

Code of practice for

Design of non-loadbearing external vertical enclosures of buildings

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Foreword

This code of practice has been prepared under the direction of the Elements and Components (of Diverse Materials) for Buildings Standards Committee.

The complex functional requirements and the need for the vertical enclosure to maintain its performance for long periods during repeated climatic cycles means there are few facets of building science which are not called into use for the design. The range of materials which can be used as components is equally wide.

This code has been prepared for use principally by all types of designer. Since, however, a designer's responsibility does not end with the completion of a design, it has also been arranged to assist those to whom a designer looks for support in the execution of the design, i.e. manufacturers, erector and main contractor. It will also be of use to the designer in his role of supervisor, assessor and advisor to his client.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 76, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

0 Introduction

The purpose of this code of practice is to provide a systematic framework within which an enclosure can be designed and constructed and extensive reference is made to other publications which cover detailed considerations of performance and design. Its purpose is not to reproduce in detail all aspects of building science relevant to the enclosure nor to deal exhaustively with all materials which might be used. It is intended to be used by designers as a comprehensive check list, incorporating useful guidance, and not for inclusion in specifications or other contract documents.

The designer, whether he is designing a walling system for a specific building or group of buildings, or a component for general use, will need to refer to all sections of this code, using the process referred to in section 3.

1 Scope

This code of practice gives recommendations for the design of non-loadbearing external vertical enclosures of buildings.

The code covers the following four main areas.

- a) Performance criteria: recommendations for establishing the performance required of the walling, using the data assembled in Appendix B to Appendix F.
- b) Design: guidance on the design of the enclosure to satisfy the requirements established in section 2. Section 3 (with Appendix H) also contains a recommended process for the designer.
- c) Workmanship and contract management: recommendations for ensuring that the design is realized on site.
- d) Maintenance: recommendations for ensuring that the performance of the enclosure is maintained during its life.

NOTE 1 This code excludes all loadbearing walls (i.e. those which transmit the dead and dynamic loads of the building to the ground) and all walls (whether loadbearing or not) whose purpose is to stiffen the structure (see clause 2).

NOTE 2 Materials, components, parts and assemblies covered by this code are listed in 3.1.

NOTE 3 The titles of the publications referred to in this standard are listed on the 76. Further information on certain subjects referred to in this code is contained in the publications listed in Appendix A. Those for general information are [1] to [13]. The numbers in square brackets used throughout the text refer to the bibliographic references given in Appendix A.

2 Definition

For the purposes of this code of practice, the following definition applies.

non-loadbearing external vertical enclosure the complete construction, from external surface to internal surface, making up the vertical division between internal and external environments, including those roof elements of more than 75° to the horizontal, which carries no vertical loads other than those due to its own weight and equipment attached to it and no horizontal loads other than those due to wind, maintenance and occupancy

Section 2. Performance criteria

3 General

3.1 The performance criteria set out in this section are applicable to non-loadbearing external vertical enclosures as defined in clause 2, comprising all materials, components, parts and assemblies which make up the vertical division between internal and external environments (i.e. from finished internal surface to finished external surface) and includes the following.

- Opaque and translucent portions of the wall
- Windows, opening and fixed, including glazing and ironmongery
- Window sills
- External doors, including glazing and ironmongery
- Attachment devices for connecting the enclosure to the structure
- Framing grids, unless structural
- Flashings
- Jointing and sealing materials and components
- Railings attached to the enclosure
- Horizontal and vertical ducts forming part of the enclosure, including inlets, extracts and access panels
- Roof drainage, if integral with the enclosure
- Wall drainage
- Copings and cappings
- External shading devices
- Ventilators
- Closers to link the internal surface of the enclosure to internal elements (e.g. ceilings, partitions, columns)
- Fire barriers and acoustic baffles
- Cleaning and maintenance equipment and accessories

3.2 The headings used to define the performance criteria of vertical enclosures taken together do not constitute a performance specification. Precise levels of user requirements can only be assessed when sufficient knowledge exists about the proposed use of the enclosed spaces and the environment in which the external enclosure is to perform. It is apparent, for example, that the resistance to impact required in a storage building using mechanical equipment will be more stringent than that required for a residential building in an urban area. Similarly, the thermal properties required for enclosing a windowless cold store will be quite different from those required for a school.

The major part of this section, therefore, is devoted to providing guidance on acceptable levels and indicating the design consequences of certain levels. Where minimum requirements are suggested, it is implicit that these refer to buildings for human occupation, other conditions of use possibly requiring different standards than those proposed.

The main purpose of this section is to enable the designer to quantify the level of requirement for the enclosure before proceeding to design in detail and Appendix B to Appendix F give guidance on obtaining basic data in respect of certain performance criteria.

4 Size and weight

The practical maximum weight of components is governed by structural, manufacturing, transport and handling considerations. Where walling is supported by existing structural members, the maximum allowable load should be determined and used for design purposes, taking into account any deterioration which may have occurred.

In addition, the maximum weight of components is influenced by the skill and experience of available manpower, the degree of site management and the availability of cranes and hoists. Scaffolding or adverse wind conditions may make the handling of large, light components difficult. The handling of heavy items on a small job may be impossible because of the absence of mechanical handling equipment. A good general guide if mechanical equipment is not available is to design no item heavier than that which can be lifted and manoeuvred into position by four men. If components are supplied with finished surfaces or may be easily damaged, it is advisable to position them by hand, and restrict their size and weight to that which can be manoeuvred by two men, i.e. 55 kg.

5 Appearance

The acceptable degree of variation in the colour, texture, pattern and evenness of internal and external visible surfaces will depend on the material used, the surface finish, the nature of the building and the designer's requirements. The quantification of properties relating to appearance are difficult to establish. The acceptable degree of variation should be established in agreement with the manufacturer, e.g. from samples.

6 Strength: structural strength and stability

6.1 Wind loadings

Wind load should be calculated using the basic wind speed in accordance with CP 3:Chapter V-2. In determining ground roughness factor S_2 , class A should be used. It should be noted that higher pressure coefficients are used at the corners of each elevation.

6.2 Load resistance and transmission

The external vertical enclosure should be capable of resisting and transmitting to its points of support all static and dynamic design loads without fracture or permanent deterioration of its performance. There should be no significant irreversible deformation of surfaces resulting from such design loads.

6.3 Permanent fixture loading

Enclosures which are intended to support permanent fixtures attached to either internal or external faces should, in addition, be capable of withstanding without excessive deflection or permanent deterioration of its performance the forces arising from these fixtures (see clause 9).

6.4 Components for general use

Where components are designed for general use, the manufacturer should indicate the wind loads they will withstand.

Should different loadings be required the designer should specify the maximum design loadings depending on the conditions expected in use and during construction of the building.

6.5 Operational forces

The size and position of operation forces acting on the enclosure depends on expected conditions of use and position. The enclosure should be capable of accepting the likely horizontal load applied on the surface of opaque panels (excluding glass) or on framing members without permanent damage to the component. Typical examples are:

Man leaning against the wall	400 N
Man on ladder	500 N

For loads to be resisted by patent glazing see BS 5516.

Loads resulting from the operation of cleaning cradles should be obtained from the cradle manufacturer.

Enclosures protecting a difference in adjacent level greater than 0.5 m should either be designed to withstand the forces given in Table 1 or Table 2 of BS 6180:1982 or be supplemented by an additional protective barrier designed in accordance with that code.

Handrails across recesses or balconies or those at roof level should be in accordance with BS 6180.

