Guidance on the actions on non-loadbearing building envelopes

July 2017

Foreword

Information on the design of building envelopes to resist actions is diverse with the requirements appearing piecemeal in many codes and standards. Actions are described in numerous Eurocodes and National Annexes but acceptable performance is described in Product Standards, where they exist. Some forms of building envelope are not covered by product standards and recourse is made to project specification.

The ‘Standard for systemised building envelopes’ published by CWCT gives ‘non-contradictory complementary advice’ to support the use of European product standards such as EN 13830 ‘Product standard for curtain walling’ and assist the Specifier in setting appropriate levels of performance. It is also the only guidance available for some types of envelope construction.

This document brings together this wide range of guidance on actions to provide a single source of ‘non-contradictory complementary information’ on the loads acting on building envelopes.

This document supplements the information given in EN 13830, EN 1990 and the Eurocode 1 series. It should be read in conjunction with these Standards and the UK National Annexes to them. Further guidance on wind loads in the UK is available in PD 6688-1-4.

Glazing infills require more detailed consideration. Insulated glazing units are subject to additional environmental loads due to temperature and pressure. The structural behaviour of glass is dependent on load duration. The consequences of failure may be less severe if glass is prevented from falling post failure. This document should be read in conjunction with Draft BS EN 16612 when considering glazing infills.

This document should be read in conjunction with CWCT – Standard for systemised building envelopes. The document brings together earlier supplements and amendments to the standard for systemised building envelopes given in CWCT Technical Updates: TU7, TU8, TU12, TU14, TU15, TU18, TU20, TU21.

Contents

Definition

Non-loading bearing building envelopes have been defined as building envelopes that carry only their own weight and loads applied directly to them. That is to say they do not contribute to the strength or stiffness of the primary building structure.

Traditionally these have been walls erected as single storey heights of cladding attached to the primary structure with accommodation for differential movement of the cladding and primary structure made at the points of connection.

Today a curtain wall may be supported at its base and extend upwards for several floors with only the horizontal loads transferred to the primary structure at the upper levels. The self-weight loads carried at the lower levels are considerably greater but are still derived from the actions described in this document.

Attachments such as shading devices and screens may not be wholly supported by the building envelope. A screen may be several storeys high supported from the base but with connections at each storey height to transfer only horizontal loads and stabilise the screen. Again the structure may be analysed on the basis of the actions described in this document.

This document covers single skin and layered building envelope construction. However for double facades where there is a greater separation between the inner and outer skins a more comprehensive study of the distribution of wind load on each skin will be required. All other actions described in this document can be clearly applied to one or other of the two skins.

1 Basis of design

Building envelopes should be designed to be safe and serviceable when subjected to actions and combinations of actions that may reasonably be expected to occur. These are known as the Ultimate Limit State (ULS) and Seviceability Limit State (SLS). Furthermore building envelopes may be required to fail in a safe manner when subject to extreme or accidental actions.

1.1 Ultimate Limit State

The building envelope should be designed to safely carry the actions and combinations of actions that may reasonably be expected to act on it. The performance criterion for the ultimate limit state is that no part of the wall should fail and assessment is based on testing or on calculation of the forces and stresses in components of the building envelope. Load combinations are described in Section 6 and performance criteria in Section 7.

1.2 Serviceability Limit State

The building envelope should be designed to function in all respects during and following the actions that may reasonably be expected to act on it. There are several criteria for the serviceability limit state and these are based on testing or calculation of deflections, they are described in Section 7.

1.3 Post failure behaviour

When assessing post-failure behaviour consideration should be given to the following (in order of importance):

1.3.1 Progressive collapse

Failure of a single component should not lead to more extensive failure or collapse of a wall or roof. The building envelope should have sufficient redundancy that in the event of failure of a component the remaining components are able to prevent collapse albeit with large deflections. Examples of progressive collapse are:

- Ground supported stick systems for which the possibility of a ground floor mullion being knocked out should be considered.
- Ground supported brise soleil frames and other screens which may be severely damaged near ground level.

Progressive collapse may be prevented by:

- Ensuring that the structure has sufficient strength with the damaged component missing.
- Ensuring that the damaged component has sufficient residual strength.

For instance a wall supported by glass fins may be designed to work with a glass fin missing or the fins may be of laminated construction so that they have adequate residual strength after failure of a single ply of glass.

1.3.2 Falling components

Failure of a component may cause it to fall from the building envelope. Acceptable performance is assessed by considering the possibility of components falling, the height of any fall, and the resulting consequences of components falling.

1.3.3 Ease of repair

Damage to a component will require repair. The acceptability of possible damage will require consideration of the probability of damage occurring, the ease of repair, the success of any repair and the cost.

2 Actions on building envelopes

Actions may be imposed directly on the wall or they may be transferred to the wall as a consequence of actions on fitments and attachments to the wall; these include but are not limited to brises-soleil and other shading devices, fit-out, signage and lighting. Forces may be induced in the building envelope as a result of temperature action, lack-of-fit and restrained movement.

2.1 Classification of actions

Actions are classed as permanent actions, variable actions, and accidental actions according to their duration and frequency of occurrence.

2.1.1 Permanent actions

These are sometimes referred to as dead loads. They include self-weight of the envelope, permanent fixtures and attachments, and loads induced as a result of lack-of-fit.

2.1.2 Variable actions

These are sometimes referred to as imposed loads or live loads. They include wind load, snow load, thermal action, maintenance loads and barrier loads.

2.1.3 Accidental loads

These include explosion, vehicle and cleaning cradle impact, glass failure and wind loading resulting from the formation of a dominant opening.

2.1.4 Construction period

When considering the construction period it is necessary to consider the temporary condition when the envelope is partially complete.

When considering movements that occur during the construction period the self-weight of the envelope is not a single permanent action and the sequence of construction and corresponding load increments have to be taken into account.

2.2 Characteristic actions

Actions are specified as characteristic actions. They are obtained from knowledge of the building design and its intended usage. Actions such as wind load, snow load and barrier load are normally taken from Standards although wind loads may be obtained from wind tunnel tests. Actions such as maintenance loads may be obtained from testing or calculation taking account of the proposed access methods.

Specification of loads is often simplified. For instance a single value for design wind load may be given. It has to be assumed that this is the wind pressure of greatest magnitude (positive or negative) anywhere on the building. Further study may show that lower values apply on some parts of the façade and that positive pressures are of smaller magnitude than negative pressures.

Characteristic actions are just that, the loads that it is believed may be imposed on the building envelope. The characteristic action may be given as an upper bound or it may be associated with a risk of exceedance. In the case of wind load the characteristic load is typically taken as the pressure that has a 0.02 probability of exceedance in any one year although other probabilities may be used.

Characteristic actions are sometimes called unfactored actions or unfactored loads.

2.3 Factored actions

The partial factor method applies a partial load factor to account for uncertainty of the action and a partial material factor to account for uncertainty of the material/component, and/or workmanship.

For elements such as fixings or bonded joints the partial material factor is greater than the partial load factor giving rise to large overall factors, typically a factor of 3 for fixings. Partial material factors for the main construction materials may be found in the structural Eurocodes.

2.3.1 Partial load factors

Characteristic actions are multiplied by a partial factor to account for the possibility that the actual load may be greater than the characteristic load. The partial factors are different for different loads and are set to recognise:

- The risk of a single action exceeding its characteristic value,
- The significance of the characteristic value being exceeded,

Permanent loads are generally easier to predict and the partial factors associated with them are lower than those for variable loads. It is possible to make the mistake that we know precisely the self-weight of a building envelope assembled from factory made components and its effect. It is important to note that the partial factor for self-weight takes account of:

- Position of the load which will depend on adjustment for tolerance and position,
- Magnitude of the load which will depend on dimensional tolerance and possible saturation of porous material.

