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WELCOME

Energy in Buildings and Industry and the Energy Institute are delighted to have teamed up to bring you this Continuing Professional Development initiative.

This is the eighth module in the third series and focuses on **The Building Envelope**. It is accompanied by a set of multiple-choice questions. To qualify for a CPD certificate readers must submit at least eight of the ten sets of questions from this series of modules to *EiBI* for the Energy Institute to mark. ***Anyone achieving at least eight out of ten correct answers on eight separate articles qualifies for an Energy Institute CPD certificate.*** This can be obtained, on successful completion of the course, for a fee of £15 (for members) or £25 (for non-members).

The articles, written by a qualified member of the Energy Institute, will appeal to those new to energy management and those with more experience of the subject. The following topics will appear in the next two issues of *EiBI*: fuel cells; the building envelope; water management; and lighting.

If you miss any of the modules in the series (the first seven were on BEMS, small-scale CHP, power quality, refrigeration, the Energy Performance of Buildings Directive, integrated renewables, and fuel cells) let me know (mark.thrower@btinternet.com) and we will send the missing modules to you by e-mail in 'pdf' format.

The previous 20 modules from the first two series are also available free of charge. Please contact me by e-mail if you would like to receive these.

MARK THROWER, MANAGING EDITOR

CURRENT THINKING ON...

BUILDING ENVELOPE

By Patrick Waterfield, CEng, Fellow of the Energy Institute

The building envelope describes everything that separates the interior of a building from the external environment, ie the outer walls, windows, roof and the floor. A primary function of the building envelope is to provide shelter from cold, rain, winds or excess sun. The envelope can also allow beneficial interaction with the external environment in the form of natural daylighting, direct solar heating gains and natural ventilation. The envelope of the building is thus a key aspect of the design in terms of the impact of external climatic drivers upon the internal environment.

The envelope of the building arguably has the greatest potential impact on heating or cooling energy consumption and can also influence lighting and ventilation loads. There has been much talk in UK recently of escalating energy prices and the fact that fossil fuel reserves are reaching peak production. A bewildering array of boilers (some 3,000) are listed on the SEDBUK (Seasonal Efficiency of Domestic Boilers in UK) database and condensing boilers are becoming mandatory in UK in most cases. Yet an efficient boiler is still wasting energy in an inefficient building envelope. Where cooling is required, the reason is often excessive solar gains (exacerbated by high internal gains) and insufficient opportunities for ventilation – both envelope-related issues.

In vernacular architecture throughout the world, the physical properties and composition of the envelope are determined by the external climatic drivers at a given location. Igloos are hemispherical, minimising external surface area for a given internal volume, and openings are minimal. African mud huts absorb heat in the walls by day, retaining the heat for the night-time, while openings either side and grass roofs allow air movement through the structure thus providing cooling. There are many ways in which a geographical location can be classified including, cold, temperate maritime, tropical wet/dry, arid, etc, each of which will require different treatment of the envelope. However, in view of space restrictions and the need to provide a reasonable depth of content, the focus here is on temperate maritime climates such as in the UK.

There are two basic approaches to energy-efficient design, as characterised by interaction with the outside environment - the "selective" and "exclusive" approaches. The selective approach allows the envelope to make use of natural solar heating, natural ventilation and daylighting, to offset the energy otherwise used in providing a comfortable internal environment – in other words "passive solar design", as exemplified in vernacular design. Ventilative heat loss may be offset by preheating ventilation air via glazed elements such as atria. In order to justify a greater envelope area - often with attendant higher capital cost - the thermal and daylighting benefits of passive solar design need to be realised.

With the exclusive approach, the emphasis is on excluding the external environment, i.e. reducing the external surface area for a given volume (that is, achieving a compact form) and using high levels of insulation and advanced glazing systems, etc – in other words, "super-insulation". Below an overall U-value of about 0.2 W/m^2K, internal and solar gains can provide most if not all of the heating requirement of a building, thus removing the need for central heating systems. As windows are the main source of heat loss, the glazing area is likely to be kept to a minimum, thus increasing the reliance on artificial lighting. Ventilation may also be provided mechanically in order to closely control heat loss.

The two approaches are not entirely mutually exclusive - in its temperate

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maritime location the UK has opportunities to utilise both in order to significantly reduce the energy requirement of a building. Elements of passive solar design can be incorporated in the south façade of a super-insulated building, while the super-insulated approach would be a feature of the north side of a passive solar building.