6.6 Deflection

The acceptable deflection under load depends on the extent to which it may affect the overall performance of the enclosure. Deflection characteristics vary considerably with differing materials and because of that it is important when selecting materials to be joined together to ensure they are sufficiently compatible not to cause serious defect by deflection. The deflections given in Table 1 are generally acceptable. The figures in Table 1 for frames containing glass are only applicable where the glass is supported on four edges.

6.7 Tests

Panel units and similar forms of enclosure may need to be tested to ensure the design is effective and weatherproof when in position. Wind-pressure simulating tests may be carried out using a pressure chamber similar to the test described in BS 5368-3 or the tests in BS 5427.

Test loads simulating operational forces should be applied perpendicularly to the enclosure at its weakest point.

7 Strength: impact

7.1 General

The visible surfaces of vertical enclosures should be capable of withstanding applied or transferred impacts that occur during normal use without sustaining damage which is not easily repairable and without deterioration of its performance. There should be no visually unacceptable indentation marks resulting from such impacts.

The risk of hazard to occupants or to people outside the building due to the more severe but infrequent accidental impacts should be minimized.

Table 1 — Maximum recoverable deflection under design load

Component	Measurement	Maximum deflection
Storey-height assemblies ^a	Between points of attachment to structure	1/200 span
Opaque infill panels in secondary framing, excluding glass	Between points of support	Dependent on material but usually within the range 1/90 to 1/500 span
Framing containing glass: single glass double-glazed glass	Between ends of frame Between ends of unit	1/125 span of member 1/175 span of double glazed unit
NOTE For profiled cladding materials see BS 5427 and for patent glazing see BS 5516. ^a Does not apply to masonry.		

7.2 Performance category

The vulnerability of a wall surface to impacts varies considerably with location, both location on an individual building and of the building itself. Larger and more frequent impacts will tend to occur on vertical surfaces adjacent to public areas as compared with privately used areas. For those with access to a vertical surface, the degree of incentive to exercise care will also be an important factor in determining the likely impact loads. This provides a wide spectrum of use but for practical purposes four categories may usefully be considered for vertical surfaces up to 1.5 m above pedestrian level (A to D in Table 2). Above this level the vulnerability to damage is reduced giving two possible further categories (E and F in Table 2).

These categories are suggested to aid the designer in selecting suitable vertical enclosure components. Further research is required to quantify the impact resistance for all categories. Minimum performance levels are however suggested in 7.3 and 7.4 in the more commonly occurring categories B, C, E and F, excluding openable components such as doors and windows.

NOTE A Draft for Development is in preparation which will cover performance levels for doors.

In addition special consideration will need to be given to wall adjacent to areas used by vehicular traffic. The use of guardrails is often appropriate in this situation and such guardrails should be designed in accordance with BS 6180 where vehicular speed is low (less than 16 km/h).

7.3 Impact resistance

If tested in accordance with Appendix G, minimum test impact values for opaque wall components as described in Table 2 should be as suggested in Table 3 and Table 4. (For transparent, translucent and opaque glazed areas see 7.4.) The intention is for the wall to provide resistance to all of the impacts shown for the relevant category.

Wall surfaces may have a lower resistance than those values indicated in Table 3 if they are easily replaceable or repaired (e.g. slates and tiles).

Table 2 — Categories associated with impacts on surfaces of the vertical enclosure to buildings

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

Table 3 — Test impacts for retention of performance of exterior wall surfaces

Wall category (see Table 2)	Test impact energy for impactor shown		
	H1	H2	S1
	N m	N m	N m
A	(see note 1)		
B		10	120
C	6		120
D	(see note 2)		
E	6		
F	3		

NOTE 1 No test impact values are given for category A walls. In each case the type and severity of vandalism needs to be carefully assessed and appropriate impact values determined.

NOTE 2 With category D walls the risk of impact is minimal and impact test values are therefore not appropriate.

The wall, when subjected to the impacts in Table 3, should not have a reduced performance.

The results of tests should be defined as follows:

- Brittle materials: failure or no damage
 Other materials: damage to surface finish, indentation or no damage

Where the damage is a dent, the depth of the dent should be quantified although the criterion for failure may be an aesthetic one only. The depth of indentation which is acceptable visually depends on the characteristics of the material, its finish and location.

Table 4 — Test impacts to ensure safety to persons

Wall category (see Table 2)	Test impact energy for impactor shown	
	H2	S1
	N m	N m
A	(see note 1 to Table 3)	
B and C external and indoor surfaces	10	500
D	(see note 2 to Table 3)	
E external and indoor surface	10	
E and F external surface if access is required for regular cleaning and maintenance		350

The wall when subjected to impacts in Table 4 should not put at risk the structural safety of the building or make parts of the building liable to fall or to cause serious injury to people inside or outside the building. In addition, the soft body impactor S1 should not pass through the test wall. Damage to the finish and permanent deformation on the far side of the wall may occur.

7.4 Glazed areas

Guidance on the impact strength requirements for transparent, translucent and opaque glass and plastics glazing sheet materials should be obtained from the safety and security recommendations in BS 6262.

8 Strength: explosive forces

Potential internal or external forces due to explosions should be either dissipated or confined to cause negligible damage to the essential structure or injury to the occupants and passers-by.

An explosion inside or outside the building may result from leaks in a central gas supply, concentrations of dust or vapour, dangerous contents, e.g. propane cylinders, or terrorism. Explosions are more damaging within a space if confined and enclosures which act as a relief to the blast may be advantageous. The explosion, if predictable, may be obstructed by heavy construction, in the form of blast walls, or allowed for by specially weakened or hinged panels acting as vents. The blast force thus channelled should be dissipated away from essential structure.

An enclosure which distorts and expands to absorb the blast without total disintegration may be advantageous if excessive forces are not transmitted to the essential structures, and may help to prevent personal injury. The materials of construction, e.g. secondary framing, infill panels and glazing, should be chosen together with their fixings, to minimize the effect of flying debris, on occupants or passers-by. If glazing is essential in these areas of high risk, special material and techniques (e.g. plastics or laminated glass) should be used and provision of heavy net curtains considered to reduce the danger of personal injury due to flying splinters.

9 Strength: fixings

9.1 General

The permanent fixings of any component should be capable of withstanding the combined dead load and maximum wind load arising from that component with an appropriate factor of safety. The following points should be noted.

- a) Components and component assemblies should be capable of withstanding stresses resulting from transport, off-loading and erection. If hoisting points are provided, each point shall be capable of supporting the entire dead load of the item.
- b) Enclosures required to support fixtures on their internal or external surfaces should be capable of withstanding loads and their resultant forces due to the fixtures, together with any superimposed loads, without loosening or failure of the fixings, damage to the wall surface or visible deflection of either face exceeding any limits given in clause 6.
- c) Walling assemblies and their fixings should be capable of resisting any overturning moment due to permanent fixtures and their superimposed loads.

9.2 Limiting values

Table 5 lists some typical loads which may be applied to internal surfaces and can be used to determine the bending and overturning moment which the enclosure is required to resist. The local stress to be resisted by the wall or walling component will depend on the number and spacing of supports. The manufacturer of the walling component should be consulted on the methods of support and the type of fixings which will not loosen or withdraw or deform the surface of the component when subjected to specified loads.

Table 5 — Typical loads supported from internal surfaces

Fixture	Load
	N
Well loaded cupboard 1.2 × 0.7 × 0.3 m	2 500
Washbasin	1 500
Bookshelves	
per metre of shelf	600
per square metre of wall face	2 000

10 Fire

10.1 General

10.1.1 The possibilities for the design of external enclosures are more circumscribed by mandatory requirements for fire than in any other respect. These requirements relate the performance of the construction to the size and position of openings, the internal arrangement of the building, its height, purpose and distance from the boundary. The main concern is with health and safety, and requirements are aimed at allowing the escape of the occupants and preventing a fire progressively spreading from compartment to compartment, from building to building, and, ultimately, from site to site.

