Building Research Establishment Report

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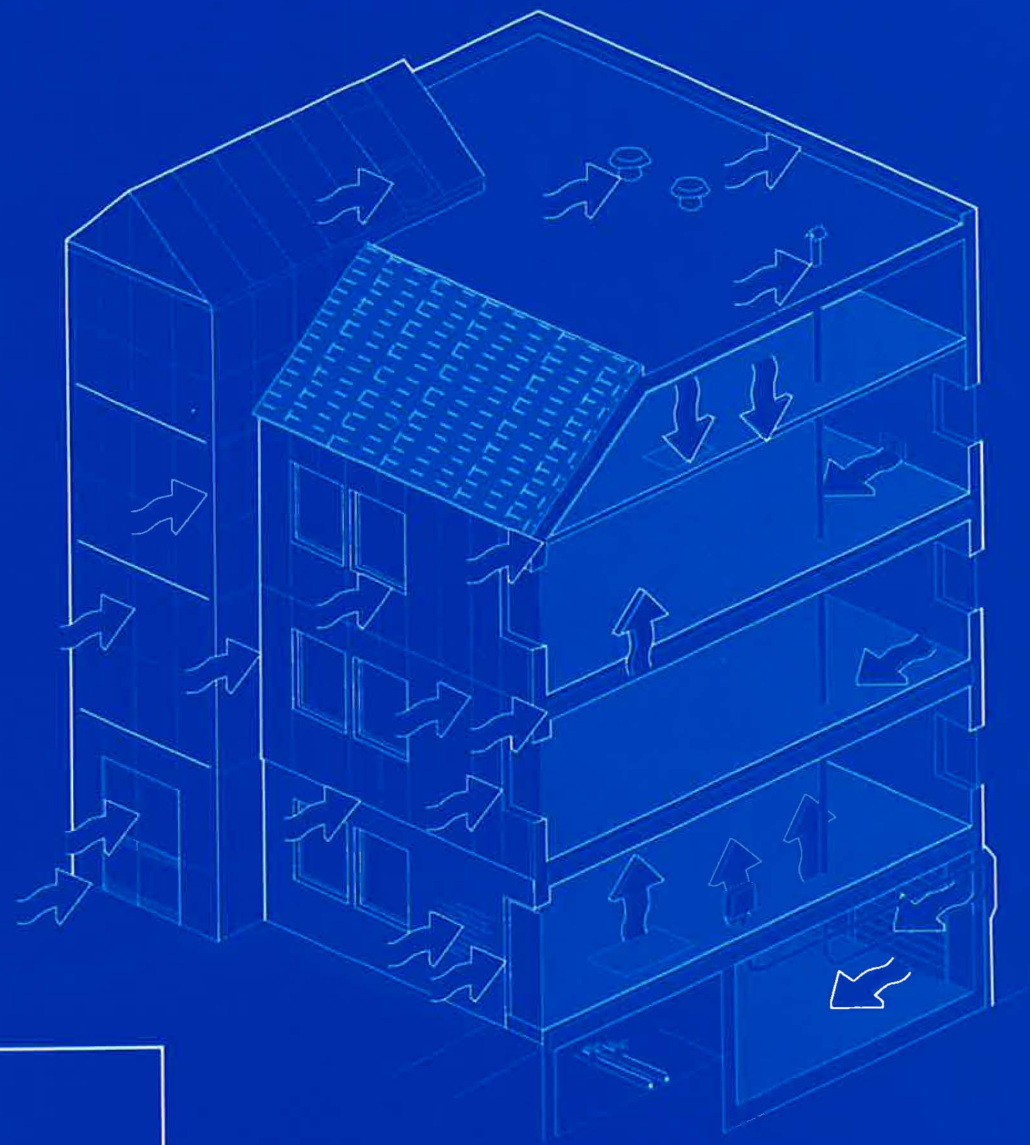
Minimising air infiltration in office buildings

M D A E S Perera, C H C Turner and C R Scivyer



Building Research Establishment Report

Minimising air infiltration in office buildings

M D A E S Perera BSc, PhD, CEng, MRAeS, FRMetS, C H C Turner BSc
and C R Scivyer MCIOB

Scope of the report

This report aims to promote greater awareness of the importance of minimising air infiltration and how this can improve building performance, particularly in relation to the internal environment. It has been produced in support of new requirements on airtightness which have been incorporated in Approved Document L (1995 edition) which supports the Building Regulations (England and Wales).

