therefore often used in connection with facade renovation of concrete buildings with incipient attacks on the reinforcements.

External post-insulation makes large energy savings possible, as this type of insulation contributes not only to a reduction of the heat loss through the large wall surfaces but also eliminates the traditional thermal bridges where floor and internal wall are anchored in the exterior wall. The resulting energy savings depend on the insulation thickness and the amount of thermal bridges that occur in connection with the post-insulation.

2.3.5.2. Use of solar walls

Solar walls are alternatives to traditional external post-insulation of walls with a southerly orientation where the solar radiation on the walls is used for heating the rooms behind and/or for reducing ventilation loss.
Solar walls have been roughly divided into ventilated and unventilated solar walls. The principle in both cases is to cover the original facade with glass to form a layer of air between the glass and the surface of the wall, which is painted black for greater solar absorption. Solar radiation causes the temperatures on the wall surface and in the layer of air to rise. Depending on its construction, the high temperature can be used in different ways to reduce the heat loss of the rooms behind the solar wall.

Unventilated solar walls

The unventilated solar wall is the most primitive form of solar wall as it consists of covering? the facade with a layer of glass. The solar heat is transmitted by heat conduction through the wall to the room behind. The principle is to exploit a time shift between solar radiation on the external side of the wall and the time when the heat reaches the internal side of the wall and can be supplied into the room.

The unventilated solar wall solution provides no possibility for regulating the heat transfer to the room behind the solar wall, unless it can be covered against solar radiation. This would be necessary in the summer period.

An unventilated solar wall is mounted by first repairing any defects on the existing facade and then by painting it black or adding a coating for improved absorption of the solar radiation. The selective coating can be added by supplying the surface of the wall with a selectively coated metal foil. The coating is characterised by high absorption of solar radiation (short-wave radiation) and low emissivity of heat radiation (long-wave radiation) and thus a major part of solar energy is transmitted into the wall.

Next a transparent cover is mounted on the wall by mounting glass or acrylic boards in a profile system fastened to the original facade. The gap between the cover and the facade should be optimised so that the best possible insulating properties are obtained, which causes a gap of approximately 15-20 mm. In cloudy periods this simple unventilated solar wall does not result in significant reduction of the heat loss through the wall. Alternatively the gap of air can be filled with a transparent insulation material that reduces the heat loss from the wall, also during cloudy periods, while at the same time reducing the amount of solar energy that is

transmitted to the surface of the wall. Transparent insulation materials will typically be constructed as a thin-walled matrix of plastic tubes perpendicular to the surface of the wall, thus transmitting a major part of the solar radiation to the wall. If transparent insulation materials are used in the solar wall, the thermal bridge effect of the profile system should be assessed like traditional external post-insulation. Preferably the profile should have low heat conductivity while at the same time be able to resist the high temperatures that may occur in the solar wall. The combination of a low thermal bridge effect and high temperature stability can be obtained, for example. by using punctured steel profiles. The unventilated solar wall is only suitable for poorly insulating solid constructions as the heat absorbed on the outside of the wall must be supplied by transmission through the wall to the room behind.
The existing facade must be reasonably smooth and the strength of the wall must be able to absorb loads from the added cover, ie the weight of the glass, which is transmitted to concentrated areas via the profile system. It must be ensured that materials close to the wall surface are able to resist temperatures of up to approximately 100 ^oC.
When constructing an unventilated solar wall, an almost 100% diffusion tight cover must be mounted on top of the original wall. This might cause moisture problems in the construction and, in spite of the term 'unventilated', a slight ventilation of the layer of the air between the cover and the outside of the original wall must be ensured. In Denmark the suggested size of ventilation openings per m^2 solar wall is a 10 mm whole at the top and also at the bottom. The ventilation openings are considered to reduce the insulating effect by 3%. Mounting of a solar wall will generally result in draining of the original wall construction as its mean temperature will increase at the same time as it is protected against moisture from the outside. It is recommended to paint the outer surface (black paint for improved solar absorption) with a diffusion open paint, so that any accumulated moisture in the wall may diffuse into the slightly ventilated layer of air.

Contrary to the traditional post-insulation, the energy saving potential by using solar walls depends on a number of factors such as the orientation of the surface, shading conditions and internal heat load. The internal heat load is important for the utilisation rate of the heat transported from the solar wall. In general, the use of suitable computer programs is recommended for calculating the energy saving potential in each case. As a rough estimate of the potential energy saving it is important to remember that, in contrast to traditional post-insulation, the use of solar walls will have the effect that during certain periods energy is transmitted through the wall to the room behind it. A precondition for obtaining the calculated energy saving is that the transported energy can be used without causing significant overheating**.** This also means that a doubling of the solar wall area does not necessarily result in a doubling of the energy saving.

