Kawneer White Paper 2001

Thermal Performance

Kawneer
An Alcoa Company

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PLEASE NOTE:

2. Standards
The standards information quoted in this document is current and correct, to the best of our knowledge, as we go to press. However, standards are regularly updated and superseded, and we cannot guarantee the accuracy of standards information or its suitability for specific uses, and we recommend that readers make their enquiries where detailed information is required.
All information contained herein E&OE.

1.0 Introduction

1.01 Preface

Although aluminium extrusions have been used in the manufacture of window frames and curtain walling systems for more than 70 years, the past decade has seen the insulating properties of glazed windows and curtain walling systems increased significantly, with the widespread use of insulating glass units and thermally-broken framing. This is important because aluminium has a high coefficient of conduction, 220W/mK, which means that unless care is taken at the design stage, the many benefits of using aluminium components in construction - notably its ability to provide simple elegant solutions to complex design problems due to its unrivalled ability to be extruded into complex shapes - can be compromised.

The thermal issues surrounding aluminium are complex and subject to different interpretations even within the industry itself. In practice, however, there are two issues which should concern architects and specifiers. The first is the provision of effective thermal breaks within building components themselves. The second, more complex, is the avoidance of construction details which can obviate the good thermal performance of components and systems.

1.02 Thermally Broken Components

Without effective thermal breaks, aluminium's high coefficient of thermal conduction can compromise the thermal performance of windows, curtain walling and other engineered construction systems.

There are proven and effective strategies for thermally breaking even the most complex aluminium extrusions. The advent of CAD systems has optimised the extruder's ability to design and deliver components capable of exceeding the thermal performance stipulated in the Building Regulations.

There are two basic systems for thermally-breaking aluminium extrusions. One technique involves the insertion and mechanical fixing of a thermal web, or webs, usually glass fibre reinforced polypropylene or nylon 66 (polyamide), into a channel on the aluminium section. One of the major advantages of this system is that it allows different colours to be used on either side of the finished assembly.

The alternative system, known as the "pour and cut", involves pouring a special liquid resin, usually isocyanate, into a semi-closed channel in a single extrusion. Once the resin has set, the aluminium joining section is cut out, leaving the resin as the thermal break. This system, which is becoming less popular, has the disadvantage that sections have to be painted before the break is made.

1.03 Structural Detailing

Despite the wealth of knowledge within the architectural, engineering, fabrication and installation professions, it is an unfortunate reality that buildings are still being constructed with fundamental design flaws. These usually only manifest themselves once the building is in service. With aluminium window and curtain walling systems, the primary indicators of poor design are condensation and condensate run off. Typically the blame falls initially on the fenestration systems or their installation. Often, however, the problem is actually found to lie in the structural concept, such as a projecting steel beam causing cold bridging. This White Paper will address these issues, and also consider the individual roles and responsibilities of architects, structural engineers, fabricators and installers in ensuring that such fundamental defects are ironed out at the design stage.

2.0 Thermal Performance and the Building Regulations

2.01 Introduction

National Building Regulations for insulation were not introduced until 1965. Since then, however, the standards have been raised several times, with the 1994 revisions representing the most comprehensive changes since the 1960s. The driving force behind the steady tightening of the Building Regulations has been the recognition that buildings are responsible for approximately 50% of CO_2 emissions. In a typical UK home, heating accounts for 57% of all energy consumed and produces over one tonne of CO_2 annually. The introduction of Regulation 14A specifically recognised this factor with its requirement that all newly created dwellings be provided with an energy rating calculated by the Standard Assessment Procedure (SAP), which takes into account fuel costs and can thus be updated in line with fuel inflation.

One of the four main platforms of the Building Regulation's drive to conserve fuel and power is setting limits for the amount of heat which can be lost through the building fabric. In this respect, Approved Document L treats dwellings separately from other buildings. However one technique for assessing thermal performance, the Elemental Method, is common to all building types. Designers can also use Target U-value or Energy Rating methods to assess the thermal performance of dwellings, or the Calculation or Energy Use methods for other structures with a floor area of more than 30sq. metres.

2.02 Area Allowances

The Building Regulations provide area allowances for windows, doors and rooflights in different types of buildings. These may be increased providing that the average U-value of the elements is improved accordingly. For residential buildings, windows and doors are restricted to 30% of the exposed walls and rooflights to 20% of the total roof area. In shops and offices, the figures are 40% and 20% respectively, while in industrial buildings the figures are 15% and 20% respectively. For dwellings, 22.5% of the total floor area can be allocated to windows, doors and rooflights combined.