BS EN 1990 allows two approaches to applying partial load factors. The simplest approach is to use equation 6.10 of BS EN 1990 given below:

$$E_d = \sum_{j\geq 1} \gamma_{G,j} G_{k,j} \text{ "+" } \gamma_{Q,1} Q_{k,1} \text{ "+" } \sum_{i>1} \gamma_{Q,i} \varphi_{0,i} Q_{k,i}$$ *(Equation 6.10 of BS EN 1990)*

Where;

- E_d is the design load
- $\gamma_{G,j}$ is the partial load factor for permanent action
- $G_{k,j}$ is a permanent action
- $\gamma_{Q,1}$ is the partial load factor for the leading variable action
- $Q_{k,1}$ is the leading variable action
- $\gamma_{Q,i}$ is the partial load factor for another variable action
- $Q_{k,i}$ is another variable action
- $\varphi_{0,\iota}$ is a combination factor described in Section 6.

The leading variable action is the action having the greatest effect on the component under consideration.

The partial factors given in NA to BS EN 1990 for use with the above equation should be used in the UK; they are given in Table 2.1.

This approach is always conservative, is relatively simple to apply and has been widely used in façade design.

Load type	Ultimate limit state	Serviceability limit state
Permanent unfavourable action (γ_G) *(self-weight, signage,..)*	1.35	1.00
Permanent favourable action (γ_G) *(self-weight, signage,..)*	1.00	1.00
Leading variable action (γ_Q) *(wind, snow, thermal,..)*	1.50	1.00
Other variable actions (γ_Q) *(wind, snow, thermal,..)*	1.50 $\varphi_{0,\iota}$	1.00

Table 2.1 - Partial load factors used in the UK.
(equation 6.10)

The alternative approach given in BS EN 1990 is to use equations 6.10a and 6.10b of BS EN 1990. The design load is the greater of:

$$E_d = \sum_{j\geq 1} \gamma_{G,j} G_{k,j} \text{ "+" } \gamma_{Q,1}\varphi_{0,1}Q_{k,1} \text{ "+" } \sum_{i>1}\gamma_{Q,i}\varphi_{0,i}Q_{k,i}$$ *(Equation 6.10a of BS EN 1990)*

or,

$$E_d = \sum_{j\geq 1} \varepsilon_j \gamma_{G,j} G_{k,j} \text{ "+" } \gamma_{Q,1}Q_{k,1} \text{ "+" } \sum_{i>1}\gamma_{Q,i}\varphi_{0,i}Q_{k,i}$$ *(Equation 6.10b of BS EN 1990)*

This approach allows the inclusion of a factor ε_j that reduces the effect of permanent loads. However, more calculation is required and the difference in magnitude of the design load from the simpler approach of equation 6.10 is seldom more than a few per cent as the wind loading is normally by far the dominant action.

When using equations 6.10a and 6.10b the partial load factors given in BS EN 1990 NA should be used in the UK; they are given in Table 2.2.

	Equation 6.10a	Equation 6.10b
Load type	Ultimate limit state	Ultimate limit state
Permanent unfavourable action (γ_G) *(self-weight, signage,..)*	1.35	0.925*1.35 (1.25)
Permanent favourable action (γ_G) *(self-weight, signage,..)*	1.00	1.00
Leading variable action (γ_Q) *(wind, snow, thermal,..)*	1.50 $\varphi_{0,1}$	1.50
Other variable actions (γ_Q) *(wind, snow, thermal,..)*	1.50 $\varphi_{0,\iota}$	1.50 $\varphi_{0,\iota}$

Table 2.2 - Partial load factors used in the UK.
(equations 6.10a and 6.10b)

The informative Annex C of BS EN 13830 suggests that curtain walling failure is of lesser consequence than failure of the primary building structure and that a class of consequence factor may be included when designing framing members. This would have the effect of reducing partial load factors for loads applied to curtain wall framing elements. The class of consequence should not be applied in the UK and loads on framing members should not be reduced simply because they are applied to the building envelope.

BS EN 13830 allows each country to set partial load factors in a National Annex. In the absence of a UK National Annex the values in Tables 2.1 and 2.2 should be used for curtain walling as well as other forms of building envelope except when the conditions below are met:

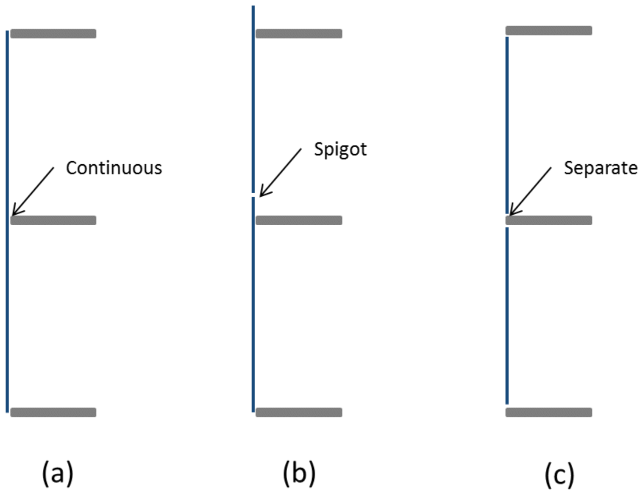
Permanent actions

Ultimate limit state partial factors for self-weight lower than those in Tables 2.1 and 2.2 may be justified if the exact weight of the components (saturated if appropriate) is known and their position in the building envelope is controlled. When the ultimate limit state is checked both extreme tolerances for position and component dimensions should be considered in calculations. Rigorous site monitoring is required to ensure tolerances are not exceeded. EN 13830 gives a load factor (γ_G) of 1.15 for framing members.

Variable actions

Lower ultimate limit state partial factors for variable actions may be adopted for;

- A wall where failure is limited to a zone wholly between consecutive floor slabs, a single storey (Figure 2.1).
- A roof where failure is limited to a single glazing bay.



(a) and (b)	Failure not limited to a single storey
(c)	Failure limited to a single storey

Figure 2.1 - Mullion configurations

Lower partial load factors for variable loads than those in Tables 2.1 and 2.2 should only be used if a risk assessment shows that the consequences of failure are acceptable. It will be difficult to show an acceptable consequence of failure for anything but simple low rise glazing systems but even these should be the subject of a risk assessment before using reduced partial load factors. EN 13830 gives a load factor (γ_Q) of 1.25 for framing members.

Partial load factors for variable loads lower than those in Tables 2.1 and 2.2 should only be used if a risk assessment shows that the consequences of failure are acceptable. It will be difficult to show an acceptable consequence of failure for anything but simple low rise glazing systems but even these should be the subject of a risk assessment before using reduced partial load factors. EN 13830 gives a load factor (γ_Q) of 1.25 for framing members.

It may be possible to show, on the basis of risk assessment, that infill panels are of lesser consequence. Note that infill panels providing containment and preventing people falling from height are not of lower consequence.

Draft BS EN 16612 allows partial load factors of 1.1 for glazing infills that have a minimum risk of causing injury on failure. This is acceptable for both variable and permanent loads provided a risk assessment has been carried out to show that the consequences of failure are acceptable. Risk assessments on a project-by-project basis are required for all glazing at height. Note that load factors as low as 1.1 are allowed for glass because the partial material factor is relatively high (1.8 for basic annealed glass and 1.2 for surface pre-stress from Draft BS EN 16612). This means that at loads marginally greater than the factored load a few panes may break.