Improved energy efficiency can often be used to help make a case for envelope refurbishment. One of the most common envelope elements to be upgraded is glazing. It is generally accepted that it is not economic, in energy terms alone, to replace perfectly serviceable single glazing, even in thermally inefficient steel frames. However, double glazing will provide additional non-energy related benefits such as reduced risk of condensation and improved acoustic insulation. Moreover, if the glazing (and/or frames) needs replacing anyway, you need only consider the over-cost of higher performance systems compared to the base-case option. Courtesy of the Building Regulations, double glazing has finally become the base-case and consideration should certainly be given to higher performance glazing such as low emissivity (low-E), inert-gas-filled and triple glazing systems.

Retrofitting insulation to the fabric is also a common and, generally, cost-effective measure. Where cavities exist of sufficient width these may be filled. Solid-walled buildings can only be treated internally, via dry-lining, or externally, via external cladding. Where conditions permit, (eg absence of significant internal architectural features) dry-lining would be the first option, eg using a plasterboard/insulation laminate on plaster dabs or mechanically fixed on timber battens secured to the masonry. External insulation, while more costly, can be less disruptive to internal function and can also provide an opportunity to refurbish the external appearance of the building, while addressing other issues such as weatherproofing.

An effective planned maintenance programme is essential in ensuring the preservation of the building envelope and thus the weather-proofing of the building. The first step in establishing a planned maintenance regime is to draw up a schedule of envelope types, materials and manufacturers/suppliers. Useful additional information includes estimated area, installation date, warranty information, contractor information, and records of repair and inspection.

Regular inspection is a vital component of a planned maintenance regime. Gutters must be regularly cleared (more frequently in the autumn) to prevent blocking of rainwater hoppers and downspouts which can lead to water spillage onto the envelope fabric. Key items to look out for during inspections include integrity of rainwater goods, any signs of plant overgrowth and pest infestation and condition of pointing, flashings, mastic seals, expansion joints, etc. Any defects should be noted and addressed in timely fashion. Exterior timbers will need repainting every five years or so – possibly more frequently in areas of high exposure.

For speed of construction and thus reduced on-site times and, probably, reduced overall contract costs, serious consideration should be given to off-site construction. Additional benefits include factory-level quality control and reduced construction waste. Structural insulated panel systems (SIPS), which are becoming more widely used these days, incorporate an insulated core within concrete or sustainable timber panels forming structural wall or roof elements. With timber construction, it may be prudent to provide some thermal mass, eg via block internal walls, to reduce risk of summer overheating.

Thermally, glazing will always be the weak point of the envelope. The following table shows the thermal performance, expressed in U-value, of various glazing configurations. The frame material would also have an impact – note that these figures apply to timber window frames.

A high level of workmanship is necessary to achieve an airtight building – it is not enough simply to rely on well-draught-sealed windows and doors. With newbuild, if working to a target airtightness level (such as $7m^3/h/m^2$ at 50 Pa), it is important to advise all tradesmen and sub-contractors, especially those whose operations are likely to influence air-tightness, that this is an integral part of the design. Particular care should be taken with detailing and construction of curtain walling systems as these can potentially give rise to high levels of direct air infiltration, or increased heat loss due to convective movement behind the inner skin.

Airtightness testing is carried out via a fan pressurisation test. Large fans, mounted and sealed in door frames, are used to blow air into the building, with all windows and specific ventilators sealed off. In this way only infiltration is measured, not designed-in ventilation. The fans are then allowed to run until a pressure of 50Pa is reached and a measurement is taken of the airflow through the fan required to maintain that pressure. Different readings may also be taken at different pressures.

The rate of airflow across the fan will indicate the level of leakiness – the greater the airflow required to maintain the pressure the more leaky the building. A smoke pen can also be used to pinpoint local areas of air leakage, for example around window frames, at skirtings etc, in order for remedial measures to be taken if necessary. Relatively small gaps can be sealed with expanding foam or even

Single Glazing	**4.8**		
Multiple Glazing	**Pane Separation**		
	6mm	**12mm**	**16mm**
Double Air-filled	**3.1**	**2.8**	**2.7**
Double Hard[1] Low-E	**2.7**	**2.2-2.3**	**2.0-2.1**
Double Soft[2] Low-E	**2.6**	**2.0-2.1**	**1.8-1.9**
Double Argon-filled[3]	**2.9**	**2.7**	**2.6**
Double Argon Hard Low-E	**2.5**	**2.1**	**2.0**
Double Argon Soft Low-E	**2.3**	**1.8-1.9**	**1.7-1.8**
Triple Air-filled	**2.4**	**2.1**	**2.0**
Triple Hard Low-E	**2.1**	**1.7**	**1.6**
Triple Soft Low-E	**1.9-2.0**	**1.5-1.6**	**1.4-1.5**
Triple Argon-filled	**2.2**	**2.0**	**1.9**
Triple Argon Hard Low-E	**1.9**	**1.6**	**1.5**
Triple Argon Soft Low-E	**1.7-1.8**	**1.4**	**1.3**