2.03 The Elemental Method

The Elemental Method specifies maximum U-values for window, door and rooflight areas for different types of building. The Building Regulations provide clear tables setting out the average U-values for windows, doors and rooflights for each building type, and separate tables show the area allowances for these construction elements. For dwellings, the maximum U-value recommended varies with the SAP rating. For a SAP rating of 60 or less, 3.0W/m2K is the limit, but this can be increased to 3.3W/m2K where the SAP rating exceeds 60. For these buildings, a maximum average U-value of 3.3W / m2K is recommended, with the area allowances for windows and doors based on the total exposed wall area, and for rooflights on the total roof area. While tables are provided giving average U-values for different types of windows, doors and rooflights, it is preferable to refer to manufacturer's certified data, since the thermal performance of different systems can be at considerable variance with the calculated norm.

2.04 Target U-values for Dwellings

When using the Target U-value method to assess buildings it is worth noting that the benefits of passive solar gain can be taken into effect when making the calculations. The Target U-value method assumes that glazing elements are equally distributed on north and south elevations. The procedure allows the area of glazing used in the calculation to be reduced to account for solar gain; allowing designers to benefit from good practice such as maximising the area of south facing glazing and minimising the area of north facing glazing.

2.05 Energy Rating Method for Dwellings

The purpose of the Building Regulations is to achieve the Government's energy conservation targets without providing unnecessary restrictions on designers. The Energy Rating method is a good example since it allows any valid energy conservation method to be employed in the design. The building will be deemed to satisfy the requirements of Paragraph 1 of Schedule 1 for the conservation of fuel and power if the SAP rating, when related to floor area, equals or exceeds that given in Table 4 of Approved Document L.

2.06 The Calculation Method for Non-domestic Buildings

The Calculation Method provides greater flexibility for designers regarding area allowances for windows, doors and rooflights than are permissible using the Elemental Method. The key feature of the Calculation Method is that the rate of heat loss from a proposed building must be able to be shown, by calculation, to be no greater than that from a standard building of similar size and shape which has been designed to comply with the Elemental Method. This allows designers to satisfy the requirements of the Building Regulations without rigidly adhering to the specified area limits on glazing elements. As thermally efficient glazing systems, incorporating Low-E and/or gas-filled DGUs, grow more and more popular, this is an increasingly important factor for specifiers.

2.07 The Energy Use Method for Non-domestic Buildings

The Energy Use Method provides complete flexibility for designers regarding area allowances, etc., and permits any valid energy conservation methods to be used. The ability to include solar gain into any calculations is particularly pertinent when it comes to windows and rooflights. The burden on designers is to carry out an energy calculation to show that the annual energy use of the proposed building, after taking into account any solar gains, etc., is no greater than the calculated energy use of a similar building designed in accordance with the Elemental Method.

3.0 Framing and Thermal Performance

3.01 Introduction

The factors which primarily influence the thermal performance of a window or curtain walling frame are the thermal break, the size of the frame projections (both internally and externally), the glazing gaskets and the amount of air within the assembly. The specifier is most concerned with the U-value and the surface condensation risk.

3.02 Testing Thermal Performance

Various test and calculation methods exist to assess the performance of window and curtain walling systems. These have been proven to give significant variation in results, due to the choice of glazing used in the test specimen or calculation, as well as variations in the methodology itself.

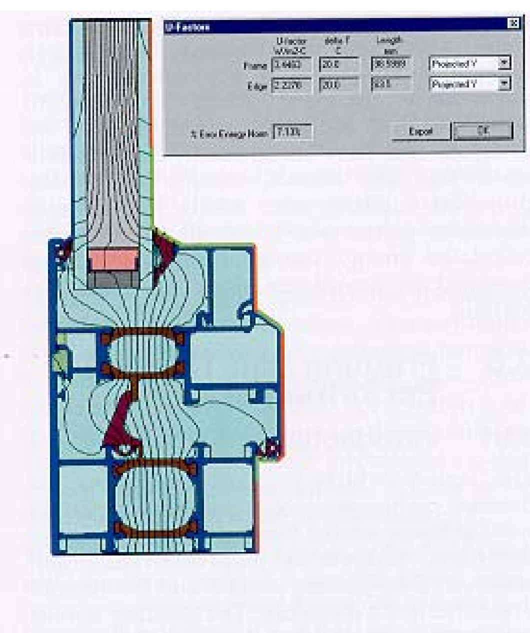
The method adopted by The Council for Aluminium in Building (CAB), calculates the frame U-value taking into consideration the edge effect of the glazing unit to produce a value for the frame and glass edge. Computer simulation programmes, such as Therm, Window or Kobru, also take into account the influence of the glazing and its edge detail.