Ventilated solar walls

In a ventilated solar wall the air in the gap between cover and wall surface is used as the primary heat transmitting medium, while the heating of the wall itself is of secondary importance. In its simplest form the solar wall works by means of openings located at the top and at the bottom of the wall which facilitates air circulation between the layer of air of the solar wall and the room behind. When the sun shines, the layer of air will be heated up and a thermal driving pressure will occur that will cause circulation of warm air to the room through the top opening and correspondingly cooler room air is driven out through the bottom openings. To avoid air flows in the opposite direction at night, the openings in the wall have been equipped with non-return valves that can work at low differential pressure.

The heat transfer will occur at the same time as solar radiation through windows in the facade, and this might lead to unpleasant overheating. The use of easily operated non-return valves does not allow control of the heat transmission. This can be obtained by using manually controlled or motor-controlled dampers. Solar walls with closed dampers will work as an unventilated solar wall thus delaying the heat transmission. In this way the ventilated solar wall provides a possibility for quick and relatively high heat transmission, if it is required (typically during winter), or a more reduced and split-time heat transmission (typically during spring and autumn).
The simple form of ventilated solar wall does not significantly improve the insulating properties of the wall, which is why energy saving is due to solar heat gain. However, the ventilated solution provides a possibility for combining post-insulation and utilisation of solar radiation. Establishment of external post-insulation means that heat transmission by conductivity through the wall is almost eliminated.

Ventilated solar walls can also be used for the preheating of ventilation air in connection with mechanical exhaust where, instead of circulation of the room air, the outdoor air is sucked in at the bottom of the solar wall. This system can be further improved to become a solar air collector where the energy from the air is transmitted to a central storage where the exploitation of the heat can be controlled by demand. The ventilated solar wall can be used at post-insulation of all types of wall construction as the primary wall transport is independent of the thermal mass and insulating properties of the wall construction.

Construction of ventilated solar walls is like the construction of unventilated solar walls, the ventilation ducts in the facade excepted. The ducts at the top and at the bottom are typically approximately 100 mm high and with a width that corresponds to the modular width of the solar wall. Non-return valves can be designed simply by mounting a frame provided with rough grating and a plastic foil fastened to its surface. During the day the plastic foil will be pressed away from the grating by thermal pressure, thereby allowing air circulation to take place, while the foil will be pressed against the grating during the night and thereby shutting off air flow in the opposite direction.
The existing facade must be reasonably plain? and the strength of the wall must be able to absorb the loads from the added cover, which means that the weight of the glass cover is distributed to concentrated areas via the profile system. It must be ensured that materials incorporated in the construction are able to withstand temperatures of up to approximately 100 ^{o}C.
Ventilated solar walls pose no risk of condensation, since moisture, which may have been supplied to the cavity between the solid part of the solar wall and the cover, will be quickly exhausted by the air flow in the solar wall when the sun is shining. It must be ensured that any moisture from driving rain and heavy condensation on cold nights can be drained away at the bottom of the solar wall. The moisture conditions in the original construction will be improved, as the construction dries out as a result of its higher mean temperature and at the same time it will be protected against moisture from the outside. It is recommended to paint the external wall surface (black paint for improved solar absorption) with a diffusion opening paint so that accumulated moisture in the wall can diffuse into the slightly ventilated layer of air.
Calculation of the energy saving potential for ventilated solar walls is somewhat more complicated for the unventilated solar wall, as there is a complicated connection between the temperature of the air in the gap between cover and solid wall, which is significant for the size of the thermal driving pressure and consequently for how much air circulates in the solar wall.

More ever, the heat transmission coefficient depends on the air flow velocity between the sunlit wall surface and the air in the gap etc The calculations can be performed by an iterative process and are solved by means of computer or pocket calculator programs.

The highest energy savings can be achieved by using the solar wall for preheating of the ventilation air, as a suitably high air velocity can be ensured through the solar wall with the increased heat transmission properties from absorber to air. As the largest part of solar energy is transmitted via ventilation air, this solution may advantageously be combined with post-insulation of the original wall construction. This will achieve energy savings by reduction of the heat loss through the wall even when the sun is not shining. The energy saving potential in Denmark ranges from 150-200 kWh/m^2 per year for a wall oriented towards south.