It is reasonable to adopt the same basis of design for infills of materials other than glass. However, it should be noted that for materials other than glass partial material factors may be low. As a consequence loads marginally greater than the factored load may cause a large number of infills to fail. Again a risk assessment should be undertaken project-by-project and this should consider the number of components that may fail and the resulting scale of damage. EN 13830 gives load factors (γ_G and γ_Q) of 1.15 for infill panels.

Any risk assessment should include but not be limited to:

- Whether failure of a framing member;
  - Leads to progressive collapse
  - Causes unacceptable failure of an infill

- Whether failure of an infill;
  - Destabilises framing members
  - Creates a dominant opening
  - Allows material or components to fall
  - Leads to an opening through which people may fall

- Greater risk of need to repair

Full advice on glazing risk assessment is available in CIRIA;2005.

2.4 Combined actions

When two actions occur simultaneously their effects are combined and the factored loads are further factored to give a reduced magnitude of the combined actions. This may be done because either:

- The probability of them acting at greatest magnitude simultaneously is much lower than the probability of them acting at greatest magnitude separately (This is the case with wind load and barrier load),
- There is a causal effect that prevents both acting at greatest magnitude simultaneously (This is the case with wind load and snow load).

Detailed guidance on load combinations is given in Section 6.

3 Applied loads

3.1 Wind load

Wind loads are evaluated according to:

- BS EN 1991-4 Eurocode 1-4
- NA to BS EN 1991-4 UK National Annex to EN 1991-4
- PD 6688-1-4 Background to BS EN 1991

However, CWCT Standard for Systemised Building Envelopes requires a minimum characteristic wind load of 800 Pa.

CWCT Standard for systemised building envelopes states 'Under normal circumstances there shall be no horizontal zoning of wind pressure to give lower design loads on the envelope nearer the ground.' Horizontal zoning of wind load is allowed (only for positive pressures on the windward face) in BS EN 1991-4. While this is accepted practice when designing the primary structure localised effects such as downdraughts make this practice unwise in the design of building envelopes. As the critical load on the façade is normally the negative wind load, horizontal zoning is not normally applicable.

3.1.1 Layered walls

These are walls were a wall comprises two layers in close proximity with an intermediate cavity sufficient to contain insulation and provide drainage and ventilation. Double facades with larger cavities require a more detailed consideration.

For walls comprising more than one layer it is necessary to establish clearly the wind load carried by each layer. Guidance is available in both EN 1991-4 and CWCT Standard for systemised buildings.

Wind pressure on any surface is calculated from the peak velocity pressure q_p obtained from EN 1991-4 and a pressure coefficient dependent on the position on the building. The pressure coefficient varies across each façade and the following coefficients are used:

External surface pressure $= q_p \times C_{pe}$
Internal surface pressure $= q_p \times C_{pi}$
Pressure in a cavity $= q_p \times C_{pc}$

Net positive pressure on a wall is defined as a greater pressure on the outer surface than the inner surface. The pressure on each layer will depend on the pressure coefficient (C_{pc}) for pressure developed in the intermediate cavity. The actual pressures in a ventilated cavity will depend on:

- Permeability of the outer skin
- The relative permeability of the two skins (openings in the outer skin)
- The cavity volume (distance between the skins)
- Rigidity of the skins
- Perimeter leakage

Taking the values of C_{pc} assumed in CWCT Standard for systemised building envelopes gives the pressures on the rainscreen and air barrier shown in Table 3.1, where C_{pe} is the external pressure coefficient and C_{pi} is the internal pressure coefficient. Note that it is necessary to compartment the cavity as described in CWCT Standard for Systemised Building Envelopes to achieve pressure equalised construction. Whether drained and ventilated or pressure equalised, vertical cavity barriers should be provided at the corners of the building.

Taking the values of C_{pc} assumed in BS EN 1991-1-4 gives the pressures on the rainscreen and air barrier shown in Table 3.2. Note that it is necessary to construct the wall as described in EN 1991-1-4 with vertical cavity barriers at the corners.

	Drained and ventilated	Pressure equalised*
Rainscreen	q_p x C_{pe}	0.67 x q_p x C_{pe}
Air barrier	q_p x (C_{pe}-C_{pi})	q_p x (C_{pe}-C_{pi})
Windows and doors	q_p x (C_{pe}-C_{pi})	

** Pressure equalisation is defined in CWCT Standard for systemised building envelopes*

Table 3.1 - Pressures assumed on each layer from CWCT

	Positive wind pressure	Negative wind pressure*
Rainscreen	0.67 x q_p x C_{pe}	0.33 x q_p x C_{pe}
Air barrier	q_p x (C_{pe}-C_{pi})	q_p x (C_{pe}-C_{pi})
Windows and doors	q_p x (C_{pe}-C_{pi})	

** The values for negative wind pressure are very low and not recommended for use in the UK.*

Table 3.2 – Pressures assumed on each layer from BS EN 1991-1-4

The pressures given in Table 3.1 should be used. CFD studies by Zammit have shown that the coefficient of 0.33 given in BS EN 1991-1-4 is far too low.

Layered walls may comprise framing members supporting sheeting to provide the enclosure. Sheets may be on the outer face (sheathing board), inner face (lining) or both faces.

Where both a sheathing board and an internal lining are used then either might be the effective air barrier depending on the relative permeability and stiffness of each. BS EN 1991-1-4 gives incomplete guidance on the pressures acting on each of two impermeable layers. Based on the information given in BS EN 1991-1-4 assuming both the sheathing and lining are impermeable the pressures in Table 3.3 may be assumed:

	Sheathing less permeable	Lining less permeable
Sheathing	q_p x (C_{pe} – C_{pi})	q_p x C_{pe}
Lining	q_p x C_{pi}	q_p x (C_{pe} – C_{pi})

Table 3.3 - Net pressures on sheathing and lining

The requirement for the sheathing to be less permeable will probably be met if the sheathing boards are close fitting to each other or to a common seal/support such that the permeability (μ) is less than 0.1%. Note that the achieved permeability is dependent on the quality of workmanship.

The actual pressure in the cavity, q_p x C_{pc}, is dependent on the duration of the wind gust, the volume and geometry of the cavity, the size and the disposition of venting openings. By its nature, the pressure in the cavity is a transient action that requires a certain time period to reach its peak, thus creating different load scenarios on each facade skin. It is possible to calculate cavity pressures different from those implied in Tables 3.1 and 3.2, by detailed calculation or measurement based on the actual facade construction and properties. For layers with more than two skins, each cavity may have different internal pressure

3.1.2 Brises soleil and canopies

Guidance on wind loading on canopies is given in PD 6688-1-4. In the absence of further guidance; brises soleil, although permeable, may conservatively be treated as solid canopies.

Below the mid-height of the building it is assumed that brises-soleil and canopies are subject to a downward pressure on the windward face ($\theta = 0^o$). Brises soleil and canopies attached to the side walls ($\theta = 90^o$) below the mid-height of the building are subject to upwards forces. Global vertical force coefficients are given in Table 3.4. These will normally be conservative because the downdraught will be slowed by successive levels of brises soleil.

H/h	2	3	6	12	18	24	30	36
$\theta = 0^o$	+0.3	+0.4	+0.69	+0.87	+0.92	+0.93	+0.93	+0.91
$\theta = 90^o$	-0.24	-0.70	-0.95	-1.04	-1.16	-1.30	-1.29	-1.16

H is the height of the building above ground level

h is the height of the canopy or brise-soleil above ground level

Table 3.4 – Force coefficients *(Cf)* on brises-soleil and canopies (PD 6688-1-4)

The force on a canopy is calculated as:

$$F = Area \times C_f \times q_p$$

The force *F* acts at the centroid of area and q_p is calculated using reference height z to be the height of the building above ground level.