Test methods such as the guarded hot box (conducted to BS 874: Pt 3) measure the framing values taking into account the glazed element and its edge effect. This form of test also assesses the glazing element, producing a centre pane U-value.

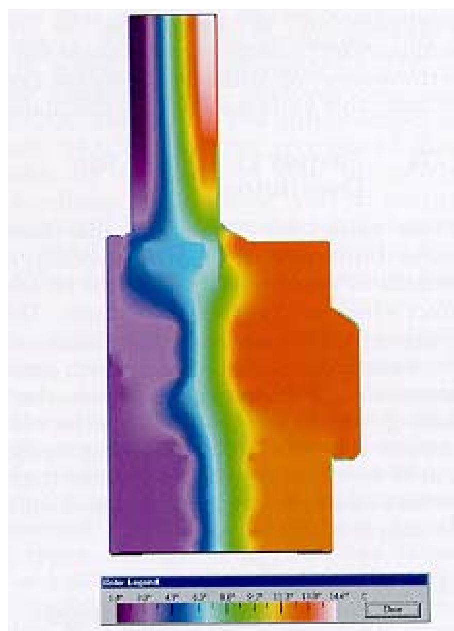
Confusion among specifiers is largely caused by the variance between the results obtained using the methodologies above with those used in the test method to DIN 52619-3, prevalent in Germany, which assesses framing with a standard insulating panel in place of the normal glazing element. This form of test cannot take into account the influence of the sealed units and metal edges and, consequently, tends to overstate the thermal efficiency of a frame. A typical frame tested according to the CAB method, the Therm computer model or measured according to BS 874, will produce a result between 3.80 and 3.94W/m2K. When tested under DIN 52619 to DIN 4108 Pt 4, the same window would be classified as Group 2.2, with a U-value spread of between 2.8 and 3.5W/m2K. Given the importance of the 3.3 W/m2K target in the Building Regulations, there is clearly room for manufacturers and specifiers to give themselves a false sense of compliance using the DIN methodology, whereas the actual performance of the completed building may well fall below the statutory requirements. This discrepancy is even more stark when curtain walling systems are assessed by the two contrasting methodologies, which may lead to unsafe condensation predictions. Thus, while the DIN standards are widely respected across Europe, it is currently advisable that architects base their specifications for windows and curtain wall systems on one of the three systems (BS 874, CAB Guide or Therm computer simulation) that have been proven to give a more accurate guide to actual performance.

The current redraft of Part L of the Building Regulations, currently the subject of a Government Consultative review, requires the use of BS EN ISO 10077-1 for calculation methods. The CWCT's Fenestration and Revision of the Thermal Regulations paper (7th August 2000) states that "U-values specified and quoted in the UK should be to this standard which is based on sound scientific principles and calculates a true U-value".

As an example, below is a simulation through a Tiltum frame and vent with 4-16-4 Low-E glass argon filled with an aluminium spacer.



Typical Tilturn frame and vent detail showing Isotherms



Typical Tilturn frame and vent detail showing Infrared Temperature Spectrum

3.03 Effective U-values

Glass, being transparent, allows solar energy to enter a building. The U-value conventionally used to calculate heat loss ignores this fact. This means that calculations may not give a true picture of the building's actual performance. It is now becoming more acceptable to combine heat losses with solar gains, modifying a traditional U-value into an effective U-value, sometimes known as an Energy Balance Value. There are now calculation methods available which identify, in a single figure, the influence of the window on total energy use. It draws on standard meteorological data and the known thermal characteristics of the glazing, of the type to be found in CIBSE Guide A and Guide C.

4.0 Glazing and Thermal Performance

4.01 Energy Conservation

One major focus of the Government's attempts to cut the nation's energy bill is domestic housing. As a result of the Home Energy Conservation Act, consumption must be reduced by 30% over the next decade. Space heating alone accounts for around 57% of energy used in housing, so preventing heat loss in the home is one way of achieving this ambitious target.