10.1.2 Statutory Instruments and regulations are not standard throughout the UK, control being exercised separately in Inner London, England (excluding Inner London) and Wales, Scotland and Northern Ireland. In addition some county and other authorities also have certain powers in connection with fire precautions and other statutory provisions apply within the Isle of Man and the Channel Islands. Designers should obtain such documents as are relevant to that part of the country in which the building is to be located. Consultations should be held with the local Fire Officer, the Building Control Officer and the client's insurance company at an early stage of any development.

Depending on the function, position and design life of the building the designer should consider the desirability of including the following criteria which aid in reducing loss of life and property.

- a) The external vertical envelope should retain its stability and have sufficient resistance to flame penetration and heat transmission during a fire to ensure its satisfactory performance.
- b) The external vertical envelope should shield the building structure and contents from ignition by an external source of radiation such as a burning building on an adjacent site.
- c) The spread of fire over the external surface and within the cavities of the external vertical enclosures may be required to be controlled by the use of materials which are difficult to ignite and which have a low surface spread of flame classification.
- d) Cavities within the external vertical enclosures and between the components of the walls and the fire-resisting elements of the structure should be interrupted so as to prevent the passage of flame and hot gases in any direction.

e) All the components of the external vertical enclosures should either:

- 1) be secured in such a way that they do not become detached from the building structure owing to heat, thermal shock or combustion before criteria a), b), c) and d) have been met; or
- 2) in falling, not represent an unacceptable hazard to the escaping occupants or fire fighters.

f) The external vertical enclosures should be composed of materials which, if ignited, would not form a significant part of the total combustible materials represented by the building and its contents.

g) The room surface of the external vertical enclosures should have a low surface spread of flame classification, so as to limit the rate of growth of a fire within and the spread without the envelope, particularly in relation to vertical spread.

h) The materials used in the external vertical enclosures should be considered in relation to the emission of toxic gases, dense fumes or smoke when subjected to the temperatures arising in a fire in such a manner or to such an extent that the lives of occupants are put at risk.

i) Openings in the external vertical enclosures should be provided to vent heat and smoke from a fire and for the safe escape of the building occupants.

j) The external vertical enclosures should protect adjacent escape routes from radiated heat, hot gases and smoke arising from a fire inside or outside the building.

10.2 Escape

NOTE The designer's attention is drawn to the following matters, which are not specifically dealt with in the regulations and consideration of which may be in the client's interest.

10.2.1 Windows. Windows provide a possible means of escape or rescue in emergency and, to meet criteria i) in **10.1**, they should (where so used) have a minimum opening size of 840 mm × 530 mm with a sill height not more than 915 mm inside and, if possible, a safe landing on the ground or other platform outside, or be accessible from an area providing clear access for the approach of mobile fire escapes. Escape routes parallel to external enclosures either inside the building, on access balconies and external staircases, or at ground level, should meet criterion j).

10.2.2 Venting. Ventilation openings may be required in external walls to dispose of smoke which might collect in escape routes and for general release of smoke and heat from all storeys. BS 5588-4 gives recommendations for vents used in pressurized escape routes.

10.3 Framing materials

Framing materials are of particular importance in external walling for securing panels and for windows. Where it is necessary to meet criterion e), metal frames and fixings should have sufficiently high melting points to satisfy the period of fire resistance specified. If distortion of frames in a fire is liable to release panels, these should be fixed to the structure independently and the frame designed with expansion gaps or sliding joints. Timber frames char but do not distort. The rate of charring depends on the fire intensity, number of surfaces exposed and type of wood. Charring rates of timber are given in BS 5268-4.1:1978 (see especially 5.1.2). Heat conducted by metal fixings may lead to local failure of frames. For further information see CP 153-4.

10.4 Glazing (glass or plastics)

The choice of type, material and quality of external glazing is important in relation to criteria a), b), c), e), f), g), h) and j). Ordinary glazing, although non-combustible (if glass), constitutes a weakness in the wall because, unless wired or of special composition, it is soon penetrated in a fire allowing the passage of hot gases. Falling glass may cause personal injury. Glazing allows heat transmission by radiation.

BS 6262 should be consulted for further information.

10.5 Insulating materials

The effect of insulating materials in the form of loose fills, foams, quilts, slabs and core materials should be considered in relation to all criteria. Many such materials are basically non-combustible but may include resin or other binders, or paper facings, which may affect the required performance. Insulating materials are frequently used in cavities which may become flues conducting hot gases in a fire, which is intensified by any fuel, however slight. Some concrete products may, for insulation or other purposes, contain plastic fillers, aggregates or inserts and the designer should be satisfied that these do not adversely affect the performance in a fire. Guidance on the fire risk of insulating materials can be found in [14].

10.6 Voids and cavities

Voids and cavities occur within enclosures in association with insulation, weather shielding and vapour barriers, as ducts for services and ventilation or merely as a result of the method of construction used to achieve the internal and external profiles of the walling and its linings. Such voids constitute a serious hazard, as they frequently contain builders' rubbish, and can conceal a fire and provide a path for its spread within the building.

10.7 Buildings on the same site

The principles given in the appropriate regulations may have to be applied, or such systems as drenchers used to prevent the spread of fire between buildings on the same site to meet criteria a), b) and c). Combustible materials or waste stored on the site may be a source of fire, or be set alight by a fire within a building and in this case, a fire resistance from both sides may be necessary for the external walling of a higher standard than that in the regulations.

10.8 Adjacent sites

Although the minimum requirements of construction and distance from the boundary in the regulations will, when uniformly applied, protect adjacent buildings in different ownership from mutual ignition, there may well exist a hazardous use or building in the vicinity of a project, which should be considered as a particular source of fire under criterion b), for example, buildings which may have been constructed to a lower standard than that set by the current regulations, or industrial and storage uses, oil tanks, timber yards and heath land.

10.9 Combustibility of building contents

The fire load (fuel) represented by the contents of the building is only loosely covered in the regulations by the use of purpose groups, and the nature of the contents and the overall proposals for controlling their combustion in a fire, e.g. sprinklers, should be considered in designing for criteria a) and f). In some cases, contents might be affected by heat or radiation from a fire in another building and this should influence design for criteria b).

10.10 Fire fighting

The arrival of the fire service within a short period cannot be assumed. In some rural and other conditions, there may be a delay and this should be a consideration for criterion b). The use of water in fire fighting subjects materials to considerable thermal shock and this, and the danger to fire fighters, of collapsing and falling components, should be borne in mind in relation to criteria a), b) and e). Openings may be required in external walls for the purpose of venting heat and smoke to aid fire fighting (see BS 5588).

10.11 Alterations

The various building regulations are normally applied to new projects. Buildings are subsequently subjected to a variety of alterations in use and construction. Not all of these will be subject to control of the regulations or even executed under qualified supervision, and any of the performance criteria a) to j) may be defeated. For example, the installation of telephones or pipework may result in openings into or through cavities, affecting criterion d); decorative finishes or additional insulation may be attached to the interior or exterior of the enclosure, affecting criteria c), f), g) and h); repairs may be carried out or materials substituted, affecting any or all criteria. Building owners, surveyors and designers should pay particular attention to the effect of repairs and alterations on the performance in fire of the enclosure and supervise the work to ensure that the recommendations of this code are followed.