2.3.6. Post-insulation of roofs and floors

Roofs usually offer the most economical surface for placing thick layer of insulation, often by merely utilising the force of gravity, laying the insulation on top of the ceiling or structural part of the roof. A flat or almost flat roof present a hygrothermal problem as they must have an extremely tight cover to prevent snow and rain penetration as well as an internal vapour barrier. For more information see chapter 2.4 concerning overcladding systems.
The insulation from self-supporting floors is not significantly different from walls. Post insulation of floors is often done for comfort reasons to obtain higher floor temperatures and avoid draughts along the floor. A weak point to which special attention is required is the floor/wall connection for buildings with slab-on-ground constructions.

2.4. Overcladding systems

2.4.1. Introduction

Overcladding system is often the most logical solution to achieve a range of sensible improvements to the thermal performance of the external envelope of buildings,. It is best suited to be used in a comprehensive rehabilitation scheme, including windows and doors replacement and the installation of new heating and ventilation systems.
Overcladding system, in its generic form, is a composite one consisting of three key components:
Insulant (see chapter on Insulant materials and systems)
Fixing or framework
A variety of fixing are used:

- Mechanical fixing - metal or timber batten/rail system or framework and mechanical anchors or dowels
- Chemical fixing - various adhesives
- Mechanical and chemical fixing - a combination of the above fixings, eg chemical anchors.

Finish
There are two generic finishes:

- Wet render - polymer and fibre-reinforced cementitious renders (PMCR), polymeric coatings, insulating renders and cementitious renders
- Dry cladding - rigid boards, panels and tiling in a variety of materials.

2.4.2. Selecting overcladding systems

Overcladding system is appropriate for refurbishment projects when

- The external walls are poorly insulated
- The external walls are deteriorating or insufficiently weather tight, leading to damp, draught and heat losses.
- Wall cavities are bridged or blocked, limiting the possibility for cavity fill insulation.
- The use of internal lining insulation would be too disruptive, would alter critical internal dimensions or make room sizes too small.

General factors to consider in application of overcladding systems:

- overcladding system will involve alteration in various details of the building such as at windows, doors and where services punctuate the external envelope;
- the planning authority should be consulted for all overcladding system refurbishment projects. Overcladding system may not be appropriate where its application may alter the appearance of a sensitive or historic building.

2.4.3. Overcladding systems available

The following generic systems are available to choose from:

- Wet render systems
- Dry cladding systems
- Bespoke overcladding systems

Wet render and dry cladding systems are often proprietary products, developed and tested with third party accreditation for use in particular situations. Bespoke systems are designed by architects or others for particular projects and combine all the elements of proprietary systems.

Advantages of overcladding system

- ✓ Improves thermal performances
- ✓ Improves air tightness
- ✓ Transfers the dew point outside the structural wall element
- ✓ May contribute to improve sound insulation
- ✓ Optimises use of thermal mass
- ✓ Is relatively easy to install, leading to faster construction
- ✓ Ease of quality control as insulation coverage is clearly visible
- ✓ Renews ageing exterior facades
- ✓ Contributes to eliminate internal problems: damp, condensation and mould growth, when accompanied by controlled ventilation
- ✓ Avoids internal building works and can be installed during occupancy
- ✓ Increases life expectancy of buildings
- ✓ Limits disruption to the fabric of the building
- ✓ Does not reduce the size of the rooms
- ✓ Lowers maintenance costs

Drawbacks of overcladding system

- ⇒ Overcladding system finishes are not as robust as solid construction; without attention, damage can lead to dampness and weathering problems
- ⇒ Critical detailing requires knowledgeable design and care during installation
- ⇒ Approved installers must be used for proprietary systems
- ⇒ Guarantees are only provided if a proprietary system is used, otherwise performance becomes the designer liability
- ⇒ Small project demand the same level of technical support from system manufacturers as larger projects, hence they are relatively more expensive
- ⇒ Overcladding system is not suitable where an existing substrate is structurally unsound or cannot be repaired
- ⇒ Overcladding system may not be suitable for listed or sensitive historic buildings

2.4.4. Wet render systems

There is a wide range of wet render systems on the market. As insulation and fixing components are common to most systems, the component that distinguishes a high performance wet system from a low-performance wet system is the thickness and quality of the render. Wet render system consists of:

- Insulant
- Adhesive mortar and/or mechanically fixings, eg mushroom-headed dowels; fixing materials include polypropylene, nylon, stainless steel and plated steel
- Profiles and edgings in galvanised steel, stainless steel, plastic or aluminium, used on corners, at damp-proof course (DPC) level, window reveals, verges and copings
- Base-coat render, incorporating a glass fibre, plastic or metal mesh
- Top coat render with or without a finish

2.4.5. Use of wet render systems

Traditional render and PMCRs can be used on both low rise and high rise buildings. Polymer helps to make the render more workable on site, and in higher quantities provides weather protection and elastic flexibility in the render. Thin polymeric coatings can be used on both low-rise and high- rise buildings. The reduced weight of the render can be found to be advantageous in high-rise buildings. Polymeric coatings are relatively new on the market.