4.02 Low Emissivity Glazing

A study by a group of European glass and glazing specialists calculated that if the UK's stock of single glazed windows, an estimated 266 million sq. metres, were replaced with high-performance double glazing with low emissivity (Low-E) glass as the inner pane, energy worth £1.5 billion a year would be saved and CO_2 emissions would be cut by 17.7 million tonnes.

The appropriate choice of glazing system can eliminate the need for air conditioning; it can achieve controlled passive solar gain; it can prevent heat loss from inside buildings; and it can substantially enhance the internal visual environment. Low-E glass has a special coating which limits the rate of heat emission to a certain, specified level. In airspaces with uncoated surfaces, around 60% of the total heat exchange across the airspace is accounted for by long wave radiation. When one of the panes has a Low-E coating (the emissivity is usually less than 0.2 compared with 0.88 for plain float glass) the radiation exchange is reduced by around 75% and, consequently, the U-value is improved.

A 1994 study by the BRE concluded that for every £1 saved by tenants in dwellings which had been designed or refurbished along energy efficiency guidelines, the landlord could save at least the equivalent amount in previously unquantified management and maintenance costs. The BRE concluded that savings could be as high as £1,000 per dwelling per year.

There are no comparable large scale studies of the financial impact of the adoption of high-performance double glazing in the commercial and industrial building sectors. However, extrapolating from the results of the domestic studies, the potential energy and building maintenance savings are clearly considerable.

The amendments to the Building Regulations have caused designers to take more interest in the whole concept of Low-E glass. Approved Document L, Conservation of Fuel and Power, 1995 Edition, effectively requires all but the smallest windows to be double glazed if the thermal efficiency of the house as a whole is to demonstrate compliance. Designers have not been slow to recognise that the use of Low-E glass gives them extra flexibility when it comes to manipulating elements of design to achieve compliance. For a single pane of glass, the U-value is 5.6W/m2K. For standard double glazing the figure falls to 2.8W/m2K. Double glazing with Low-E glass can achieve, typically, 1.5 to 1.9W/m2K, which is actually superior to triple glazing using standard float glass. A triple-glazed unit with two Low-E panes can achieve a U-value as low as 1.0W/m2K, while the ultimate window, a triple-glazed window with Low-E solar-control glazing to two panes and krypton filling, can achieve 0.7W/m2K.

The Energy Saving Trust has estimated that in a domestic dwelling, replacing existing single glazed windows with standard DGUs has a 5 to 6 year payback, while Low-E DGUs have a 7 to 8 year payback.

4.03 Airspace Width

Thermal performance is improved by increasing the width of the airspace. Due to convection occurring within the airspace, little thermal benefit accrues from increasing the airspace beyond 16mm. Adding a third glass pane and, consequently, a second airspace, gives further improvement.

4.04 Gas-Filled DGUs

Gas filled DGUs or TGUs, where the air in the sealed units is replaced by a gas, such as argon, with lower thermal conductivity, can further improve performance. An argon filled cavity in a Low-E DGU will, typically, reduce the U-value from 1.9 to 1.6W/m2K. With a krypton gas filling, this performance can be increased still further to 1.35W/m2K.

4.05 Thermal Barriers and Gaskets

Often overlooked by specifiers, the material choice for thermal barrier and the actual shape of gaskets can have a considerable effect on the thermal performance of a window or curtain walling system.

Simply replacing a polyamide double insulating strip in a typical window frame with a polyurethane alternative can reduce the U-value from, say, 3.95W/m2K to 3.72W/m2K. This is because the K value, or thermal conductivity, of polyurethane is just 0.17W/mK, compared with 0.28W/mK for glass fibre reinforced polyamide.

However, polyurethane is not as versatile as polyamide, as it is limited in width of thermal bridge design. Polyamide thermal breaks offer greater flexibility in profile design and are commonly available in widths from 12 to 36mm.

Gaskets can influence the thermal performance of a complete window assembly to a comparable degree. Not only does the thickness and positioning of the gaskets impact on thermal performance, but there is also clear evidence that gaskets with ‘tails’, which compartmentalise the air spaces within the framing, improve the thermal performance still further.