Indicative U-values (W/m^2K) for different glazing configurations in a timber frame

1 Hard Low-E glazing emissivity 0.15-0.2
2 Soft Low-E glazing emissivity 0.05-0.1
3 Gas mixture is 90 per cent Argon:10 per cent air

flexible sealants. Larger gaps may need something a little more substantial, such as insulation, mortar, etc. In newbuild, it is a good idea to carry out the pressurisation test before installing fitted furniture etc in case remedial measures are needed. However, if water appliances are installed, ensure that water traps are filled or in some way blocked, otherwise a false reading will be given. Pressurisation tests can also be carried out on existing buildings, though remedial measures may be harder to carry out.

To date, airtightness testing has been an option under Building Regulations in England and Wales. However, this is set to become a requirement under proposed amendments to the Building Regulations across the UK. It is likely to be a key element of demonstrating compliance for "big shed" industrial buildings, which tend to be inherently of lower envelope thermal performance.

A thermal imaging camera can be effective in checking for thermal bridging (eg via missing insulation) as well as air leakage from a building. Even low-cost systems will indicate areas of relative high heat loss, while more advanced equipment can provide accurate surface temperatures.

Shading is another function carried out at the building envelope. There are many ways in which the envelope can accommodate shading, for example via overhangs and depth of reveals, brise-soleil (either fixed or moveable) and solar control glazing or films. The most effective form of shading is external (since solar gains may be screened out before they penetrate the glazing) and moveable (in order to respond to variations in solar intensity and incidence angles). However, external moveable shading is more prone to mechanical failure and thus requires greater maintenance. External shading is also likely to involve higher capital costs and makes a considerable impact architecturally on the building. Internal shading is less effective as solar gains will already have penetrated the glazing and, unless reflected back out directly, will result in a build-up of heat behind the glazing. Fixed shading can be positioned and sized to cope with extremes but will be inherently unable to adapt to all situations. Be wary, when considering shading strategies, of denying useful daylighting gains thus defaulting to artificial lighting. A combination of internal and external shading, via brise-soleil extended internally into a light shelf, can reduce unwanted glare and heat gains while helping to transmit useful daylighting into the building. If considering solar control glazing or films, be careful to select the type with the required properties of thermal and daylighting transmittance.

New construction techniques and products are coming to market all the time. It is not the intention here to provide a comprehensive account of all available innovative technologies but, simply, to focus on a few which may be of interest.

Increasingly, in the future, there will be an emphasis on buildings being able to meet a proportion of their energy loads from within the site itself, rather than simply being "plugged in" to the available utilities. One such opportunity with a direct envelope application is photovoltaics (PV). Building-integrated PV (BIPV) in particular presents an opportunity (especially in a newbuild situation, though also with envelope refurbishment) to integrate a zero-carbon technology into the building fabric.

Particularly in a retrofit situation, the sheer thickness of sealed glazing units (especially multi-layer) can become a problem. At research and development stage currently, though probably within 5 years of market, is "evacuated glazing". As convective and conductive losses are eliminated in a vacuum, the overall thermal performance of the system is high. Moreover, as the width of the vacuum is immaterial, the units can be made very thin. In order to prevent the panes being pulled together under vacuum and touching (which would provide a thermal bridge), tiny aluminium spacers are used to maintain pane separation. These spaces are so small that they do not present either a significant heat conduction path nor a visual obstruction.

Adaptable glazing systems are also being developed which may be able to react to changes in solar radiation either direct or via a control signal. Electrochromic systems are already available which can change from transparent to opaque under action of an electric current. Such a system could provide, at different times as required, shading from solar gains as well as reduction of radiative heat losses from the building. Thermochromic systems, which would react to variations in temperature, could respond to changes in direct solar gains to provide shading. Such systems have the potential to allow the envelope to self-adjust to changes in solar gains without the need for mechanical shading devices.

Some "breathing walls" simply allow water vapour to pass through the envelope, much as it does with human skin. Certain materials and constructions will allow the wall to "breathe" in this way, including composite concrete/woodchip blocks, lime products and various forms of timber frame construction. Where airflow into and out of the building is involved, this can entail heat lost from the inner skin of the envelope being used in a cavity to pre-heat incoming fresh air. There is interest in breathing walls currently as a means of improving internal air quality and preventing condensation and mould growth, which have come to the fore due to the progressive sealing-up of building envelopes.