2.4.6. Critical detailing - Wet render systems

For wet systems, there are standard details and methods of application that must be followed according to manufacturers' recommendations. Particular care should be taken in the following areas:

- Fire spread and fire barriers - all systems must meet the current standards and regulations. Note that in multi-storey buildings, unless mineral wool insulation is used, fire breaks will be required in the overcladding system to prevent the spread of flame externally.
- Fixings to substrate - must take into account the nature and condition of the substrate, dead and imposed loads (wind pressure and dynamic suction), corrosion of fixings, and the movement of the system, with or isolated from, the building fabric.
- Render specification - to ensure weather protection, resistance to cracking, durability, aesthetic requirements, resistance to dirt and algae and to fulfil maintenance requirements.
- Specification of PMCR - the quantity of polymer used may vary considerably and the specifier should seek assurance from the manufacturer that the render is suitable for a specific application.
- Racking of renders and differential movement - cementitious-based renders must have movement or expansion joints in accordance with manufacturers' recommendations.
- Movement joints in the existing structure - Overcladding system will need joints at the same location
- Day-work joint - should be specified in the render system.
- Work on site - precautions should be taken to minimise particle spread from rasping of polystyrene insulation.
- Air leakage - must be prevented through the construction by correct detailing to avoid heat loss.

- Sealing of joints - must prevent water ingress into the system.
- Bi-metallic corrosion - must be avoided by correct specification
- DPC detailing - in existing and new buildings must not be compromised by insulation cover.
- Existing and new services - designers and installers need to resolve how to treat, for example, down pipes, gutters, gas mains, phone lines and aerials.

2.4.7. Dry cladding systems

Many dry cladding systems are available. They use a variety of supporting frameworks fixed back to the substrate or building structure. A cladding material is fixed to the framework based on standard cladding technology. Dry cladding systems consist of:

Insulant

Independently fixed to the substrate with a mechanical or adhesive fixing, or partially retained by the framework. Quilt material can reduce the risk of thermal bridging forming a tight fit around the framework.

Support framework or cladding fixing system

Support framework are constructed of treated timber, steel or aluminium. An adjustable framework ensures a true plane can be achieved over an uneven substrate. A stand-off framework or cross battening allows a continuous layer of insulation to the substrate, minimising thermal bridging. Spans can be mounted over substrate areas where fixings cannot be obtained. Frameworks members, their size, frequency and strength of fixing to substrate are designed to withstand wind-loadings in accordance with manufacturers' recommendations. Supports will accommodate the insulation and a ventilated cavity behind rainscreen cladding.

Ventilated cavity

Most dry cladding systems incorporate a ventilation cavity between the cladding and the insulation to ensure that any moisture penetrating the cladding through the joints or migrating from inside the building is carried away

Cladding materials and fixing

Many cladding materials are available, including resin-impregnated laminates, highly compressed mineral wool, fibre-reinforced calcium silicate, aluminium panels and clay tiles. It is possible to have open joints to form a rainscreen cladding, or sealed joints for a fully sealed system. A wide range of colours and textures are available. Cladding fixings include nails, screws, rivets or partial secret fixing using adhesives. Pressed profiles, trims and cover/edge retention strips can add to the decorative effect of a panellised cladding system

2.4.7.1. Use of dry cladding system

Dry cladding system is particularly useful where fixings are restricted to particular areas of the building. Dry cladding is not used frequently on low rise buildings, where the cost can be prohibitive. Moreover the necessity to avoid possible damages of the system at the lower levels of the building suggests the use of different insulation methods for low rise buildings.

2.4.7.2. Critical detailing - dry cladding systems

As for wet systems, methods of application and system detailing should be according to manufacturers' recommendations. Particular care should be taken in the following areas: *Fire spread and fire barriers* - all systems must meet current standards and regulations.

Fixing to substrate - must take into account the nature and condition of the substrate, dead and imposed loads (wind, pressure and dynamic suction), movement of system with or isolated from the building. *Thermal bridging* - prevention by the use of a stand-off framework or cross-battening and ensuring the insulation is fitted tightly around the framework.
Maintenance of ventilation behind rainscreen cladding - by correct configuration of the supporting framework, correct fixings and retention of the insulation material and provision of permanent ventilation openings and non perforated cavity barriers. Bird and insect barrier or mesh should be added. *Air leakage* - must be prevented through the construction by correct detailing to avoid heat loss. *Existing and new services* - designers and installers need to resolve how to treat down pipes, gutters, gas mains, phone lines and aerials.