Above the mid-height of the building it is assumed that brises soleil and canopies are subject to the same wind loads as free standing canopies. The upper most brise soleil will be subject to the greatest load. The worst case will be for a brise soleil or canopy at roof level for which there will be a pressure on the underside equal to the pressure on the wall immediately below the brise soleil and a pressure on the top surface equal to the pressure on the adjacent roof.

3.1.3 Vertical shading devices

The worst case will be for a vertical shading device at a corner for which there will be a pressure on each surface, each equal to the pressure on the immediately adjacent wall.

For vertical shading devices elsewhere on a wall it is conservative to assume that one surface experiences the pressure on the wall immediately adjacent to it while the other surface is free from pressure.

3.2 Snow load

Snow loads are evaluated according to:

- BS EN 1991-3 Eurocode 1-3
- NA to BS EN 1991-3 UK National Annex to EN 1991-3

Brises soleil and canopies are not specifically dealt with in the codes and it must be assumed that they are subject to the same snow loads as flat roofs. Drifting may be ignored as the effect of any drifting would move the line of action of the force closer to the façade.

3.3 Occupancy loads

Occupancy loads are given in BS EN 1991-1, NA to BS EN 1991-1 and PD 6688-1-1. These may be more extensive and of different magnitude than the guidance given in BS EN 13830 Product standard for curtain walling where it is given as an informative annex.

The occupancy loads to be used in the UK are shown in Table 3.5. Classes C1, C2, C3, C4 and C5 were defined as 'Areas where people my congregate' in BS 6399.

Category	Use	Line load (kN/m)	Horizontal point load (kN)	Vertical point load (kN)	Vertical line load (kN/m)	Uniform load (kN/m^2)
			Anywhere			
A	Areas within or serving exclusively one dwelling (excluding balconies)	0.36	0.25	1.0	0.6	0.5
	Other residential areas (including balconies).	0.74	0.5	1.0	0.6	1.0
B	Office area	0.74	0.5	1.0	0.6	1.0
C1	Areas with tables etc. Areas in schools, cafes, restaurants, dining halls, reading rooms, receptions	1.5 0.74 (Stairs)	1.5	1.0	0.6	1.5
C2	Areas with fixed seating Churches, theatres, cinemas, conference rooms, lecture halls, assembly halls, waiting rooms	1.5	1.5	1.0	0.6	1.5
C3	Areas without obstacles for moving people Museums, exhibition rooms, access areas in public and administration buildings, hotels, hospitals, railway station forecourts	1.5	0.5	1.0	0.6	1.0
C4	Areas with physical activities Dance halls, gymnastic rooms, stages	1.5	N/A	1.0	0.6	
C5	Areas susceptible to large crowds Concert halls, sports halls, stands, terraces and access areas, railway platforms	3.0	1.5	1.0	0.6	1.5
D	Shopping areas	1.5	1,5	1.0	0.6	1.5
External	External areas accessible to people	1.5	1.5	1.0	0.6	1.5

Note: These loads do not act concurrently

Table 3.5 - Occupancy loads

A point load is normally applied distributed over a patch 100mm x 100mm. A line load is normally applied over a strip 100mm wide.

The duration of occupancy loads is not given in the above documents. Duration of load is not critical for most materials but for glass it is. It should be assumed that in dwellings the occupancy load is of duration 30 seconds. For other classes of occupancy it should be assumed that the load is of 300 seconds duration.

3.4 Maintenance loads

CWCT Standard for systemised building envelopes requires a wall to carry a maintenance load of 500N applied horizontally on a square of 100mm side. This load represents a ladder leaning against a wall, or a roped access worker or a cradle at rest. Impact loads from cradles and other access equipment may be larger (Section 4.0).

Maintenance loads on roofs have to be specified taking account of the expected maintenance regime and maintenance methods.

For roofs only accessible for maintenance and repair EN 1991-1 sets the following requirements for imposed loads.

Roof slope (α)	q_k (kN/m^2)	Q_k (kN)
$\alpha < 30^o$	0.6	0.9
$30^o \leq \alpha < 60^o$	$0.6\ (60 - \alpha)/30$	0.9
$\alpha \geq 60^o$	0	0.9

Table 3.6 - Maintenance loads on roofs

For light duties such as cleaning and inspection where the operatives are the dominant load a further concern is impact by falling operatives or equipment which is covered in Section 4.3. Where heavier plant or materials are to be employed a fuller consideration of loading is necessary.

3.5 Fit-out loads

Guidance on a general allowance for loads due to internal fixtures is given in BS 5234-2. No guidance is given on the number or position of fixtures as the Standard considers only a single panel and not a whole wall. Where fit-out loads are to be considered they should be clearly defined in the project specification otherwise it may be assumed that the loads are not transferred to the wall.

Fixture	Direction	Load	Eccentricity
Wall cupboards	Vertical	2000 – 4000 N	300 mm
Wash basins*	Vertical	500 – 1500 N	350 mm
Lightweight anchorages	Horizontal	100 N	
Lightweight anchorages	Vertical	250 N	16 mm

** Includes an element of occupancy load*

Table 3.7 - Loads applied to internal surface (Summary from BS 5234-2)

4 Impact loads

Impact loads are considered separately from other loads. Impact resistance is demonstrated by test rather than by calculation.

Impact loads are generally larger than other loads on the building envelope. The contribution of other loads is normally ignored when considering impact performance.

4.1 General impact loading on walls

Full guidance on impact loading specification and testing is given in CWCT TN75 and CWCT TN76. A summary is given below.

4.1.1 Serviceability impact

It has been UK practice to require serviceability under impact. Following a serviceability impact test, there should be no loss of performance. Damage of an aesthetic nature, such as indentations on metal panels, may be acceptable depending on the severity of the damage, the nature of the material and location of use.

Damage to components under serviceability impacts may be acceptable where the components are readily replaceable. Where materials may require replacement following impact, the acceptability depends both on the ease of replacement and the ease of obtaining replacement materials several years after construction.

Where it is impractical to use materials that can withstand serviceability impacts without damage, the loss of performance can be mitigated. For example brittle materials may be reinforced with a mesh backing to prevent cracks opening up so that they remain in place until replacement can be carried out.

4.1.2 Safety impact

The building envelope may be subject to more severe accidental impacts which it is unreasonable to resist without damage but where the consequences for the safety of those in and around the building must be considered. Safety considerations include:

- Ensuring that the structural stability of the building or parts of the building are not compromised
- Ensuring that the wall is not penetrated by the impact presenting a risk to people inside the building
- Ensuring that people outside the building are not put at risk from falling debris
- Ensuring that the failure mode of the cladding does not create risks to a person impacting the surface that are disproportionate to the impact

The third of these requirements is normally the most relevant. Failure of cladding panels will rarely affect structural stability of components other than the panels themselves and even if a cladding panel is penetrated by the impact, the back wall will normally prevent risk to people inside the building. The fourth requirement may be applicable with some cladding materials that produce sharp edges on failure.

4.1.3 Classification of impact performance

The results of safety impact tests are assessed using the classification in Table 4.1 below. Using this classification the preferred outcome would be negligible risk but this is not possible with all materials. Low risk may be acceptable with the possible exception of areas where debris could fall from a significant height onto an area where people are likely to be present. Moderate risk would normally be acceptable for cladding within 1.5m of ground level and at higher levels where any falling debris is unlikely to hit people below and high risk would only be acceptable where falling debris is unlikely to hit people even if only falling from low levels.