The report is intended as an outline guide to design. It sets out the principles of providing an effective airtightness layer and advises on some of the common pitfalls which can reduce the performance of this layer. The drawings are not intended to highlight the airtightness performance of specific components, but to draw attention to airtightness issues and to identify some typical details that need to be addressed.

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Contents

Glossary*

Air change rate
The rate at which outside air enters a space, divided by the volume of that space.

Air curtain
A stream of high velocity, temperature-controlled air which is directed downwards across an opening. It enables control of conditions in a space which has an open entrance.

Air exfiltration
The uncontrolled outward leakage of indoor air through cracks discontinuities and other unintentional openings in the building envelope.

Air infiltration
The uncontrolled inward leakage of outdoor air through cracks, discontinuities and other unintentional openings in the building envelope.

Air leakage rate
The leakage of air in or out of a building space under test conditions involving artificially induced pressures.

Airtightness
A term describing the leakiness of a building. The smaller the leakage for a given pressure difference across a building, the greater the airtightness.

Airtightness layer
A layer built in to the external envelope to minimise air infiltration/exfiltration. It may consist of a wide range of materials (eg. sealants, gaskets, glazing or membranes) and should be continuous to be effective.

Breather membrane
A water resistant sheet which allows transmission of water vapour, but which provides resistance to air flow.

Conditioned zone
The occupied zone in a building which needs to be heated or cooled and which is normally bounded by an airtightness layer.

Draught
Excessive air movement within the conditioned zone, which may cause discomfort.

Draughtproofing
Filling of gaps between opening parts of windows and doors and their frames.

Infiltration rate
The rate at which outside air infiltrates a room under natural conditions (normally expressed in air changes per hour or as litres per second).

Leakage path
A route by which air enters or leaves a building or flows through a component.

Minimum ventilation requirement
The minimum quantity of outdoor or conditioned air which must enter a building to maintain an acceptable indoor air environment for occupants.

Natural ventilation
The movement (caused by wind and outside temperature) of outdoor air into a room or space through intentionally provided openings, such as windows and doors and non-powered ventilators.

Pressurisation
A method of testing air leakage of a building. It allows air flow and pressure difference across the envelope to be measured and an estimate of leakage to be obtained.

Stack effect
The pressure differential across a building created by differences in the density of air which, in turn, are caused by temperature differences between inside and outside.

Vapour control layer
A layer impervious to water vapour and usually enclosing an occupied space.

Ventilation
Supplying or removing air, by natural or mechanical means, to or from a space.

Windbreak
A construction or belt of planted trees/shrubs designed to deflect wind and reduce windspeed around a building.