2.4.8. Bespoke overcladding system design

Designed individually by architects and designers, such a system tends to be simply detailed, allowing a non-specialist building contractor to construct it. The potential for bespoke overcladding system design mainly lies in dry cladding. A typical design may incorporate a rainscreen onto a substrate such as single blockwork, employing simple timber framing technology.

2.4.8.1. Critical detailing and watchpoints for bespoke overcladding systems

As for dry systems, the design should consider: water ingress - maintain a ventilated cavity; dynamic suction and imposed loads; fire protection - incorporate cavity barriers and prevent surface spread of flame; maintenance and durability - suitable specification of cladding material and ease of replacement.

2.4.9. Selecting a system

2.4.9.1. Factors affecting the choice of a system

The main aspect to check in choice of a system is the suitability for the proposed application, for this purpose proprietary systems should be tested and accredited for use in a particular situation. The design and type of fixing and strength of the system have to fit the requirements for wind loading resistance. The condition of substrate can influence the choice of system, according to the type of fixing and framework available. The performance of insulation influences thickness to be achieved. Mouldability and flexibility of the system is required to form or fit around external features on a façade. Incorporation of fire barriers and prevention of fire spread can affect fire performance evaluation. Vapour permeability have to be checked in order to ensure the correct dew point position in the construction. Buildability and ease of construction evaluation may prevent problems on site and increase speed construction for a cost-effective solution. Ease of access itself may affect cost of supply and installation. Maintenance requirement have to be evaluated in order to ensure longevity and low long-term costs. Rough costs of different systems can be indicated as follows: wet traditional, insulated and PMCR renders present the lower cost per square meter, wet polymeric coating and dry bespoke design have medium costs and dry cladding systems present the higher costs per square meter (up to 3 times the cheapest one).
Systems described above present advantages and drawbacks. The following table suggest some of the possible of them in order to facilitate the choice of the system suitable for different situation.

	Advantages	Drawbacks
Dry cladding systems	• Panels can be removed easily for inspection or for replacing • A dry system with a ventilated cavity may be more appropriate where driving rain and high exposure levels are a problem • Vapour permeability is maintained where a ventilated cavity is used • Faster construction than wet systems • Fixing system or framework can provide some degree of stability or span over problem areas • Can be applied in freezing conditions • Manufacturers technical service available	• High performance dry system can be relatively expensive compared with high-performance wet render systems • Supervision is required for correct installation of insulation to ensure reduction in thermal bridging and maintenance of ventilated cavity • Thermal bridging may arise unless carefully designed out • High quality control required on site • High performance dry system can be relatively expensive compared with high-performance wet render systems
Wet render systems	• Different systems are available in a range of technical performances for varying situations • Polymeric coatings do not need movement joints where they are not required in a substrate • Manufacturers' technical service available	• Renders cannot be applied in low temperatures, especially polymeric coatings • It is not possible to inspect behind render after application without remedial works • High quality control required on site • Mess on site may occur when rasping polystyrene
Bespoke systems	• Gives control of the composition and costs of individual materials as they are not part of a manufacturers' package • Gives the opportunity to use sustainability sourced products and materials • Gives the ability to design the system to allow vapour permeability through the wall construction • A wider variety of finishes can be used - eg weather boarding, stone, glass, terracotta and tile hanging • Is of tailor-made design to suit the building and its context	• No guarantee is available • No technical service is available from system manufacturers • Guaranteed performance becomes designer's liability • New designs are untested

2.4.10. Ventilated Roofs

This kind of system may be obtained by the use of an air layer of constant thickness placed between the covering elements and the below layers. This layer has the function to contribute to the control of the igrothermal characteristics of the roof through adequate air changes. This system comes adopted to the aim of:

- in the warm season: reducing the heat gains below the tiles through activation of convective flows, making comfortable the lving of the attic
- in the cold season: avoiding the humidity stagnation under the tiles, with consequent condensations that may deteriorate the insulating materials and the other structures of the cover.

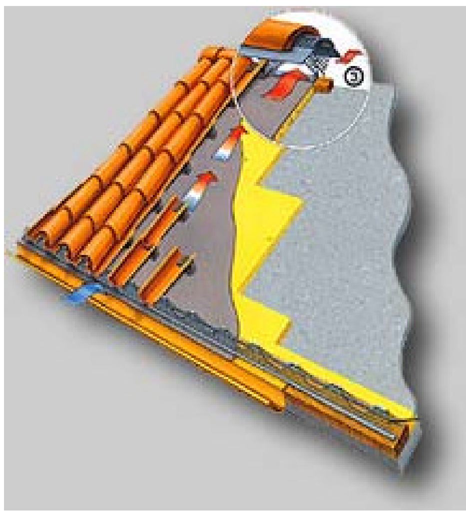
The discontinuous covers, regarding to the methodology of control of the igrothermal behavior of the structure, can be characterized and classified in the four following functional outlines:

- roof without insulating layer neither the ventilation one.
- roof without insulating layer, but equipped of the ventilation one.
- roof equipped with insulating layer, but lacking in the ventilation one (hot roof).
- roof equipped with insulating layer and the ventilation one too (cold roof).