For a serviceability test the criteria in the CWCT Standard are:

- Fracture of components,
- Punching failure,
- Indentation of any component surfaces,
- Displacement of panels or components such as gaskets,
- Subsequent failure of an air permeability or water penetration test.

Some judgement is required in interpreting these requirements as metal panels may suffer minor dents which are acceptable and fracture of components such as terracotta tiles may be acceptable if they are readily replaceable. In considering the acceptability of damage the ability to obtain replacement materials sometime after construction should be considered. The classification given in Table 4.2 is used to assess the results of serviceability tests.

Class	Explanation/examples
Negligible risk	No material dislodged during test, and No damage likely to lead to materials falling subsequent to test, and No sharp edges produced that would be likely to cause severe injury to a person during impact, and Cladding not penetrated by impactor
Low risk	Maximum mass of falling particle 50g, and Maximum mass of particle that may fall subsequent to impact 50g, and Cladding not penetrated by impact, and No sharp edges produced that would be likely to cause severe injury during impact
Moderate risk	Maximum mass of falling particle less than 500g, and Maximum mass of particle that may fall subsequent to impact less than 500g, and Cladding not penetrated by impact, and No sharp edges produced that would be likely to cause severe injury during impact.
High risk	Maximum mass of falling particle greater than 500g, or Cladding penetrated by impact, or Sharp edges produced that would be likely to cause severe injury during impact.

Table 4.1 - Classes for safety performance

4.1.4 Exposure categories for assessing required impact performance

Table 4.3 gives six exposure categories for impact. This classification was originally given in BS 8200 and has now been adopted in BS 8298 which relates to stone cladding. Risk of impact can be reduced by site security, design of site layout to keep people away from the building surfaces and avoiding the presence of materials that could be used as missiles.

4.1.5 Impact energy

The values for impact energy given in Tables 4.4 and 4.5 below are based on BS 8200. The test procedure, which uses a sphero-conical ball for the soft body test, is given in CWCT TN 76. This is also based on the procedure given in BS 8200 but gives more detail both of the construction of the impactor and the test procedure.

4.1.6 Curtain walling impact tests

EN 14019 gives a method of assessing impact resistance of curtain walling using the double tyre impactor. This is intended to assess the frame, frame connections and opaque infill panels for safety. Glass is not tested as part of assessing a curtain wall in accordance with BS EN 13830. Glass performance should be assessed separately both for the ultimate state, and for the serviceability state if required. Serviceability tests on infill panels may also be required.

There are six classes of impact performance as shown in Table 4.6 below.

Class	Definition	Explanation/Examples
1	No damage	No damage visible from 1m, and Any damage visible from closer than 1m unlikely to lead to significant deterioration
2	Surface damage of an aesthetic nature which is unlikely to require remedial action	Dents or distortion of panels not visible from more than 5m (note visibility of damage will depend on surface finish and lighting conditions - damage will generally be more visible on reflective surfaces), and Any damage visible from closer than 5m unlikely to lead to significant deterioration.
3	Damage that may require remedial action or replacement of components to maintain appearance or long term performance but does not require immediate action	Dents or distortion of panels visible from more than 5m, or Spalling of edges of panels of brittle materials, or Damage to finishes that may lead to deterioration of the substrate.
4	Damage requiring immediate action to maintain appearance or performance. Remedial action may include replacement of a panel but does not require dismantling or replacement of supporting structure	Significant cracks in brittle materials eg cracks that may lead to parts of tile falling away subsequent to test, or Fracture of panels causing significant amounts of material to fall away during test.
5	Damage requiring more extensive replacement than 4	Buckling of support rails.

Table 4.2 - Classes for serviceability performance

	Areas within 1.5m of ground	
	Description	Examples
A	Readily accessible to the public and others with little incentive to exercise care. Prone to vandalism and abnormally rough use.	External walls in vandal prone areas.
B	Readily accessible to the public and others with little incentive to exercise care. Chance of accident occurring and of misuse.	Walls adjacent to pedestrian thoroughfares when not in category A.
C	Accessible primarily to those with some incentive to exercise care. Some chance of accident occurring or of misuse.	Walls adjacent to private open gardens. Back walls of balconies.
D	Only accessible, but not near a common route, to those with a high incentive to exercise care. Small chance of accident occurring or of misuse.	Walls adjacent to small fenced decorative garden with no through paths.
	Areas more than 1.5m above ground	
	Description	Examples
E	Above zone of normal impacts from people but liable to impacts from thrown or kicked objects. May also be subject to impact during maintenance.	1.5 to 6m above pedestrian level in location categories A and B.
F	Above zone of normal impacts from people and not liable to impacts from thrown or kicked objects. May also be subject to impact during maintenance.	Wall surfaces at higher positions than those defined in E above.

Table 4.3 - Exposure categories

Exposure category	Safety	Serviceability
A	No values are given as severity of potential vandalism needs to be assessed	
B	500J	120J
C	500J	120J
D	No values given as risk of impact is minimal	
E	350J	120J
F	350J	120J

Table 4.4 - Soft body impact

Exposure category	Safety	Serviceability
A	No values are given as severity of potential vandalism needs to be assessed	
B	10J	10J
C	10J	6J
D	No values given as risk of impact is minimal	
E	10J	6J
F	3J	3J

Table 4.5 - Hard body impact

Class	Drop height (mm)	Impact energy (J)
0	n/a	n/a
1	200	98
2	300	147
3	450	221
4	700	343
5	950	465

Table 4.6 - EN 14019 impact classes

4.2 Impact by cradle or other access equipment

Impact loads caused by a cradle or other access equipment may be greater than the impact loads described above. Full guidance on cradle impact loads is given in CWCT TN96.

4.3 Impact loading on roofs

Roofs may be required to resist impacts from:

- Maintenance operatives falling,
- Tools, materials and components that have been dropped,
- Hail

4.3.1 Maintenance impacts

Impacts arising from maintenance activities should be assessed with regard to particular maintenance methods, methods of access and whether access beneath the glass is restricted. The principal concern is post-failure performance and performance is assessed by testing. CWCT TN66, CWCT TN67, CWCT TN68, and CWCT TN92 describe the specification, assessment and testing of overhead glazing.

4.3.2 Hail impact

Hail impact is not normally a design consideration in the UK. However, elements such as solar collectors and photo-voltaic panels are assessed for hail impact according EN 12975.

Impact damage clearly depends on the size of hail stones. Table 4.7 shows the impact velocity and energy for hailstones of different size; the velocities are calculated as the terminal velocity of a sphere of that size. These values are taken from prEN ISO 9806 but all standards have the same relationship between diameter and energy. Hail impact tests are conducted in a laboratory normally using balls of ice.

Diameter (mm)	Mass (g)	Velocity (m/s)	Energy (J)
25	7.53	23	2
35	20.7	27.2	8
45	43.9	30.7	20.7
55	80.2	33.9	46.1
65	132	36.7	88.9
75	203	39.5	158.4

Values from prEN ISO 9806

Table 4.7 - Hail impact energy

5 Induced loads

5.1 Thermal actions

The CWCT Standard for systemised building envelopes Clause 2.7 requires the building envelope to accommodate changes of shape and dimension as a result of temperature changes and differential temperatures between outside and inside.

Building envelopes are generally designed to allow movement to occur. However, restraints to movement may occur, leading to thermal stresses in components. These may be calculated when considering the ultimate limit state.

