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

SUBTASK A

Overview of Retrofitting Measures

edited by:

Tomasz M. Mróz

Poznan University of Technology, Poznan, Poland

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Chapter 2

Building Envelope

by Kirsten Engelund Thomsen, Marco Citterio, Richard Daniels

Table of contents

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.

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