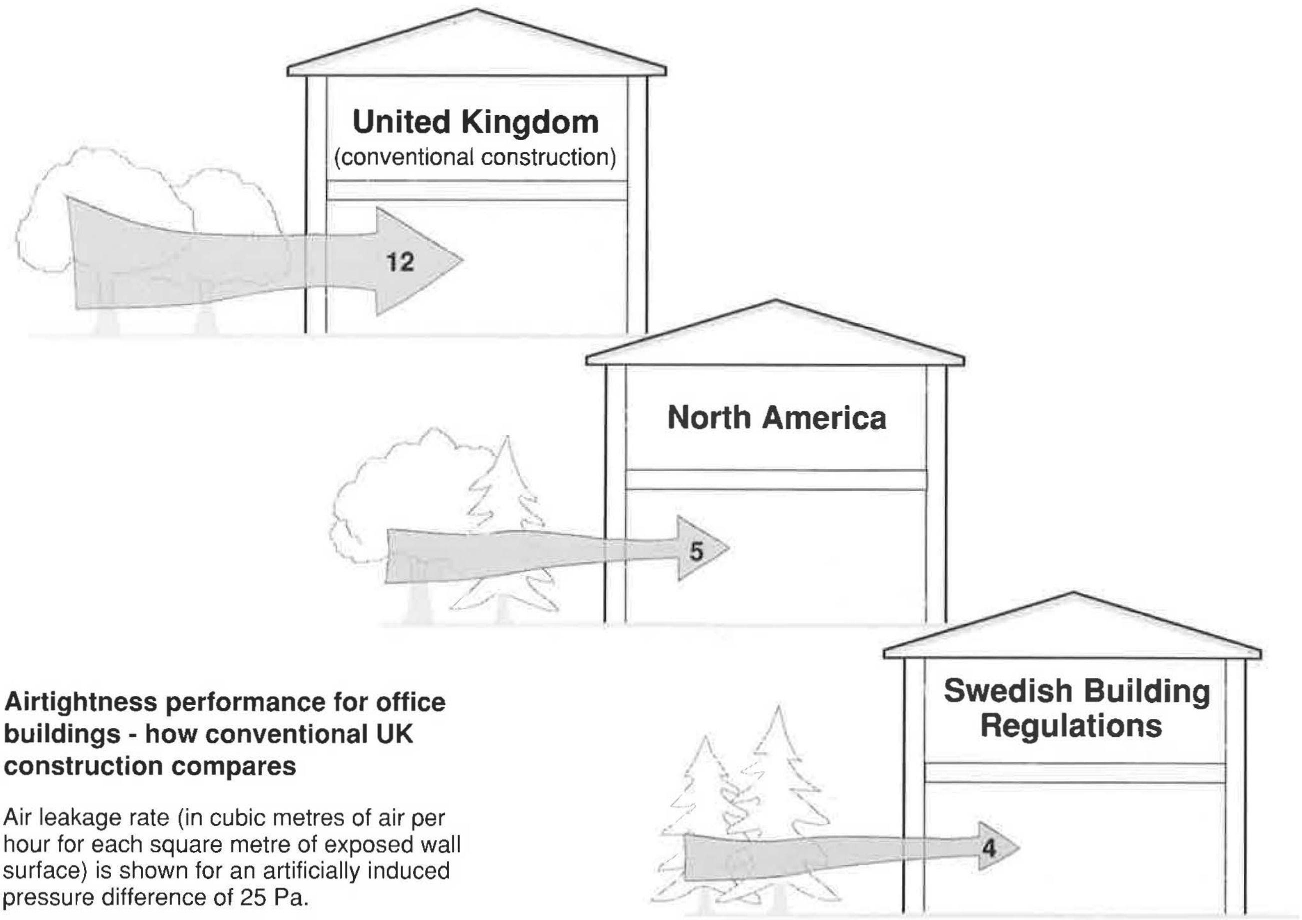
*This glossary of selected terms has been developed to be as consistent as possible with those defined in the 'Air Infiltration and Ventilation Glossary' Technical Note AIVC 36, published by the Air Infiltration and Ventilation Centre.

Introduction

An early distinction between ventilation and infiltration, albeit under extreme conditions, was made in 1902 by Captain R F Scott when over-wintering in Antarctica in the 'Discovery'. He observed that *'an ideal living-space for polar regions should certainly possess a ventilating system capable of regulation and an entire freedom from casual draughts.'* This philosophy of build tight, ventilate right is now regarded, even in temperate climates, as a sound design and construction principle which can contribute significantly to energy cost savings and improvements in levels of comfort.

Air infiltration is the uncontrolled flow of air through gaps and cracks in the fabric of buildings. It is driven by pressure and temperature differences between the inside and the outside of the building and is highly variable in response to changes in the weather. Infiltration is not a reliable substitute for properly designed ventilation of the interior or the building fabric. It may significantly increase heat losses to the outside and can depress comfort levels by allowing unwanted draughts and cold spots.

Good office design should therefore separate the mechanisms which provide a good supply of fresh air to occupants from the adverse and unpredictable effects of air infiltration. This demands good ventilation design, coupled with a clear and workable specification for an effective and maintainable airtightness layer.



Airtightness performance for office buildings - how conventional UK construction compares

Air leakage rate (in cubic metres of air per hour for each square metre of exposed wall surface) is shown for an artificially induced pressure difference of 25 Pa.

1 Understanding infiltration

- Infiltration is the **uncontrolled** flow of air entering the building through cracks and gaps in the building fabric.
- Ventilation is a **controlled** flow of air into and out of the building through purpose-provided openings.
- Buildings should be designed and constructed to minimise infiltration. The design must ensure that sufficient fresh air is provided by ventilation.