10.12 Tests

Tests on building materials and structures relating to external walling are described in the relevant Parts of BS 476.

The fire tests fall into two broad categories; those which provide information on the fire properties of materials, and those on the behaviour of materials built up to form constructional elements or component parts of a building structure.

The regulations make reference to the tests in BS 476 but it should be borne in mind that a revision may be made to a method of test without it necessarily being incorporated in the current regulations by amendment.

11 Air permeability

11.1 General

Air penetration through the enclosing structure should not cause an unacceptably high rate of air change and subsequent energy loss within the enclosed space or occur in such a manner as to cause draughts which may be uncomfortable to the occupiers or affect processes carried out in the enclosed space. For patent glazing consult BS 5516.

11.2 Thermal performance considerations

Air infiltration into the fabric of the external envelope should not cause significant deterioration of its specified thermal performance.

11.3 Limiting values

11.3.1 General. Knowledge of the air permeability of walls is not sufficiently advanced to allow very specific criteria on test pressures and leakage characteristics to be given. The maximum wind speed, and hence pressure, at which air permeability requires controlling are considerably less than those used for structural design purposes. A guide to variation in pressure with location are the design wind speeds used for wind loading (see CP 3:Chapter V-2). In addition hourly mean wind speeds for the UK can be determined from BS 5925.

11.3.2 Portion of wall with non-openable joints. Limited research suggests that for human occupancy (e.g. offices, houses, some industrial buildings) an air infiltration in the order of $10 \text{ m}^3/(\text{h}^{-1} \text{ m}^{-2})$ when tested at a pressure of 200 Pa is satisfactory for many buildings. Lower values may be more desirable for air conditioned buildings and higher values more appropriate for some industrial buildings.

11.4 Testing

Tests for air penetration may be carried out in a manner similar to the pressure chamber test described for windows in BS 4315-1, or BS 5368-1. Laboratory assessment of the air permeability of non-opening joints in the exterior walls of buildings may be made by using the method of test given in BS 6181.

12 Permeability to water vapour

The overall performance of the wall should not be adversely affected by water vapour which is allowed to penetrate to the interior of the wall or by condensation resulting from the presence of vapour. If water vapour or condensate is allowed into the interior of the wall, the component should be so designed as to allow it to disperse harmlessly.

Materials most seriously at risk due to build-up of moisture vapour within the fabric of the wall are thermal-insulating materials, which are usually not only able to absorb water but whose performance is thereby seriously affected. This may result in a decrease of internal surface temperature and the consequent surface condensation which, in turn, may damage the surface.

Although there are tests for determining the amount of vapour transmitted through materials, these are of little use in establishing the required performance of the walling, since the method of avoiding damage due to water vapour may vary from excluding vapour entirely from the wall to allowing it to escape through the external surface. The designer and manufacturer should be able to demonstrate the steps taken to meet the criterion in this clause.

13 Moisture content

The overall performance of the enclosure should not be adversely affected by any changes in moisture content resulting from changes in the humidity of air, either external or internal.

Unless special conditions exist (in terms of locality or manufacturing processes), the range of relative humidities in the environment in which the wall is installed can normally be assumed to be 55 % to 95 % externally and 30 % to 100 % internally.

14 Water absorption

The overall performance of the external enclosure should not be adversely affected by water likely to be absorbed by either surface.

If materials are used on either surface which may be damaged by absorbed water, the designer and manufacturer should demonstrate the steps taken to prevent damage to the material.

15 Water penetration

15.1 General

An external enclosure should be so constructed:

- a) as to prevent rainwater from reaching its indoor surface;
- b) that any rainwater entering its external surface may not cause permanent or significant temporary deterioration in its performance.

The worst conditions that walling should be designed to resist are caused by rainfall combined with high wind. The maximum 3 s gust speed with allowance for topography (S_1 factor), ground roughness (S_2 factor), and building life (S_3 factor) should be used as in CP 3:Chapter V-2 to help judge the degree of exposure.

Water penetration through opaque areas of the enclosure will usually cause greater damage to the fabric and to internal surfaces than that caused by leakage through a window. The acceptance criteria for the opaque area would normally be more stringent than that for windows.

Guidance on the resistance to rain penetration for masonry is based on the Driving Rain Index and is covered by BS 5628-3.

15.2 Testing

Permeable walling excepting panel construction using open drained joints can be tested in a pressure box as described in BS 4315-2.

Other types of walling may also be tested using the method described in BS 4315-2 to provide some guidance on the resistance the wall may have to rain penetration. This should help to identify weak areas in the walling but the results cannot be interpreted with sufficient confidence to allow grading of performance.

16 Capillarity

All components and joints between components should be designed to prevent the ingress of water by capillarity.

It is unlikely that an enclosure in accordance with clause 15 will allow the entry of water by capillarity but a check should be made, particularly at joints, for possible paths.

17 Moisture movement

Changes in the dimensions and shape of any component due to the effect of water or moisture should not adversely affect the performance of the enclosure.

The ranges of relative humidity of internal and external air are given in clause 13. Fairly large dimensional changes may, however, occur as the result of the absorption of rainwater externally, or the spillage of water internally.

In the case of concrete, concrete masonry or calcium silicate masonry there will be some long term shrinkage. The designer should provide movement joints in accordance with BS 8110 or BS 5628-3 as appropriate. In the case of brickwork there will be some irreversible long term moisture expansion and the designer should provide movement joints in accordance with BS 5628-3. In considering the design of movement joints the designer should consider the effects of thermal movements also and guidance should be taken from the appropriate code of practice. It is important that joints and fixings are designed so that changes in dimensions of components do not impose loads on adjacent components that they have not themselves been designed to resist.

18 Effect of frost

Water taken in by porous materials or trapped in joints or gaps in the enclosure and subsequently frozen should not cause spalling that would adversely affect the overall performance of the materials or permanent distortion of any part of the enclosure by its expansion.

19 Effect of weathering, atmospheric pollution and chemical attack

Materials should be capable of withstanding weathering and atmospheric pollution to which they will be exposed for their design life without suffering chemical corrosion which may cause any part to collapse or become dislodged, resulting in a hazard.

The supplier should be requested to state any measures that should be taken to ensure that no materials are used in the vertical enclosure in such a way as to create conditions in which adverse chemical or electrolytic corrosion can take place within the system.

The surface of vertical enclosures should be capable of resisting the action of specified chemicals with which it is likely to come into contact during its design life. Any system of periodic maintenance should be taken into consideration. (See also BS 5427, BS 5493 and DD 24.)

A classification of atmospheric pollution is given in Appendix VI of CP 3:Chapter IX:1950, and Appendices I, II and III of the same document describe various causes of corrosion and the reactions of various building materials to corroding agents.

The designer should, in conjunction with the client, prepare a list of chemicals and common substances which may come into contact with the enclosure surfaces. This should be used in consultation with the supplier and define:

- a) the anticipated effect of specified concentrations of the material on exposed surfaces;
- b) recommended cleaning or remedial action necessary to neutralize the effect of the substances;
- c) procedures to prevent the contact on surfaces by potentially hazardous chemicals.

In addition, the supplier should be requested to state whether his products contain any materials which, in contact with normal building materials, are likely to give rise to corrosion.

For guidance on the design life required of components, see clause 27.

20 Effect of biological attack

The materials used should be chosen having regard to the risk of attack or infestation by micro-organisms, fungi, insects and other vermin, and be so designed as to minimize the risk of ingress of vermin into the building.

Some causes of infestation are given in clause 5 of Appendix I of CP 3:Chapter IX:1950. The designer should state any measures which need to be taken to meet this criterion and ensure, via the supplier, that materials and components are in accordance with these recommendations.