4.06 Warm Edge Glazing Units

Insulating units containing high performance glass (and gas-filling) require edge spacers with a comparably high insulation performance; so called ‘warm edge’ technology. This uses glazing units which do not have exposed metal edges and therefore do not suffer the ‘edge effect’ like standard DGUs. Instead spacer bars provide an effective thermal barrier around the glazing. This is claimed to improve the U-value of the window by as much as 10%.

4.07 Condensation Risk

The key factor regarding the condensation risk of any window system, including aluminium, is the surface temperature of its inner face. If this temperature is higher than the dewpoint of the air within the building, condensation will not form. However, if it is lower than the dew point then condensation is inevitable. As a rule of thumb, the higher the relative humidity (RH) of the internal air, the greater the risk of condensation. A modern commercial building generally has an RH of between 43 and 49%, while in a domestic dwelling 50 to 55% RH is usual. Calculations undertaken by CAB have shown that with external air at -4°C at a windspeed of 2 metres per second, and internal air at 21°C SANC (still air/natural convection), the inner face of a mullion in a window with a U-value as high as 3.95W/m2K would be 10.9°C, equivalent to 52% relative humidity, even in severe weather conditions. As a rule of thumb, a non-thermally broken slimline aluminium window frame (the lowest specification) has a surface condensation risk at less than 42% RH given the atmospheric conditions listed above, whereas a thermally-broken commercial framing system/ curtain wall has a surface condensation resistance above 56% RH under the same conditions. A high performance system, therefore, will more than cope with the UK climate in all but the most extreme environments, such as shower rooms, kitchens, etc., where secondary strategies, such as forced ventilation, would, normally be employed.

Higher U-values should not be confused with a higher surface condensation risk, as large internal projections absorb heat giving better protection. Slim profiles with small thermal barriers carry a greater risk from surface condensation.

Warm edge technology incorporating insulating edge spacers around DGUs is another good strategy for avoiding condensation risk. Without edge spacers, the aluminium spacer in conventional DGUs can create a thermal short circuit at the unit edge. This affects the overall U-value and gives rise to localised low temperatures around the edges, which may lead to perimeter misting and even, in extreme weather conditions, frost formation.

5.0 Contractual, Responsibilities

5.01 Constructive Partnerships

Creating defect-free window or curtain walling installations demands effective partnership between the architect or specifier, the manufacturer and the installer. Because of the high value of many commercial contracts, and the immediate visible impact of any design or installation defects, such as condensation or water ingress, faults tend to be picked up rapidly by the developer or occupier. The result can be hugely expensive litigation.

This is all avoidable. The system’s manufacturers must accept a duty of care concerning the design and manufacture of their windows. They should provide windows that not only meet the relevant standards, but are also fit for purpose. This is a potential grey area, since manufacturers are often too willing to hide behind the argument that they merely supplied a system according to the architect’s drawing or written specification. What is needed is early consultation between the specifier and the specialist sub-contractor/system’s supplier. This can investigate potentially serious issues such as the proposed RH of the building, or the type of cavity closer to be used in the aperture, and systems can be produced to meet the requirements, or the design amended according to the manufacturer's experience.

The same openness and early consultation is also needed between the installer and the architect. This can help overcome potential problems such as a design calling on a steel structural frame to project beyond an aluminium curtain walling system. In such an instance, perfect installation of high quality components can still lead to cold bridging, condensation and the building failing to achieve its anticipated performance. Through early consultation with system manufacturers and specialist sub-contractors, architects and engineers are able to call upon the experience of these specialists to help eradicate design defects before a building gets to site, minimising the risk of failure and lengthy, expensive post-contract disputes.

6.0 The Future

6.01 Environmental Issues

One thing is certain: thermal standards for new buildings will become tighter in the future. Environmental issues are moving ever higher on the construction agenda and there are no signs that global warming or ozone depletion have been slowed. In 1998 the Government announced a comprehensive review of the energy efficiency provisions in the Building Regulations with the purpose of establishing "the maximum possible contribution that can be made through the Building Regulations to the Government's aim of reducing CO_2 emissions, whilst still observing proportionality, allowing flexibility for designers and avoiding unreasonable technical risks or excessive cost." The Government has a manifesto aim of reducing CO_2 emissions to 20% below the 1990 levels by 2010, and has also signed up to the Kyoto protocol to the Rio Convention which requires the EC to cut greenhouse gas emissions by 8%.