Infiltration

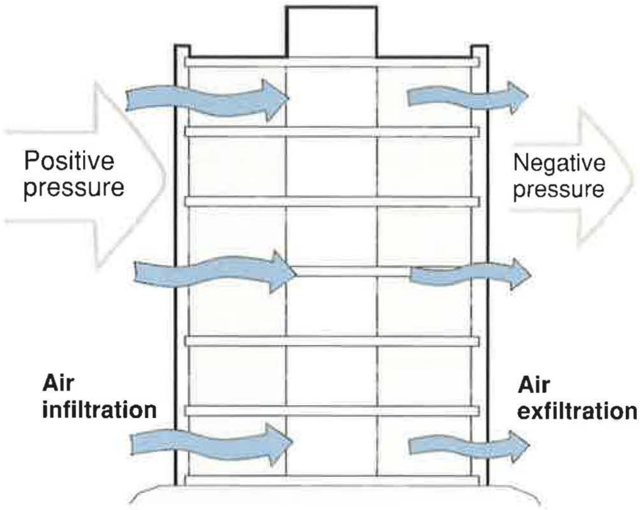
Infiltration is air leakage which occurs through cracks and gaps in the building fabric and is a measure of the leakiness (or airtightness) of a building. It is affected strongly by design decisions and construction quality. Pressure and temperature differences between the inside and the outside of the building lead to infiltration, which will rise and fall uncontrollably, largely in response to fluctuations in external wind speed and temperature.

The effect of wind Wind pressure on the building facade causes pressure differences between the inside and outside of a building. The result is that, in general, air tends to enter on the windward face (infiltration) and exit on the sides and the leeward face (exfiltration). The typical effect of wind is to create a small negative pressure internally.

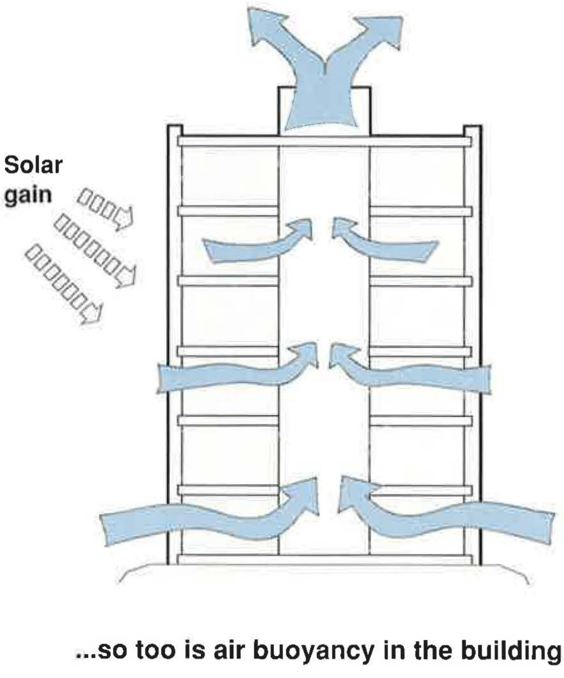
The effect of air buoyancy Heat produced by the heating system, by people and equipment and from solar gain makes the internal air more buoyant (less dense) than the external air. Within a building, the warmer and therefore more buoyant air will rise by convection. This upward air movement draws a flow of cooler external air (infiltration) into the lower part of the building and increases air pressure in the upper storeys where exfiltration will occur. This effect, which is commonly called the stack effect, is sometimes very pronounced in tall buildings where the pressure differences between lower and upper storeys can be quite large.

Ventilating without infiltration

Natural ventilation also relies on internal air movements caused by wind or internal air buoyancy; the design should allow controlled use of these processes wherever possible. Detailed guidance is available on natural and mechanical ventilation systems and ventilation requirements for buildings (see page 28 and Appendix 2). Any additional adventitious air entering the building through infiltration should be minimised to enable efficient control of the internal environment and reduce energy wastage.



Wind pressure difference across a building is a cause of infiltration...