21 Thermal properties

21.1 General

21.1.1 The overall thermal transmittance of walling between any internal space and the exterior should be such that an acceptable proportion of the heat energy is conserved and, under the maximum temperature difference between interior and exterior, the inside surface temperature is maintained at a level which is acceptable to the occupants and which will help to control surface condensation.

21.1.2 Thermal capacity of the walling should be such that it is suited to the type of thermal design adopted.

21.1.3 The thermal transmittance of all parts of the opaque areas should be sufficiently uniform and sufficiently low to prevent the creation of cold bridges (which may show later as unacceptable pattern staining).

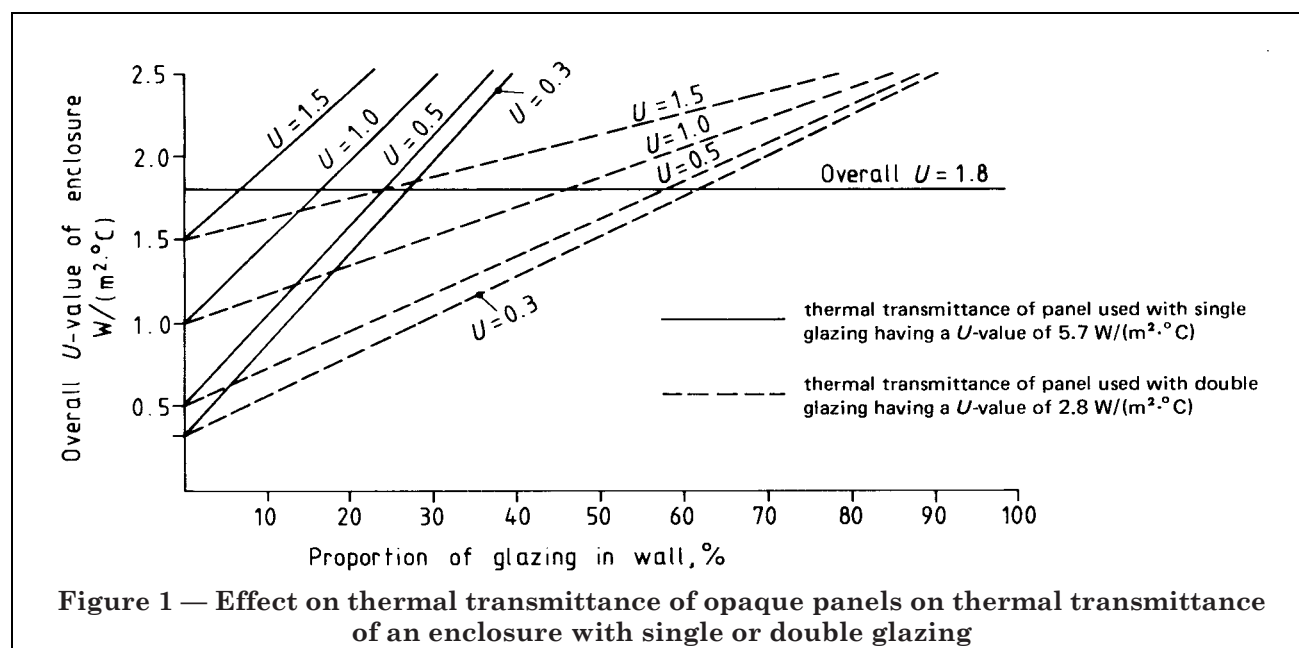
21.2 Overall transmittance

Where single glazing is used, the overall thermal performance of the walling, in terms of heat loss and the creation of conditions of thermal comfort internally, will be governed primarily by the thermal transmittance of the opaque panels only when the proportion of glazing in the enclosure is comparatively low. Figure 1 shows that, as the proportion of single glazing increases, the thermal transmittance of the panel has a steadily decreasing effect.

If double or multiple glazing is used, its lower thermal transmittance means that much larger areas can be used. For example, Figure 1 shows that, for an overall value of $1.8 \text{ W}/(\text{m}^2 \cdot ^\circ\text{C})$, the maximum possible area of glazing assuming a panel U -value of $0.5 \text{ W}/(\text{m}^2 \cdot ^\circ\text{C})$, is 25 % for single glazing and just over 56 % for double glazing.

In establishing a value for the overall thermal transmittance of the enclosure for the purpose of heat loss calculations and to conserve energy required for heating, care should be taken to ensure that the value does not restrict the allowable areas of glazing to such an extent that daylighting requirements, for example, cannot be met.

The Building Regulations set minimum standards for thermal transmittance.



21.3 Design air temperatures

21.3.1 General. The possible range of external air temperatures for specific localities is obtained as described in Appendix A. Acceptable internal temperatures depend upon user requirements. These temperatures may not, however, describe the critical thermal conditions in which the walling should perform. On the exterior, a sudden cold spell may cause a drop in temperature below the expected minimum and radiation from the enclosure to clear night skies may result in a surface temperature below that of the surrounding air. Internally, periods when the building is unoccupied, either overnight or for longer periods, may result in temperatures below those necessary for comfort when it is occupied.

For the assessment of critical thermal conditions, the following temperature ranges may be used, modified, where necessary, in the light of special local conditions:

external air temperature	– 20 °C to + 35 °C
internal air temperature	0 °C to + 30 °C

21.3.2 Internal surface temperature. One criterion for ensuring acceptable conditions of internal comfort is that the average difference in temperature between room air and bounding surfaces be not greater than 3 °C for sedentary purposes. This is almost impossible to achieve where large areas of glazing are used since, to meet this criterion, the maximum difference between internal and external air temperature can only be 5 °C for single glazing and 8 °C for double glazing. For large areas of opaque walling with high emissivity surfaces, the criterion will be met if the following expression is true:

$$U \leq \frac{25}{\theta_d}$$

where

U is the thermal transmittance of panel [in $\text{W}/(\text{m}^2 \cdot ^\circ\text{C})$];

θ_d is the maximum difference between internal and external air temperatures for period under consideration (in $^\circ\text{C}$).

Figure 2 shows the difference between the indoor air and the surface temperature that can occur for elements of the vertical building envelope having particular values of thermal transmittance. This is applicable to steady state conditions; fluctuating air temperatures can cause a larger difference.

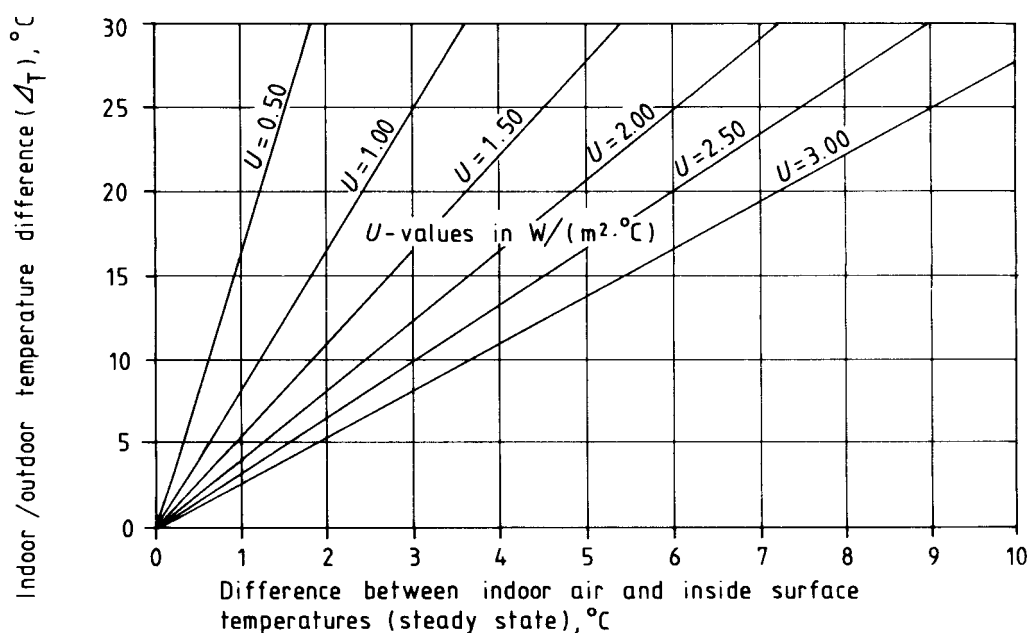


Figure 2 — Relationship between indoor and outdoor air temperatures, inside surface temperature and thermal transmittance