6.02 Building Regulations and Thermal Performance

This will impact on the window and curtain walling industry. Average heat loss through the glazed elements is in the order of 40% of the total, conduction losses. Improving glazing performance would, therefore, result in a significant reduction in total heat loss. With the U-value standard in some European countries already set at 1.6W/m2K, it is reasonable to anticipate the standard for window assemblies for the UK being tightened to 2.0W/m2K.

The Department of the Environment, Transport and Regions would like to see a rating system introduced for windows and curtain walling, along the lines of that run in the USA by the National Fenestration Rating Council. In this model, in addition to the window U-value the solar heat gain coefficient (found by calculating the glazing performance and climatic data), are built into the equation to produce an energy rating number. In the UK, the first steps along this path have already been taken with the formation of the British Fenestration Rating Council under a DETR-funded Partners in Technology programme. So far this initiative is restricted to domestic windows.

Currently, while manufacturers can prove that they can produce windows that perform better than the generic guidelines outlined in the Building Regulations, the regulations themselves cannot recognise them. The introduction of higher statutory standards would also encourage building owners and their clients to take a more long term view. While it is quite feasible to design buildings which out perform the current Building Regulations, the payback periods are so long that only the most environmentally-conscious developers will make the investment. With typical energy costs only representing approximately 5% of expenditure, there is little incentive for occupiers to insist on more energy efficient structures. Future legislation is likely to not only lower target U-values, but also to take into account other factors such as air leakage through air-tightness standards. Most likely a CO_2 target index will be developed for assessing total buildings. This will provide design flexibility and allow some trade off between individual elements. For domestic buildings, the index would build on the existing SAP rating system, while for non-domestic buildings it would help drive improvements in building performance currently held back by financial concerns.

The aluminium window and curtain walling industry, working in harmony with the glass suppliers, already have the systems to meet the impending requirements of Document L and are working beyond this regulation to ensure that future designs will further reduce the production of man-made carbon dioxide (CO_2) in line with UK Government and International targets set for the year 2010.

7.0 Definition of Terms

7.01 U-value Environmental Issues

The thermal transmittance coefficient, or rate of heat transfer in watts through one square metre of structure when the combined radiant and air temperatures on each side of the structure differ by 1 Kelvin (i.e. 1°C). This is stated in watts per square metre of fabric per Kelvin (W/m2K). Certain elements of a construction, such as structural framing and window frames which act as thermal bridges, should be allowed for in U-value calculations.

7.02 K value

Thermal conductivity calculated as the amount of heat per unit area, conducted in unit time, through a slab of material of unit thickness, per degree of temperature difference. This value is expressed in watts per metre of thickness of material per degree Kelvin (W/mK). Certified test results of thermal conductivity of individual building components should be obtained from the manufacturer. These values can then be used to calculate U-values provided that allowances are made for the effects of thermal bridging.

7.03 Thermal Break

Also known as a Thermal Barrier, a Thermal Break is a component with low thermal conductivity (up to 0.3 W/m2K) used to separate the inner and outer aluminium elements of framing profiles, while at the same time providing mechanical continuity of sufficient strength to withstand calculated windloads, deadloads, etc.

7.04 SAP Rating

The Standard Assessment Procedure (SAP) is the Government's approved method for arriving at an energy rating for a dwelling based on the calculated annual energy cost for space and water heating. SAP ratings are expressed on a scale of 1 to 100, where the higher number indicates the better standard.

7.05 Surface Condensation Risk

The relative humidity at which condensation will form on the interior frame surface under the standardised CIBSE exposure conditions of 21°C SANC (still air/natural convection) internally and -4°C at a 2 metre per second windspeed externally.

8.0 Acknowledgement
8.01 The Author

Joe Simpson, 42, has been a construction journalist for twenty years. He started his career at RCI, and later edited both Building Products and Building Refurbishment before founding his own publishing company of which he is still a director. In recent years Joe has been freelance Technical Editor of Building Design, and founder Editor and Publisher of ECO magazine.

Joe currently works as a freelance journalist, as well as editing Tile UK and a number of industry reports. He also lectures to the RIBA, local authorities and other professional bodies on a range of subjects from sustainable construction to new roofing technology.