From the igrothermal point of view the last type of cover is perhaps the one which gives the best guarantees of a satisfieing operation. The insulating layer allows to catch up the demanded value of total thermal resistance while the ventilation layer contributes to regulating the igrothermal characteristics of the cover

The ventilated layer (always placed immediately over the insulating one) can be realized by means of the space attic or also obtained by means of an appropriate ventilated air layer of constant thickness, tilted, adjacent to the structural layer. There are several techological systems to obtained ventilated roof.

- Under-tile ventilation system: it consists in a ventilated preassembled panel which makes possible to put down the insulating material, the room of ventilation and the support for the cover mantle in one operation only. The ventilation room has the height of cm.4. The system includes the supply of one antisparrow grill and a ventilated overflow to realize in work.



- Ventilated/Anchorated roof: the system consists in one room of ventilation obtained by means of the application, on every channel between the tiles, of an element with functions of rise-spacer and, at the same time, anchorage of the tiles. The obtained interstice complies with the following technical prescription: ventilation surface not less than cmq./ml.600; absolute absence of horizontal fillets limiting the upward air flow of warm air. The direct contact of the cover with the ventilation interstice takes advantage of the overheating of the air increasing the outflow speed. This system adapted to install new or recovered tiles and it is equipped of an antisparrow grill in a position to let the warm air coming go out

2.5. Doors

2.5.1. External doors

Heat loss through doors can be prevented by draught sealing and also by thermal insulation. The potential heat loss due to air infiltration is however far higher than that due to poor thermal insulation.

Prevention of air infiltration heat losses can be achieved in a number of ways.

1. Provision of draught lobbies
2. Fitting of weatherproof draught seals to external doors
3. Provision of an indoor unheated buffer space between the inside and the outside.
4. Fitting revolving doors fitted with brush seals
5. Fitting draft prevention air curtains
6. Fitting door closers on external doors (although the opening pressure may be too high for primary age or disabled pupils).

Thermal insulation of external doors

Doors should be insulated as far as possible. The UK Building Regulations give minimum standards to be applied to all buildings, see
http://www.safety.odpm.gov.uk/bregs/brpub/ad/ad-l2/pdf/complete.pdf
The maximum elemental U-values for the construction elements are given as:

	Maximum U-values (W/m^{2}K)
Windows, roof windows and personnel doors (area weighted average for the whole building), glazed in metal frames	**2.2**
Windows, roof windows and personnel doors (area weighted average for the whole building), glazed in wood or PVC frames	**2.0**
Windows, roof windows and personnel doors (area weighted average for the whole building), glazed in metal frames	**0.7**

For doors which are half-glazed the U-value of the door is the average of the appropriate window U-value and that of the non-glazed part of the door (eg 3.0 W/m^{2}K for a wooden door).

Draught prevention on external doors

Main entrances to schools should always be lobbied to prevent large heat losses due to the frequent movement of people into and out of the building. Wherever possible, draft lobbies should also be provided on external doors on circulation routes and on external classroom doors.

Fitting a revolving door fitted with brush seals is an alternative in a large school or university building but a lobby is preferable where there is room to incorporate one.

Revolving doors can be manual or motorised. The manual ones require quite a large force to open them against the brush seals and would not be suitable for primary school children. Generally an additional door must also be provided for wheelchair users and others with mobility problems therefore the space taken up by a revolving door is likely to be larger than a lobby with manually operated doors.

Lobby doors can be motorised and operated by proximity detectors. These are not often necessary in most schools. Because of the use of a lobby the door seals can be simpler and therefore easier to open than doors opening directly to outside.

2.5.2. External classroom doors

External classroom doors are frequently used by the children in early years education where the children spend a lot of time outside, playing with sand and water, using climbing frames, bicycles, wendy houses and the like. A frequent flow of children in and out is encouraged. Sometimes the whole classroom wall can be opened and an inside-outside space is created in summertime. During the colder months however this leads to large heat losses unless some way can be found to prevent the entry of cold air.

Due to space restrictions it is not always possible to lobby a classroom door opening directly to outside. One way of economising on space is to make the lobby serve another function such as a cloakroom or corridor to a toilet area.
A lobby to a primary school classroom can include a changing area and storage for coats. It can also accommodate individual toilet accommodation for each classroom. This is preferable to toilet provision centrally in a primary school as it allows better supervision of the use of toilets.