A further factor in assessing the required thermal transmittance is the need to control indoor surface condensation from reaching an unacceptable level. Figure 3 allows the maximum thermal transmittance, required to prevent surface condensation, to be determined for a range of air temperatures and internal relative humidities. This again is applicable to steady state conditions and can be used as an approximate guide only. Changing air temperatures, especially from intermittent heating, can cause condensation on the surface of elements with lower thermal transmittance values.

21.4 Testing

The manufacturer of all sheet and panel materials used for the enclosure should state the thermal conductivity, k , of the material in $\text{W}/(\text{m} \cdot ^\circ\text{C})$, where appropriate determined by a method described in BS 874. The manufacturer of composite panels or assemblies which include both internal and external surfaces should state the thermal transmittance, U , of the component.

22 Protection against solar radiation

The need to protect the interior of the building against the effects of solar radiation will depend on, among other factors, the locality and orientation of the facade, the proportion of glazed areas, the capacity of the ventilation system and the activities to be carried out behind the enclosure.

Methods to protect the interior include the provision of external shading devices, tinted, solar reflective or heat-absorbing glass and internal blinds or curtains. The need for these and their efficiency are discussed in section 3.

Should some form of control be required, the following criteria should be determined:

- the maximum proportion of solar energy to be transmitted to the interior through the walling;
- the period (s) during which control is required;
- whether control is to be adjustable and, if so, the limits of adjustability and whether it is to be operated internally or externally.

Solar control devices should not reduce the performance of the walling below that required by the other design criteria.

23 Effect of changes in temperature

23.1 Changes in the dimensions and shape of any component resulting from changes in air or surface temperature should not adversely affect the performance of the enclosure.

The enclosure should not suffer any mechanical or chemical changes which adversely affect its performance when exposed to extreme temperatures and no damage should occur as a result of rapid changes between these extremes.

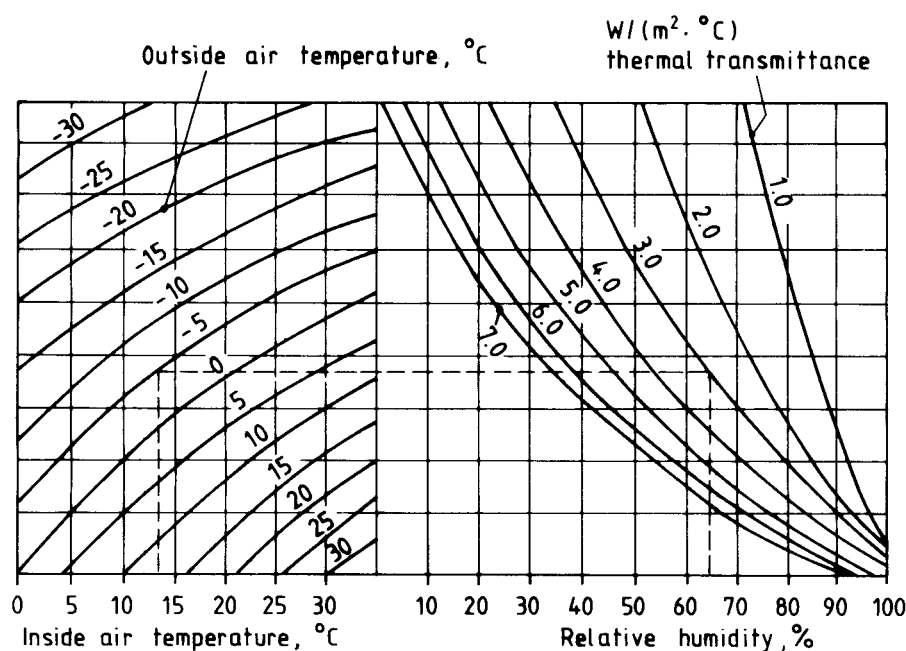


Figure 3 — Surface condensation prediction chart

23.2 Suggested ranges of design air temperatures are given in 21.3. The surface temperatures to be expected depend on the orientation of the facade, its material and colour and its proximity to insulation or heat-producing equipment.

If radiators are placed against or near to interior surfaces, the internal surface temperature range should be 0 °C to 65 °C; otherwise the air temperature range of 0 °C to 30 °C may be used.

On the exterior, absorption of solar energy, particularly by components of low thermal capacity, can lead to surface temperatures of 80 °C. An approximate estimate of exterior surface temperatures can be obtained from the equations:

$$t_s = t_a + 55a \text{ for panels of low thermal capacity}$$

$$t_s = t_a + 40a \text{ for panels of high thermal capacity}$$

where

t_s is the maximum surface temperature (in °C);

t_a is the maximum air temperature (in °C);

a is the absorption coefficient of material.

Panels of high thermal capacity may be taken as those in which superficial weight is over 100 kg/m², and absorption coefficients of some common clean building materials are given in Table 6.

The equations should be used with caution for panels of low thermal capacity combined with low thermal transmittance and should not be used for panels behind clear glass.

Table 6 — Absorption coefficients of some common clean building materials

Material	Absorption coefficient
Black, non-metallic surfaces	0.85 to 0.98
Bricks	0.40 to 0.70
Stone	0.30 to 0.55
Concrete	0.65 to 0.75
Asbestos cement	0.65
Red tiles	0.40 to 0.80
Dull brass, copper, aluminium	0.40 to 0.65
Polished brass and copper	0.30 to 0.50
Highly polished aluminium, chromium	0.10 to 0.40
Stainless steel, bright polished	0.45
Stainless steel, dull polished	0.65

In the absence of specific data on the type of material to be used, the following approximate absorption coefficients may be used for building surfaces when dirty:

light surfaces	0.5
medium surfaces	0.8
dark surfaces	0.9

For further information consult either the manufacturer or [15].

24 Effect of sunlight

No part of the enclosure which is liable to be exposed to direct sunlight should, as a result of such exposure, suffer any chemical, mechanical or optical changes which adversely affect its specified performance.

Methods of testing some materials for colour fastness are included in [16] to [18].

25 Sound transmission

An approximate method of estimating the average sound insulation required of the walling is to subtract the background noise of the space enclosed in dB(A) (see Appendix E) from the expected exterior noise level in dB(A). Provided the octave analyses of the interior and exterior noises are of similar distribution over the range 100 Hz to 3 150 Hz, this will provide an approximate measure of the average insulation required over the same range.

Where the analyses are of markedly different distribution, the subtraction should be made in each octave band and the average calculated as described in A.2 of CP 3:Chapter III:1972.