The service temperatures are shown in Table 5.1.

External surface temperatures	Min	Max
Cladding walling and roofing		
Heavyweight, light colour	-20°C	50°C
Heavyweight, dark colour	-20°C	65°C
Lightweight (insulated), light colour	-25°C	60°C
Lightweight (insulated), dark colour	-25°C	80°C
Glass		
Clear	-25°C	40°C
Coloured or solar control	-25°C	90°C

Internal room temperatures	Min	Max
Building empty or not in use	-5°C	35°C
Building in normal use	10°C	30°C

Table 5.1 - Service temperatures

Note that some façade components may be always shaded and subject only to external ambient temperature. Ambient temperatures are site dependent.

Account should be taken of the temperatures at the time of construction and these are project dependent.

5.2 Lack of fit

Loads induced in the building envelope as a result of lack of fit should not occur in an accurately manufactured wall installed on a primary structure constructed to the specified tolerance.

Where components do not fit and force is applied to locate them there will be residual forces induced in the cladding components. Examples are pulling components apart to insert the next component or to align holes to allow insertion of a bolt.

If a structure is determinant any lack of fit results only in a different geometry and no additional primary forces occur. If a structure is indeterminate it is possible to calculate the forces generated by a given movement these can be allowed for in design and the allowable forced movement can be included in a site method statement.

5.3 Imposed movements

Provision should be made to support the building envelope from the primary structure in such a way that movement of the primary structure does not impose movement on the building envelope and induce loads in it.

CWCT Technical notes TN 55, TN 56 and TN 57 describe the movements of primary structures and cladding and the accommodation of movement at the cladding structure interface.

Where it is not possible to avoid imposed movement of the building envelope; the forces generated in the building envelope components should be considered as an action on the building envelope.

5.4 Restrained movement

5.4.1 Inadvertent contact

Where a component deflects far enough to come into contact with a restraint the loads in the deflected component will change and loads will be induced in the restraint.

Examples of this occurring include:

- A rainscreen rail deflecting and coming into contact with the sheathing boards
- A balcony deflecting and coming into contact with cladding panels

Deflections should be limited to avoid contact between components and potential restraints. Where that is not possible an analysis of the resulting structural system should be performed to determine the loads in the cladding and in the restraining component.

5.4.2 Additional restraint

Where a component has an additional restraint to movement:

- All restraints should be included in the structural assessment,
- Forces generated in the restraint should be considered.

An example of this effect is the joining of panes of glass or IGUs at the corner of a building. What may initially be conceived as a seal against air and water becomes a structural seal if it is to restrain glass in one plane against glass in the other plane.

6 Combined actions

When actions may occur simultaneously their combined effect should be analysed. All credible combinations should be considered.

The effect of each action should be calculated on the basis of the factored load. The leading action can then be established. It is the action having the greatest effect on the outcome, which may be stress or load at a particular position. The leading action may differ depending on what is being calculated (For instance a positive or a negative bending moment in a mullion or the load on a fixing). When loads act in combination a combination factor may be applied to some or all of the loads.

Normal load combinations for facades are considered below and a summary is given in Table 6.1. For other combinations the guidance in BS EN 1990 should be followed. Facades are normally designed to allow unrestrained thermal movement so that no thermal loads are generated. If thermal movement is restrained the resulting thermal loads should be considered in appropriate combination with other loads.

The CWCT Standard for systemised building envelopes, Clause 2.3.1. states that ‘Live loads other than snow load, do not act concurrently with the maximum wind load’. This Clause has been supplemented by CWCT TU14. Clearly other combinations are possible and it is not necessarily the case that two actions act simultaneously at their full magnitude.

6.1 Barrier loads

When considering a framing member or panel with a single horizontal barrier load acting on it the barrier load can be treated simply as a single load to be combined with other actions. If a minimum design wind load of 800 Pa has been adopted, barrier load combinations acting on the framing members only need to be considered for areas where people congregate. Barrier load combinations acting on infill panels and glazing should be assessed for residential and office use as well as places where people congregate.

If a framing member extends over two floors or projects above a roof it may be subject to barrier loads at two levels. These may occur simultaneously but each may occur separately. The effect of either load acting singly may have a more severe effect than the loads in combination. Consider the mullion shown in Figure 6.1a. The upper barrier load alone will give the greatest moment in the top span and greatest force at the top bracket. The lower barrier load will give the greatest moment in lower span and greatest force in the bottom bracket. The two barrier loads combined will give the greatest force in the intermediate bracket and the greatest moment in the mullion at that bracket. Similar considerations apply to the mullion acting as a balustrade in Figure 6.1b. There are thus three separate possibilities for barrier load that could be combined with other loads.

6.2 Barrier load and wind load

For office and residential accommodation, design should be carried out for:

Wind load

or

Occupancy load

Whichever gives the more severe loading action.

For areas where people may congregate:

‘Areas where people may congregate’ was defined in BS 6399 as categories C1, C2, C3, C4 and C5 described in Table 3.5 in this document. It may be necessary to regard category D (Retail) as an ‘Area where people may congregate’ in some large retail developments.

Design for safety should be carried out for:

Wind load plus 0.5 occupancy load

or

0.5 wind load plus occupancy load

whichever gives the more severe action. For roof balustrades it may be assumed that crowds will not be present on the roof during the highest winds and that the first combination given above is not a credible combination.

Design for serviceability should be carried out for:

Wind load

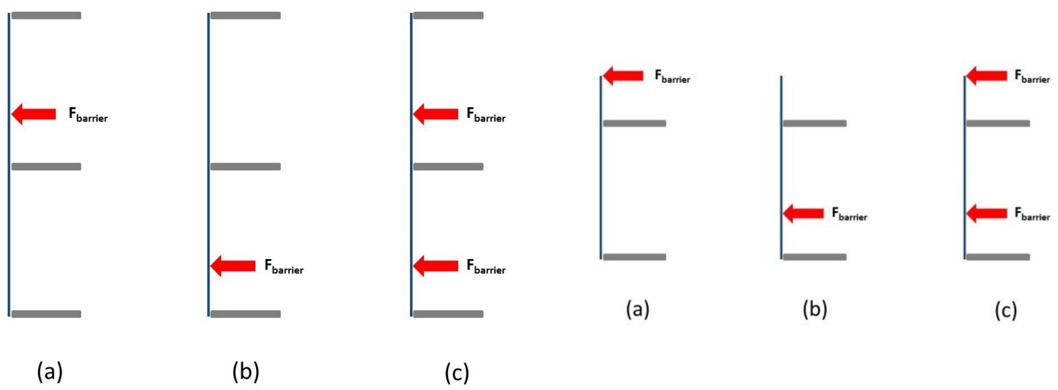
or

Occupancy load

whichever gives the more severe action.

These combination factors are justified by considering that the maximum wind is of short duration (approximately 3s) and has a probability of occurrence of 0.02 in any year. A wind event causing a wind load equal to fifty per cent of the design wind load will occur on average 24 times each year.

Barrier loads are also transient loads and are likely to apply for only a few minutes. These loads will rarely be applied in residential or office accommodation and are unlikely to be concurrent with the maximum wind load.



a) Two storey continuous mullion   b) Mullion including upstand

Figure 6.1 - Barrier load combinations

6.3 Wind load and snow load

The design *for both serviceability and safety* should be carried out for:

Wind load plus 0.6 snow load

or

0.6 wind load plus snow load

whichever gives the more severe loading action.

These combination factors are justified by considering that snow is associated with cold northerly winds whilst the strongest winds are warmer winds from the South West. These factors are the ones adopted in BS 5516:2004.