Double skin construction on a south façade, using two layers of glazing separated by up to a metre, can both offset heat input/loss during the heating season and also assist in summertime cooling. In winter, the void between the layers will act as a buffer to heat loss. Furthermore, fresh air entering the void from the outside via low level vents can be heated under solar action and delivered via natural buoyancy means into internal spaces. In summer, by opening low level vents on the inner skin and high level vents on the outer skin, air can be moved from the building interior, entrained by natural buoyancy in the void, thus assisting ventilative cooling.

In a wider environmental approach, a life cycle analysis (LCA) of envelope materials can be undertaken, including the energy required to process the product from raw materials (embodied energy), energy required during construction and also the potential for re-use or recycling post-use. Natural materials will tend to score favourably in LCA, requiring less energy to process and being more easily re-used or assimilated back into the natural environment. The embodied energy of some common building materials is tabled below. Figures for density are also provided to enable conversion from a mass to a volume basis.

	Embodied Energy (kWh/kg)	Density (kg/m^2)
Brick	**0.83**	**1,700**
Dense block	**0.50**	**2,300**
Medium block	**0.42**	**ca 1500**
AAC block	**1.00**	**600**
Plaster	**0.81**	**600-1,300**
Plasterboard	**1.22**	**950**
Render	**0.50**	**1200**
Glass fibre insulation	**1.36**	**12**
Timber stud	**1.39 ca**	**500**
Glass	**3.53**	**2500**
Mild Steel	**9.44**	**7800**
Aluminium	**47.2**	**2702**
Copper	**27.8**	**1350**
PVC	**22.2**	**550-650**
MDF	**3.14**	**300**

Embodied Energy and Density of Some Building Materials

SERIES 3: MODULE 08 TEST QUESTIONS

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

1. Which of the following may not be a function of the building envelope?
- ☐ Rainscreen
- ☐ Structural support
- ☐ Provision of daylight
- ☐ Provision of solar heating gains

2. Which of the following statements is incorrect?
- ☐ The selective approach makes use of natural heating, daylighting and ventilation
- ☐ The exclusive approach relies more heavily on artificial conditioning
- ☐ The exclusive approach usually adopts a more compact form
- ☐ Superinsulation and passive solar design are mutually exclusive

3. Below what overall fabric U-value does the heating requirement in a building start to become negligible?
- ☐ 0.4 W/m^2K
- ☐ 0.3 W/m^2K
- ☐ 0.2 W/m^2K
- ☐ 0.1 W/m^2K

4. Which of the following glazing systems has the best thermal performance?
- ☐ Hard low-E coated Argon-filled double glazing with 16mm pane separation
- ☐ Soft low-E coated Argon-filled double glazing with 12mm pane separation
- ☐ Standard air-filled triple glazing with 16mm pane separation
- ☐ Hard low-E coated Argon-filled triple glazing with 6mm pane separation

5. What would be a good target airtightness level for a newbuild dwelling?
- ☐ $7m^3/h/m^2$ at 30 Pa
- ☐ $7m^3/h/m^2$ at 50 Pa
- ☐ $10m^3/h/m^2$ at 30 Pa
- ☐ $15m^3/h/m^2$ at 50 Pa

6. Which of the following statements is correct?
- ☐ Well draught-sealed windows and doors make for an airtight building
- ☐ Pressure testing can be carried out on existing buildings or newbuild
- ☐ Natural ventilation assumes a non-airtight envelope
- ☐ An airtight envelope implies no permanent background ventilation

7. Which of the following can a thermal imaging camera not do;
- ☐ Indicate relative areas of heat loss in an envelope
- ☐ Indicate the rate of heat loss
- ☐ Indicate areas of missing insulation
- ☐ Indicate areas of high air leakage

8. Which of the following is not necessarily a benefit of off-site construction?
- ☐ Reduced on-site time
- ☐ Improved quality control
- ☐ Reduced project costs
- ☐ Reduced construction waste

9. Which of the following methods of shading is most effective?
- ☐ External, fixed
- ☐ Internal, fixed
- ☐ Internal, moveable
- ☐ External, moveable

10. Which of the following statements is correct?
- ☐ A breathing wall allows moisture or air movement inn one direction only
- ☐ Evacuated glazing reduces radiative heat loss
- ☐ Thermochromic glazing systems respond to electrical control signals
- ☐ A double skin construction can assist in heating and cooling a building

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Completed answers should be mailed to:

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