The selection of a particular sound insulation for the walling as a whole is dependent among other things on the size and type of any window, particularly where glazing comprises more than about 25 % of the wall surface. Table 7 demonstrates this factor. For example, a window providing a sound insulation of 20 dB introduced into a wall with a sound insulation of 50 dB, will result in an overall insulation of 30 dB.

The opaque part of the walling should never have a sound insulation less than that of the windows and, when the area of glazing exceeds 25 % there is little advantage in increasing the insulation of the panels to more than about 15 dB greater than that provided by the window.

Table 8 gives the average sound insulation provided by closed windows and Table 9 gives examples of the practical limitations imposed on walling design by the various overall insulation values.

Table 7 — Effect of window size on sound insulation of walling

Sound insulation of window	Sound insulation of panels	Overall sound insulation of cladding with window areas of:				
		0 %	10 %	25 %	33 %	50 %
dB	dB	dB	dB	dB	dB	dB
20	35	35	29	25	24	23
	40	40	30	26	25	23
	45	45	30	26	25	23
	50	50	30	26	25	23
30	35	35	34	33	33	32
	40	40	37	35	34	33
	45	45	39	36	35	33
	50	50	40	36	35	33
40	35	35	35	36	36	37
	40	40	40	40	40	40
	45	45	44	43	43	42
	50	50	47	45	44	43

Table 8 — Sound insulation provided by closed windows

Type	Construction	Average sound insulation 100 Hz to 3150 Hz
A	Sealed double windows, separate frames, one frame fixed, 200 mm minimum air space, absorbent-lined reveals	dB 40 to 45
B	Fixed or weatherstripped openable double windows, 3 mm to 6 mm glass, 100 mm to 200 mm air space	35 to 40
C	Single fixed or weatherstripped openable windows, 10 mm to 20 mm glass. Fixed or weather-stripped openable coupled or double windows, 3 mm to 6 mm glass, 50 mm to 100 mm air space	30 to 35
D	Single fixed or weatherstripped openable windows, 6 mm to 10 mm glass	25 to 30
E	Single fixed or weatherstripped openable windows, 3 mm to 5 mm glass	20 to 25
F	Single openable windows not weatherstripped	15 to 20

Table 9 — Examples of means of achieving sound insulation

Overall sound insulation ^a	Type of window ^b	Maximum window area	Minimum sound reduction of opaque enclosure
dB		%	dB
45	A	30	50
40	A	any	40
	B	10	50
35	B	any	35
	C	25	40
	C	33	45
30	C	any	30
	D	25	35
	D	33	45
25	D	any	25
	E	25	30
	E	33	40
20	E	any	20
	F	25	25
	F	33	35

^a These are achievable values, dependent on good detailing and workmanship.

^b See Table 8, lower values used.

26 Junctions

26.1 General

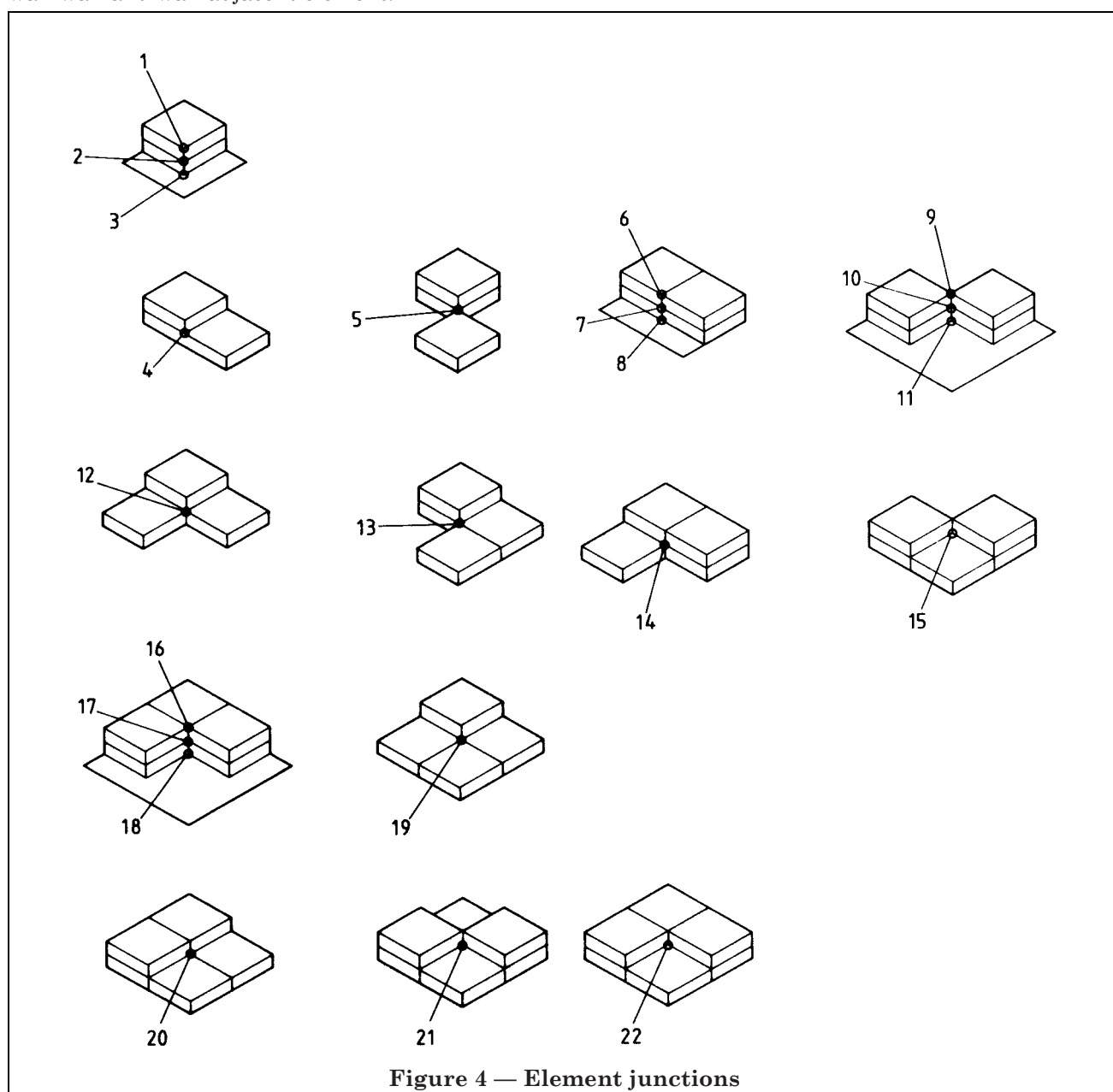
No joint should reduce the performance of the enclosure to a level below the minimum standard set in the performance criteria.

26.2 Element junctions

Figure 4 illustrates the 14 possible types of junction between adjacent elements. Within these are 22 possible combinations of external walling, roof and ground. These should be used by the designer to tabulate the required junctions of wall/wall and wall/adjacent element.

26.3 Junctions with ceilings, partitions and floors

Depending on circumstances, components to make any junction between the walling and ceilings, partitions and floors may be treated as part of the walling or as part of these elements. In either case, it is essential that such components preserve the required performance of the elements.



26.4 Junctions with internal columns

If a full-height closure piece is required for use between the internal surface of the external enclosure and the face of an internal column for situations where the column lies on the line of an internal partition, the closure piece should have the same performance as the partition.

27 Durability and design life

The durability and design life of the external face of the enclosure and its components should be related to, but not necessarily the same as, the design life of the completed building. The vertical enclosure may be independent of structure and it may be possible, therefore, to replace the whole or part during the life of the building. The designer should, nevertheless, assess as precisely as possible the required minimum life of the enclosure as a whole (with maintenance considered), during which period it should, subject to routine maintenance, repair and replacement, meet the criteria given in this section. This information should be made known to the building owner in order that the enclosure is properly maintained.