6.4 Maintenance loads

Maintenance loads are highly unlikely to occur concurrently with the maximum wind load as maintenance work should be suspended when high winds are forecast. It is therefore unnecessary to consider maintenance loads acting concurrently with the maximum wind loads. The effect of wind load will normally be much greater than that of maintenance loads and considering maintenance loads combined with a reduced wind load is unlikely to be more severe than the effect of the maximum wind load acting alone.

The combination of wind load and maintenance load is therefore not considered in design.

Wind load

	A	1.35 (or 1.0) SW + 1.5 Wind 1.35 (or 1.0) SW – 1.5 Wind	Equation 6.10	Least favourable from A or least favourable from B
	B	1.35 (or 1.0) SW + 1.5*0.5 Wind 1.25 (or 1.0) SW +1.5 Wind 1.35 (or 1.0) SW – 1.5*0.5 Wind 1.25 (or 1.0) SW – 1.5 Wind	Equations 6.10a and 6.10b	

Combined wind and snow load

	A	1.35 (or 1.0) SW + 1.5 wind +1.5*0.6 Snow 1.35 (or 1.0) SW + 1.5 Snow + 1.5*0.6 Wind	Equation 6.10	Least favourable from A or least favourable from B
	B	1.35 (or 1.0) SW + 1.5*0.6 Wind+1.5*0.6 Snow 1.25 (or 1.0) SW + 1.5 Wind + 1.5*0.6 Snow 1.25 (or 1.0) SW +1.5 Snow + 1.5*0.6 Wind	Equations 6.10a and 6.10b	

Combined wind and barrier load (Places of congregation)

	A	1.35 (or 1.0) SW + 1.5 Wind +1.5*0.5 Barrier 1.35 (or 1.0) SW + 1.5 Barrier + 1.5*0.5 Wind	Equation 6.10	Least favourable from A or least favourable from B
	B	1.35 (or 1.0) SW + 1.5*0.5 Wind + 1.5*0.5 Barrier 1.25 (or 1.0) SW + 1.5 Wind + 1.5*0.5 Barrier 1.25 (or 1.0) SW + 1.5 Barrier + 1.5*0.5 Wind	Equations 6.10a and 6.10b	

Combined wind and barrier load (Residential and offices)

	A	1.35 (or 1.0) SW + 1.5 Wind 1.35 (or 1.0) SW + 1.5 Barrier	Equation 6.10	Least favourable from A or least favourable from B
	B	1.35 (or 1.0) SW + 1.5*0.5 Wind 1.35 (or 1.0) SW + 1.5*0.5 Barrier 1.25 (or 1.0) SW + 1.5 Wind 1.25 (or 1.0) SW + 1.5 Barrier	Equations 6.10a and 6.10b	

Equations 6.10, 6.10a and 6.10b are from BS EN 1990 and are given in Section 2 of this document.

If the self-weight is favourable a factor of 1.0 is applied (not 1.25 or 1.35)

It may be necessary to include other loads such as thermal loads and other induced loads.

Table 6.1 - Load combinations (including partial load factors and combination factors)

7 Ultimate limit state

7.1 Structural design codes

The structural codes for the different materials used in building envelopes are:

- BS EN 1993 Eurocode 3 – Design of steel structures
- BS EN 1995 Eurocode 5 – Design of timber structures
- BS EN 1999 Eurocode 9 – Design of aluminium structures

There is no structural code for the design of glass structures. 'The structural use of glass in buildings (2nd Edition)' published by the Institution of Structural Engineers gives useful guidance. 'Guidance for European structural design of glass components' published by The European Union Joint Research Centre is a precursor to a Eurocode on the structural design of glass structures. Draft BS EN 16612 gives guidance on the strength of glass panes.

Structural codes require an ultimate limit state check to verify that the design loads do not exceed the design resistance of the building envelope structure. This is normally done by calculation but structural testing may be undertaken (Section 9).

All significant load combinations (load cases) should be considered, see Section 6. Checks should be carried out for all potential failure modes, including:

- Moment resistance of framing members
- Localised failure of framing members at supports
- Shear resistance of framing members
- Resistance of brackets
- Resistance of fixings

Moment, axial force, shear and so on may be calculated by any valid method.

7.2 Design charts/software

For many proprietary walling and roofing systems there are design charts or software to assist the designer. In general these are created to help in the early stage design and to assist estimators, most carry a warning that designs should be checked by a structural engineer.

When using design charts or proprietary software it is important to know the underlying basis of calculation:

- Which structural code is it based on?
- Is it an Ultimate Limit State check, a serviceability check or both?
- What assumptions have been made about supports?
- What assumptions have been made about loads?

Design charts are unable to deal with more than three variables and will normally only consider wind load. Barrier loads and loads from attachments such as brises soleil being excluded. It is often not clear whether the loads are characteristic loads or factored loads.

Software may be capable of dealing with more realistic load combinations but again it is important to know whether characteristic or factored loads are being considered and what partial load factors are embedded in the software. In general software is only valid in the country for which it has been written because of variations in Building Regulations and National Annexes to the Eurocodes.

8 Serviceability limit state

The serviceability state is a check on deflections. The Eurocodes permit any valid method of calculating deflections. The allowable deflections are not prescribed in the Eurocodes. Guidance is given on limiting values but deflections are also:

- Set in other Standards
- Specified as Client requirements
- Limited by material and component requirements
- Limited by requirements of tests

Deflection limits are set to prevent:

- Damage to materials, for instance plastered surfaces on lining systems
- Disruption of seals
- Unwanted contact of components
- Concern on the part of building occupants

Note that deflection is the movement of a point on a framing member or infill panel relative to its supports. Displacements are the total movement of a point having regard to deflection of the component and the displacement of its supports. For instance in a stick curtain wall; the displacement of a point on a transom would be the sum of the transom deflection and the deflection of the mullion from which it is supported.

8.1 Curtain wall deflections

The CWCT Standard for Systemised Building Envelopes has an overall requirement that the characteristic wind load is at least 800 Pa. This along with limits to deflection gives a minimum stiffness to the wall which is sometimes referred to as robustness.

A curtain wall is required to meet the requirements for both overall deflection and localised deflection as described below.

8.1.1 Overall deflections

For framing members spanning between supports the overall deflection should be limited to the values given below, where H is the distance between supports.

Length	Allowable deflection
H≤3000	Δ≤H/200
3000<H<7500	Δ≤5+H/300
7500≤H	Δ≤H/250

All dimensions are given in mm

Figure 8.1 - Overall curtain wall deflections

Note also that the deflections should not exceed those that occurred during the serviceability wind load stage of the test for air and watertightness. This is necessary to ensure that excessive deflections do not disrupt air and water seals. The following criteria should be applied:

- The curvature of the framing member should not exceed that occurring in the test,

$$\frac{M_{actual}}{EI_{actual}} \leq \frac{M_{test}}{EI_{test}}$$

- The rotation of each end of the framing member should not exceed that occurring in the test.

At an interface with adjacent construction it may be necessary to limit deflections so that seals are not disrupted.

Specified allowable deflections should be consistent with any fit-out behind the wall.

8.1.2 Localised deflections

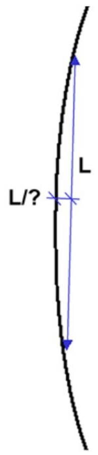
It is necessary to limit local frame deflections to ensure that:

- Glass and infill panels are fully supported,
- Materials and components are not damaged.

Allowable deflections given in Table 8.1 may be used in the absence of other information.