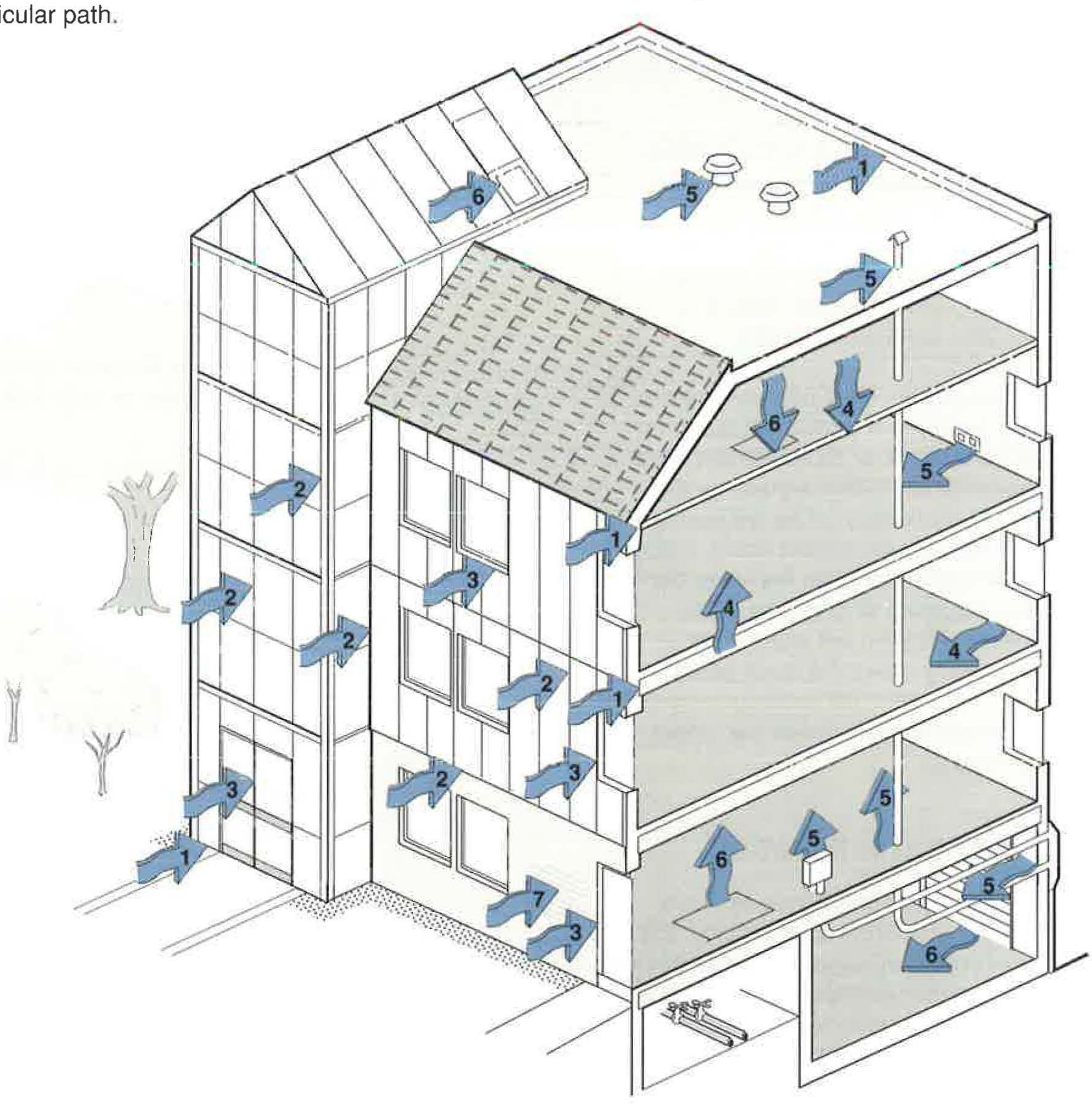
...so too is air buoyancy in the building

2 Infiltration paths

The more common infiltration paths are found:

- At junctions between main structural elements
- At joints between walling components
- Around openings such as windows, doors and roof lights
- Through gaps in membranes, linings and finishes
- At services penetrations
- Around access and emergency openings
- Through permeable materials

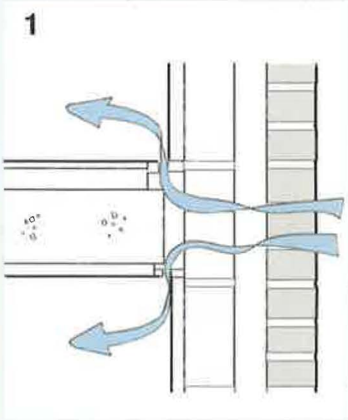
Many air infiltration paths can be minimised by correct design detailing and care during construction. Others can be minimised by careful selection of materials or components, for example the choice of cladding or window type. In practice, the amount of air passing along the different infiltration paths will vary considerably depending on the type of construction and on construction quality. The form and orientation of the building and the wind direction will influence whether infiltration or exfiltration occurs along a particular path.