The various parts of the enclosure cannot, owing to the characteristics of the materials of which they are comprised, be expected to perform satisfactorily for the same length of time. Component parts of the enclosure can be grouped as follows in a descending order of design life. Components in groups A and B should have a design life approximating to that of the enclosure as a whole; those in groups F and G may only have a design life of a few years. The design life of components in groups C, D and E should be assessed by the designer according to expected conditions of use.

- A Secondary framing and its fixings
- B Panels and their fixings
 - Thermal-insulating components and materials
 - Vapour barriers
 - Flashings
- C Window subframes
 - Door frames
 - Fixed window frames
 - Internal linings
- D Opening windows
 - Doors
 - Access equipment
 - External shading devices
- E Window and door equipment
 - Glazing
 - Gaskets and compression seals
 - Internal sills and closure pieces
 - Inlet and extract grilles
 - Duct covers
 - Access panels
- F Gun and knife-applied sealants
- G Site-applied internal and external finishes

28 Safety and security

The degree of opening of opening components may need to be controlled, to prevent violent swinging in high winds and to prevent people from falling through openings. The extent of control should be in accordance with the safety criteria contained in clauses **6**, **7** and **11** of CP 153-1:1969.

Where a high degree of security is required, it should not be possible to gain entry to the building interior from the outside by dismantling fixing devices or joints, or by unlawfully opening any opening unit from outside when in its closed, locked position.

Section 3. Design

29 Design method

Systematic design is rarely a linear process with one decision leading directly to the next. It is more usual for it to become a series of hypotheses which are tested against available data and this results in a looped or cyclic process.

Appendix H provides a check list for enclosure design.

In the case of medium or large and particularly high-rise projects it is recommended that the structural engineer sets down the functional requirements governing the principles of design, means of support and restraint and the maximum movement of the enclosure for which allowance is to be made, together with the anticipated movement characteristics of the building frame, including calculations of the anticipated shortening and how this is to be accommodated in the walling.

On such projects it is further recommended that a technical specification dealing with all aspects of the supply and/or fixing of the walling should be prepared by the structural engineer and/or architect and this should include definitions of the nature of any special tests required to be carried out on the walling in advance of the work.

30 Choice of enclosure

30.1 General

The primary decisions to be made by the designer are concerned with the mass characteristics of the enclosure, its relationship to the structure of the building, its basic constructional method and the selection of principal materials.

These decisions will result from a detailed consideration of performance requirements in the light of factors discussed later in this section. Choice will ultimately depend on the balancing of the advantages and disadvantages of alternatives and, once taken, the decisions will, to a large extent, govern the detailed design and performance of the walling.

30.2 Mass

A building of high mass is able to cushion the interior against the effects of rapidly changing external thermal conditions and, in the case of dividing elements such as walls, floors and roofs, mass is able to resist the transmission of sound in a simpler way than lighter elements. For these dividing elements, mass may also have advantages in providing fire resistance.

As the principal buffer between internal and external conditions, the external envelope has a greater effect in terms of mass than other elements. For example, the beneficial effects of heavy floors and partitions in resisting the transmission of internally-generated sound may be negated by a light external envelope which allows the ingress of external noise. Conversely, many of the thermal advantages of a basically massive enclosure may be lessened if large windows or other areas of low mass are introduced into it. Whether enclosures of high mass will provide advantages over lightweight enclosures depends largely on the function and pattern of use of the building. With some intermittently heated buildings high mass will be disadvantageous. In addition, massive enclosures impose an additional dead load on the structure and foundations, which may become significant in buildings over five or six storeys. The decision to use a heavy rather than a light enclosure limits the choice of basic materials mainly to concrete (precast or in situ), stone or brick. This, in turn, affects methods of transport and handling. Large, heavy units may result in increased transport costs and demand special lifting and handling equipment.

30.3 Relationship with structure

30.3.1 General. The basic decision to be taken is whether the walling is to enclose structural elements or whether it is to be positioned between exposed primary structural elements. The two types are referred to as sheath wall and panel wall, and the structural elements may be columns, beams, floor slabs, roof slabs or load bearing walls, such as cross walls. There are obvious aesthetic consequences resulting from this decision, but there are also consequences in construction, performance and operation.

30.3.2 Sheath wall. When a sheath wall is used, the structure is completely enveloped by the enclosure and no primary structural elements appear on the wall surfaces. Examples may vary from the highly glazed metal and glass "curtain walling" to the traditional sheeted claddings with little or no glazing or brickwork with or without windows. Because the enclosure covers the structural members, it can protect them from temperature changes resulting from changes in external air temperature and absorption of solar radiation. Where wall surfaces are smooth, modelling can only be provided by the enclosure units themselves. There are, consequently, difficulties in providing for disposal of rainwater, except at the base of the enclosure, and the build-up of water on the enclosure surface imposes greater demands on joints.

30.3.3 Panel wall. When a panel wall is used, the vertical enclosure may be contained within horizontal or vertical structural members, or within the grid formed by both. Thermal insulation may be poor where the structure is exposed and temperature changes may result in greater thermal movement of the structure than in a sheath wall. Because the enclosure is confined within well-defined bays of the exposed structure, the problem of dealing with tolerances is more difficult. On the other hand, projecting horizontal members allow for intermediate drainage of rainwater and access for erection and maintenance, and can give greater protection to joints and the wall surface against rain and sun.

30.4 Constructional method

Vertical enclosures may be composed of large, storey-height, prefabricated panels attached directly to the structure [see Figure 5 a)] or a separate, secondary frame of horizontal or vertical members, providing support for smaller walling units [see Figure 5 b)] or a system of smaller units constituting an in situ wall (e.g. masonry cladding). Panel construction, being largely prefabricated, requires considerably less sitework than framed or in situ construction but the fewer joints, while simplifying the weatherproofing of the enclosure, necessitate far greater attention to the relative manufacturing and positional tolerances of structure and walling.

These problems are simplified in frames of in situ construction, as the secondary frame provides an intermediate dimensional discipline between the comparatively coarse dimensional accuracy of structure and the fine tolerances achievable in prefabricated units. Against this should be set the additional sitework necessary, resulting in a longer interval before the structure is enclosed, and the greater number of joints to be made on site.

A combination of the two constructional methods may often be justified, employing panel construction for opaque areas and framed construction for walling containing glazing, but this may entail the use of mixed trades.

Where it is considered necessary in order to improve the thermal capacity of the building or to provide an appearance in keeping with older traditional buildings masonry may be specified. This removes the need for intermediate framing although care should be taken in the detailing at the wall head not to restrain differential movement between the frame and the masonry.

Whichever type of construction is used, the method of attachment should provide for long term safety. Ideally, fixings should be designed for easy access for maintenance checks. Where this cannot be achieved special consideration should be given in design to ensure such critical work will be adequately supervised.

30.5 Selection of principal materials

A very wide range of materials can be used to make up any system of walling but many of these, such as materials for fixing accessories, sealants and flashings are the result of detailed design. The essential character of the walling and its overall performance are governed by the materials chosen for the components which form its greatest surface area, which is usually the opaque part of the enclosure. Choice of materials is frequently made on the basis of appearance, cost and availability but, although these are important, the physical characteristics have a profound effect on design and performance. These should, therefore, be considered in such a way that they reinforce the required performance rather than become obstacles to be overcome during detailed design. Table 10 includes the most important performance characteristics and summarizes the considerations affecting the choice of materials.