For less frequently used external classroom doors, eg for older children, or where space is restricted a sliding type door may be appropriate. These may require fitting with heated air curtains which also prevent the ingress of cold air.

2.5.3. Air curtains for draft prevention

Air curtains should be considered wherever there is a single door to outside which is used during cold weather.

<u>Physical curtains</u>
Physical barriers are available as are often seen on industrial loading bays which are used by fork lift trucks and other motorised vehicles. They consist of overlapping heavy plastic or rubber flaps which have to be physically moved aside. They would only be appropriate for industrial type delivery and loading areas for example in heavy engineering laboratories.

<u>Air curtains</u>
Air curtains are widely used in schools both as a retrofit measure to single external doors and where space restrictions or other considerations results in the use of a single external door. They work by blowing a jet of air, usually from above, across the door opening, which prevents cold air from entering. Heated jets are usually used although unheated air curtains are also available. Unheated jets use fans of higher capacity. The fans are usually quite noisy as they need to be of high capacity and are within the room space and therefore can disturb teaching activities.

Both the weather tightness and the sound insulation of door sets require the use of perimeter seals. For example, UK Building Bulletin 93 *The Acoustic Design of Schools* requires a sound insulation of 30 dB R_w for doors from classrooms onto corridors and 35 dB in the case of music rooms. This requires the fitting of threshold and perimeter seals of a similar type to those used on external doors for draught sealing. The guidance for doors in BB93 is based on realistically achievable values of airborne sound insulation from affordable doors suitable for schools.

To maximise airborne sound insulation of door sets[1], doors should be heavy and be sealed around their perimeter. However, safety issues and the need to include disabled pupils in mainstream schools mean that the ease with which doors can be opened and closed and the type of door closers fitted need to be considered when specifying for schools.

The choice of door seals should consider the frequency of use of the door. BS7352:1990 (now withdrawn) gave the estimated number of door operations for buildings. Many smoke seals have been tested for robustness against frequency of operation whereas some acoustic seals have not. Therefore, it may be advisable to choose a seal profile that is rated as both an acoustic and a smoke seal. BS 7352 included the following figures for schools:

	Estimated number of operations	
High frequency heavy duty situations:	Daily	Annually
School entrance	1,250	225,000
Entrance door to school toilets	1,250	225,000
School corridor fire door	600	108,000
Medium frequency medium duty situation:		
School classroom door	80	15,000

Draught seal manufacturers:
www.lorientgroup.com (see information on their *Integrit*y range of architectural seals)
www.sealmaster.co.uk

2.5.4. Disabled and pupil access

The specification of door widths needs to take into account the needs of wheelchair users. BS8300: 2001 Design of buildings and their approaches to meet the needs of disabled people, from the British Standards Institution and Approved Document Part M:1999 *Access and facilities for disabled people,* in support of the Building Regulations in England and Wales give requirements relating to door widths, vision panels and maximum door opening pressures.

The maximum acceptable opening pressure is limited by the strength of pupils of different ages and also the requirement for a wheelchair user to be able to open the doors.

Generally the opening force required to open a door is governed by the type of seals applied to a door, the weight/width of the door, the power of the door closer if fitted, the friction in the hinges, the resistance introduced by any seals and the airtightness of the room into which the door is opening.

[1] A door set includes the door, door frame and all furniture.

2.5.5. Door Closers

Overhead or floor mounted door closing devices are often fitted to doors on circulation routes to satisfy the fire regulations. These comprise of a spring and a hydraulic control to regulate the closing speed. They may or may not have power adjustment.
When linked to an automatic fire alarm system these can be replaced with either of two types of automatically released closer devices. “Swingfree” types where the door is free to be operated manually until closed in the event of a fire or “hold open” where the closing device holds the door in the fully open position, again until released in the event of a fire. Where classroom doors are fire rated they have to be self closing and should be fitted with one of the above closing devices.
Door closing devices on external doors can be a problem in that they make doors harder to open, particularly for small or disabled children and there are cases where motorised door opening as opposed to the use of mechanical door closers will be needed on external doors to overcome this problem. An external door closer has to exert sufficient pressure on the door to overcome various amounts of wind pressure and if this pressure is applied mechanically the force needed to open the door against the mechanism can be too high for a young child to operate the door. Therefore, whilst door closers are a low cost energy saving option they need to be used with care.
Sometimes the force required to close a heavy airtight door using a closer is so high that a child would not be able to open the door against the spring pressure of the closer. It is important to provide some trickle ventilators for background ventilation to any classroom as well as larger ventilators which can be closed when the room is unoccupied. This will allow the air in the room to escape without producing undue pressure on the face of the door as it is opened.