Infiltration paths for a hypothetical office building

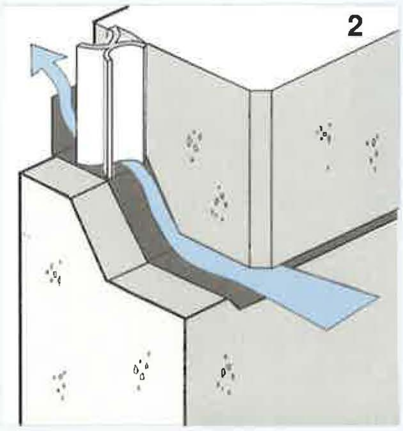
Numbers cross refer to page 3

Some common infiltration paths



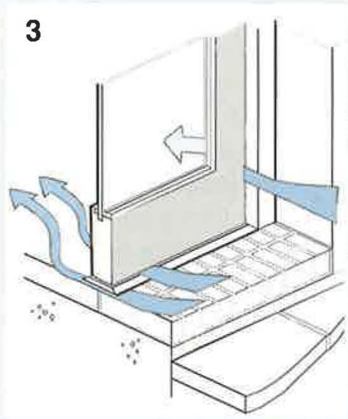
1 At junctions between main structural elements

- ○ Wall to roof junctions
- ○ Wall to floor junctions
- ○ Wall to foundation junctions
- ○ Junctions between parapets and roofs



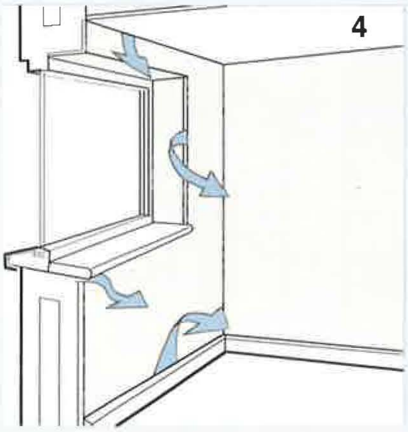
2 At joints between walling components

- ○ Sealant or gasketed joints between heavyweight or curtain walling panels
- ○ Overlapping joints between lightweight sheet metal wall panels
- ○ At boundaries of different cladding/walling systems



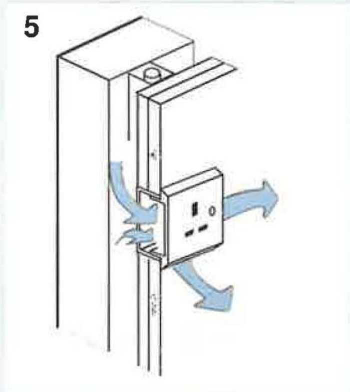
3 Around windows, doors and roof lights

- ○ Between window or door frames and walls or floors.
- ○ Between doors and windows and their frames
- ○ Between frames and sills



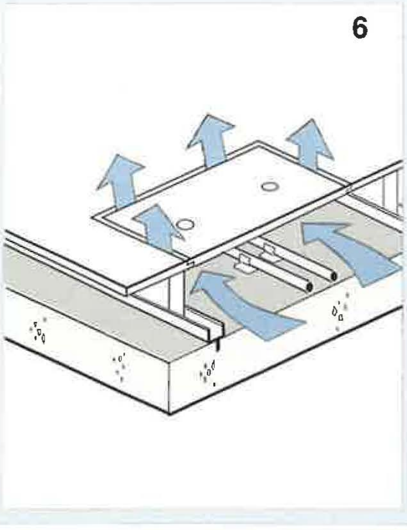
4 Through gaps in membranes, linings and finishes

- ○ In wall membranes and dry linings
- ○ In ceiling linings and boundaries with wall linings
- ○ Gaps in floor finishes and around skirtings



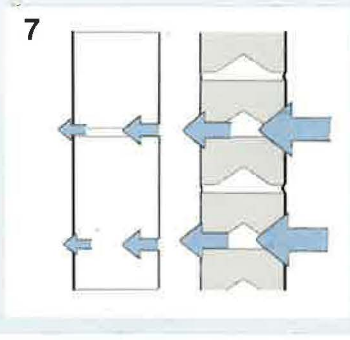
5 At services penetrations

- ○ Electrical sockets and conduits
- ○ Gas and electricity entry points
- ○ Ventilation pipes for sanitary waste
- ○ Overflow pipes
- ○ Flues