Single glazing	
4 edge support	L/125
2 edge support	1000/180 of the square of the span between supports, where deflection is measured in mm and span in m
Double glazing	
4 edge support	L/175
2 edge support	1000/540 of the square of the span between supports, where deflection is measured in mm and span in m
Triple glazing	Limits agreed with the IGU manufacturer
Structural sealant glazing	L/300 (L – the distance between fixings of members to which glass is bonded)
Plasterboard	L/360 or 10mm whichever is the lesser
Natural stone	L/360 or 3mm whichever is the lesser

Table 8.1 - Allowable local deflections (curtain walling)



This applies to any framing member including mullions and transoms.

L is the length of the infill panel or glazing in contact with the framing member.

Allowable deflections depend on the material being supported and are given below.

Figure 8.2 - Local curtain wall deflections

8.2 Built up walls

8.2.1 Back wall

The overall deflections of the back wall should be limited to the values given in section 8.1.1 for curtain walls.

Local deflections should be limited to prevent damage to components, lining and sheathing boards as required by the manufacturer of the components or materials. Manufacturers and suppliers will often give specific advice for the given component or material and the method of fixing. The values given below may be used in the absence of other information.

Edge of window opening		L/360 or 15mm whichever is the lesser (SCI ED017)
Gypsum board	Plastered	L/360 or 10mm whichever is the lesser (CWCT)
	Dry wall	L/250 (SCI ED017)
Brickwork		L/360 including the stiffening effect of the brick work L/500 ignoring the stiffening of the brickwork (SCI ED017)
Natural stone		L/360 or 3mm whichever is the lesser
Brittle finishes		L/360

Table 8.2 - Allowable deflections (Built-up walls)

8.3 Roof deflections

Where slope glazing is in close proximity to the building occupants it may be desirable to limit the deflections to the same values allowed for curtain walling. However, no limits to deflection are published for roofs. An obvious criterion is that deflections should not lead to negative slopes so that ponding of rain and melting snow does not occur. Also roofs should not come into contact with other parts of the structure giving rise to unintentional loads.

8.4 Infill and glazing

8.4.1 Barriers

Deflection limits should be tested or calculated. Calculations should include the effects of both curvature of the barrier and rotation at the base of the barrier relative to the floor. The latter effect may contribute more to the total displacement than the effect of curvature.

Different barrier loads apply depending on the situation of the barrier, Table 3.5. However the serviceability requirement should be the same in both cases in terms of reassuring the occupants. Accordingly the total horizontal displacement at the top of the barrier should not exceed 10mm when the barrier is subject to half the category A load. A further limit to deflection is given in BS 6180:2011. This requires that at the full load applicable to the barrier situation the horizontal displacement should not exceed 25mm anywhere within the barrier. Clients may discuss tighter limits to deflection for some prestigious projects.

8.4.2 Glazing other than in barriers

There are no agreed limits to deflections of glazing. Selection of glass to comply with BS 6262 is one way of limiting deflections, however some larger pane sizes and thicknesses in compliance with BS 6262 give rise for concern. Draft BS EN 16612 gives allowable deflections of L/65 or 50mm but Clients are likely to set tighter limits on most projects.

Larger deflections than those allowable for barriers may be acceptable as:

- The occupants are not concerned that they may fall
- The deflections due to wind loading are of short duration
- Occupants are probably distracted by effects of the wind outside of the building

8.4.3 Non-glass infills

There is no guidance on deflection limits for other infill panels. Many by the nature of their construction will be stiffer than glass infills. However, occupants will have a higher expectancy of them than of glass and it remains a matter of judgement whether an infill panel feels sufficiently stiff when occupants lean against it.

8.4.4 Rainscreen panels

The deflection of rainscreen panels should be limited to L/90 for panels of steel, glass and aluminium and L/360 or 3mm, whichever is the lesser, for brittle materials such as stone, where L is the distance between points of attachment.

9 Testing

Curtain walling and built-up walls may be tested for weathertightness as products or on a project-specific-basis. Full details of the testing regimes and performance requirements are given in CWCT Standard for Systemised Building Envelopes.

The test regimes may form a part of the structural assessment of a wall but are not wholly sufficient for this purpose and additional tests or calculation are normally required. Because of the cost of testing, performance on a particular project may be assessed by reference to a product test of different geometry and equivalence between the test and the project is based on structural calculation.

9.1 Serviceability testing

The sequence of testing applies the design (unfactored) wind load to the specimen. This is preceded by tests for air permeability and water leakage. Subsequent tests for air permeability and water leakage show whether the performance has been impaired by deflections due to the design wind load. This sequence of tests also allows measurement of out-of-plane deflections caused by the design wind load.

When extrapolating the result of a test to a different project geometry it is important to check that seals and gaskets do not separate, tear or become distorted. This is done by checking that the curvature of the framing profiles and their end rotations resulting from the design wind load are no greater on the project than in the test. A profile of different depth may be used on the project to meet this requirement, also to limit the out-of-plane deflection.

The requirement for curvature is:

$$\frac{M_{project}}{EI_{project}} \leq \frac{M_{specimen}}{EI_{specimen}}$$

The requirement for curvature is:

$$\theta_{project} \leq \theta_{specimen}$$

where the values of rotation and deflection are calculated values not measured values. Measured values will differ from calculated values as a result of stiffening of the framing member by glazing and infills.

The requirement for deflection is the value specified for the project.

9.2 Load testing

Subsequent to the serviceability testing, 1.5 x design wind load is applied to the specimen. This will give confidence that any components required to carry the factored wind load will do so safely. However, different components will be required to perform with different partial material factors (i.e. different overall factors of safety) and sometimes different partial load factors.

Where the partial material factor of a component is higher that component may not have been adequately load tested in the wall test. Typically these components are fixings and bonded connections. To test fixings and bonded connections at overall factors of safety in excess of 1.5 it is necessary to test them separately from the wall.

Where lower partial load factors have been adopted for infill panels and glazing these components may fail at pressures below 1.5 x design wind load. It has always been recognised that glass may fail during a test without invalidating the performance of the wall (A failed pane may be replaced once during a test on the assumption that it is a particularly weak pane). Prior to testing it may be necessary to agree the consequences of other infill panels failing during a test.

Strength under test is greater than the design load as a result of:

- Partial load factors
- Partial material factors
- Conservative calculation methods

Furthermore, the design/selection of many components is governed by the serviceability limit state rather than the ultimate limit state. It follows that many components will withstand 1.5 x design wind load even if partial load factors less than 1.5 have been assumed in the design. Should an infill panel fail during a test the substitution of alternative panels may be agreed, but only for the wind safety test.

When project dimensions are greater than those in the test a deeper profile may be selected on the basis of structural calculation. Note that:

- Longer members may be more prone to overall buckling,
- Deeper profiles may be more prone to local buckling,
- The forces on transom to mullion cleats, mullion to bracket connections and the like may be larger,

EN 13830 requires that the spans on the project are no greater than those of the test specimen; however:

- It may be agreed that longer spans are acceptable subject to project-by-project checks on buckling and structural stability.
- It may be agreed project-by-project that tests on smaller sub-assemblies are sufficient to validate these elements of construction.

It may seem that the successful construction of a specimen is evidence that it can support its own weight. However, loads on brackets will depend on the position of the plane of the wall relative to the slab edge, back wall or other structural support and components such as stone may vary in weight due to tolerance on thickness or to absorbed water. The ability of the wall to carry its self-weight and other in-plane loads should be checked by calculation using the worst assumptions of bracket extension etc. These limits to position should be communicated to site to ensure compliance at the time of erection.

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