2.5.6. Maximum opening forces for different age groups

Guidance on acceptable forces required for the disabled to open doors is given in BS 8300:1991. Section 7.2.6 of this standard states that the closing force on a double swing door across a corridor should not exceed 30N on its leading edge. Note; swing doors are doors that open in both directions, that is doors that have no stop (A dictionary of building, John S Scott, Penguin reference books,1964).
BS 8300:1991, Section 7.3.1 states that the opening force for single swing doors that are not part of a building’s fire protection and are fitted with closing devices for security, privacy or control purposes, should not exceed 20N on their leading edges.
Section 7.3.2 states that single swing fire doors fitted with a door closer should conform to the requirements of BS EN 1154:1996, *Building hardware – controlled door closing devices – requirements and test methods*.
A recent specification for educational inclusion states that “Doors that need to self close for acoustic or security reasons will be fitted with closer devices with closing forces of less than 20 Newtons on the door (30 N if the door can swing in either direction), or will have automatic or push-pad power openers fitted to them.”
Discussions with a research organisation with experience of tests according to BS EN 1154:1996 suggested that 20N is likely to be the minimum force measured in a series of tests according to BS EN 1154:1996 that would give the necessary torque to open a 20kg, 750mm leaf door fitted with a door closer. Such lightweight doors can only be used where there is no requirement for the door to achieve a high sound rating. This is another reason for using lobbies in schools where otherwise the door would prove very difficult for the pupils to open.

Table 1. in BS EN 1154:1996 contains the following information:

Door closer power size	Maximum recommended door leaf width (mm)	Test door mass (kg)	Maximum opening moment between 0^o and 60^o (Nm)
1	<750	20	26
2	850	40	36
3	950	60	47
4	1100	80	62

The values in Table 1, BS EN 1154:1996 are relevant for doors that open one way (doors that have a stop) and swing doors. The table suggests that the maximum opening force on a 40kg door with an 850mm leaf should be ˜ 42N at the leading edge (a clear door opening of 850mm is adequate for wheelchair access according to BS 8300:1991).
BRE information paper IP2/82, Ergonomic requirements for windows and doors, contains a table giving suggested maximum opening forces for females in the age groups 5 – 12 years and 60 – 75 years for hinged doors with knobs and handles.
For the 5 – 12 years age group, the suggested maximum opening forces (push or pull) in IP2/82 are:

- 20N for doors with knobs, (knobs are seldom the correct specification for educational use)
- 45N for doors with handles.

45N force applied at the lever of a door which is 800mm from the hinge side is equivalent to a moment of 36Nm. This is equal to the maximum recommended opening moment for a 40kg door fitted with a closer in Table 1, BS EN 1154:1996.
(Note: maximum operating forces for doors with lever handles of 30N for age group 5-7 years and 70N for age groups 8-11 and 60-75 years are suggested in a document containing test results provided by Janex Ltd).

Compression seals between a door and its stop are often used to improve the sound insulation of door sets and it is unlikely that these will add significantly to the force required to open the door. However seals beneath doors are also necessary to maximise their airborne sound insulation. If these seals add significantly to the force required to open and close doors they could be unsuitable for schools.
Discussions with an organisation with experience of testing to BS EN 1154:1996 suggest that ‘drop down’ threshold seals are the type least likely to add to significant frictional force. An organisation with experience of specifying and supplying doors to schools advised that they specified ‘drop down’ seals because these avoided the need for thresholds. However, it should be noted that no test data comparing the torques necessary to open doors with different types of seals beneath have been made available.

Discussions with manufacturers and examination of available test results indicate that a 30 minute fire door set (FD30) can achieve airborne sound insulation of 30dB – 32dB R_w with a drop-down seal fitted to the underside of the door. It is important to note that these are values for airborne sound insulation measured in a laboratory. For these measurements, it is usual for manufacturers to take special care that doors and seals are installed correctly. Therefore, it is reasonable to assume that the values for airborne sound insulation for doors given by manufacturers are unlikely to be exceeded when they are installed in schools.

Specialist acoustic door sets can be expensive to buy and install correctly. Therefore, it would appear appropriate that readily available fire door sets, or sets with solid core doors of equivalent mass, with appropriate seals should be specified for most situations in schools. If schools decide that specialist 'acoustic' doors are needed for specific applications, then that is a matter for those schools.

2.5.7. Management and maintenance of doors

Keep windows and doors shut when the heating is on

Look to see if draught seals are intact each term as part of energy efficiency walk round

References

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