9.0 Sources of Information
9.01 Trade Associations and Research Bodies

Centre for Window and Cladding Technology
University of Bath, Claverton Down, Bath BA2 7AY Tel: 01225 826541

Aluminium Federation
Broadway House, Calthorpe Road, Five Ways, Birmingham B15 1TN Tel: 0121 456 1103

Council for Aluminium in Building
(Architectural Aluminium Association, Aluminium Windows Association,
Patent Glazing Contractors Association)
191 Cirencester Road, Charlton Kings, Cheltenham, Gloucestershire GL53 8DF Tel: 01242 578278

Glass & Glazing Federation
44-48 Borough High Street, London SE1 1XB Tel: 0207 403 7177

9.02 Relevant Standards

BS EN 755	Aluminium Alloy Extrusion
BS EN 485	Aluminium Alloy Sheet
BS 1161	Specification for aluminium alloy sections for structural purposes
CP 118	The structural use of aluminium
BS 8118	Design Code for structural uses of aluminium
BS 5286	Specification for aluminium-framed sliding glass doors
BS 4873	Specification for aluminium alloy windows
BS 5516	Code of Practice for designing and installing of sloping and vertical patent glazing.
BS 1615	Method for specifying anodic oxidation coatings on aluminium and its alloys
BS 3987	Specification for anodic oxide coatings on wrought aluminium for external architectural applications.
BS 6496	Specification for powder organic coatings on aluminium
BS 4842	Specification for liquid organic coatings on aluminium
BS EN 12373	Aluminium and aluminium alloys. Anodizing.
BS EN ISO 6946	Building components and building elements. Thermal resistance and thermal transmittance. Calculation methods 1997
prEN 12152	Curtain Walling. Air permeability. Performance requirements and classifications.
prEN 12153	Curtain Walling. Air permeability test methods.
prEN 12365	Building Hardware. Gaskets and weatherstripping for doors, windows shutters and curtain walling.
BS EN ISO 10077-1	Thermal performance of windows, doors and shutters - simplified method
BS EN ISO 10077-2	Thermal performance of windows, doors and shutters - numerical method
prEN 12412	Windows, doors and shutters. Determining thermal transmittance by the hot box method
BS EN 1026	Windows and doors. Air permeability test methods.
BS EN ISO 14683	Thermal bridges in building construction. Linear thermal transmittance.
BS EN 673	Glass in building. Determination of thermal transmittance. Calculation method.
BS EN 674	Glass in building. Determination of thermal transmittance. Guarded hot plate method.
BS EN 675	Glass in building. Determination of thermal transmittance. Heat flow meter method.
BS EN ISO 8990	Thermal insulation. Determination of steady state transmission properties.
BS EN ISO 12567-1	Thermal performance of windows and doors - Determination of thermal transmittance.
BS EN ISO 6946	Building components and building elements - Thermal resistance and thermal transmittance.
prEN 19347	Thermal performance of curtain walling.
BS EN ISO 10211-1	Thermal bridges in building construction.
BS EN 1027	Windows and doors. Watertightness test method.
BS EN 12211	Windows and doors. Resistance to windload test method.
prEN 2207	Windows and doors. Air permeability classification.
prEN 12208	Windows and doors. Watertightness classification.
prEN 12210	Windows and doors. Resistance to windload classification.

9.03 Further Reading

The Properties of Aluminium & Its Alloys — ***Aluminum Federation***

Guide to the Specification of Windows — ***Aluminum Window Association***

Fundamentals of Building Construction: Materials and Methodology — ***Author: Edward Allen***
ISBN: 0-471-18349-0

Aluminium Extrusions: A technical design guide — ***Author: Howard Spencer, AEA***

Advanced Uses of Aluminium Extrusions in Commercial Fenestration — ***Aluminum Extruders Association***

Aluminium Structures: a guide to their specification and design — ***Authors: J Randolph Kissel & Robert L Ferry***
ISBN: 0-471-05385-6

The Practical Design of Structural Elements in Aluminium — ***Author: John W Bull***
ISBN: 0-291-39798-0

Aluminium in Building — ***Author: John Lane***
ISBN: 1-85742-082-9

Architectural Metals: a guide to selection, specification and performance — ***Author: L William Zahner***
ISBN: 0-471-04506-3

Guide to the design of thermally improved glazing frames (guide) — ***CWCT***

The effect of edge details on heat transfer through insulated panels (guide) — ***CWCT***

Thermal performance and condensation risk (standard) — ***CWCT***

The influence of frame design on the thermal performance of advanced glazing. — ***Solar Energy Society***
ISBN 0-051-4504-6-x

Glass and Thermal Insulation (technical bulletin) — ***Pilkington Glass***

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