6 Around access and emergency openings

- ○ To roof space
- ○ To roof
- ○ To floors
- ○ To services and delivery points



7 Through permeable materials

- ○ Some materials, for example brick-work cladding, are not impermeable to air, and may be very permeable if construction quality is low

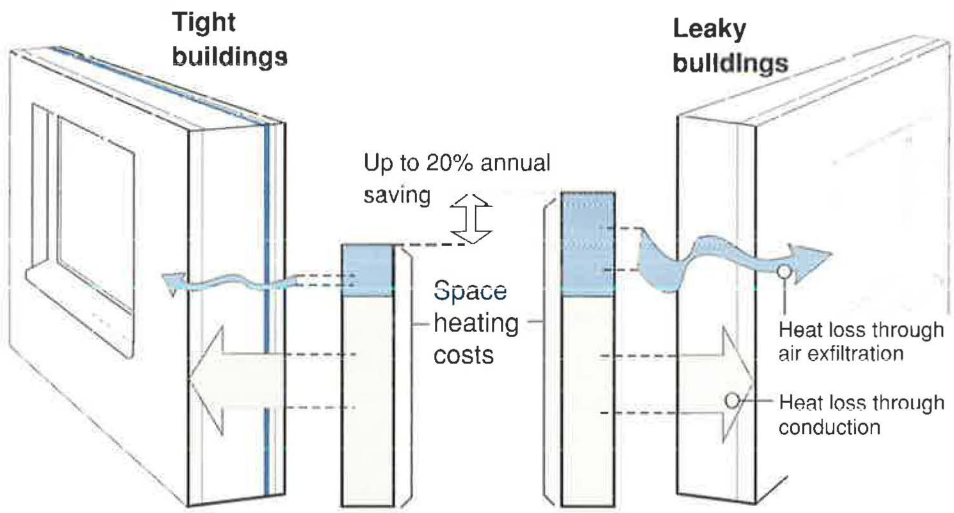
3 Benefits of minimising infiltration

- **Energy savings** In a tight building the energy costs for space heating may be up to 20% less than for an equivalent but leaky building. Additionally, sophisticated energy-saving heating control systems and heat recovery systems can be economically viable options in tight buildings.
- **Comfort** In a tight building, draughts and localised cold spots are minimised. Controlled ventilation should ensure adequate fresh air for occupants.
- **Reduced risk of deterioration** In a properly ventilated, but tightly constructed building there may be less risk of humid internal air causing moisture build-up in the building fabric.

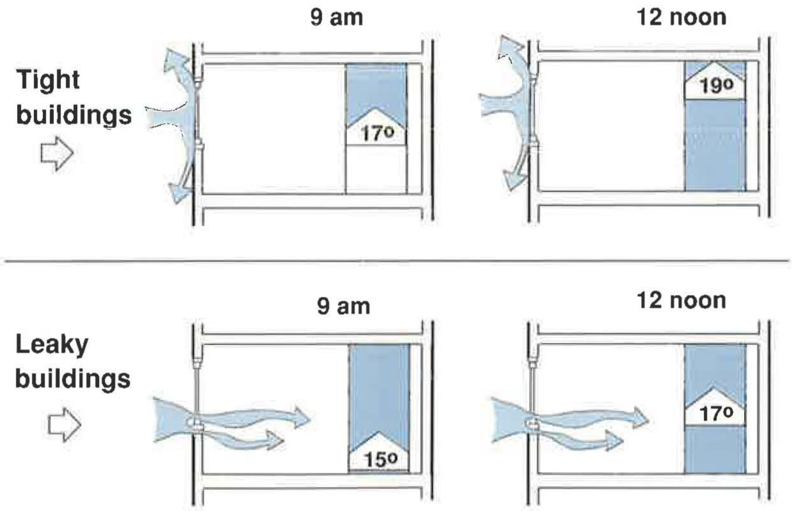
Energy savings

Space heating

Total space heating costs in a tight building may be up to 20% less than in a leaky building: in a typical medium sized office building, energy savings may be in the order of 200 GJ per year. Studies on leaky buildings indicate that exfiltration of warm air can account for as much as 30% of the total heat loss through the envelope.



An effective airtightness layer can reduce space heating costs significantly



Optimum start heating controls can only be expected to be effective in tight buildings

Control systems and heat recovery

A **tight building** will have reasonably predictable behaviour under the normal range of weather conditions. Investment in energy saving measures such as heat recovery systems and optimum start and stop controls for space heating can be worthwhile. In a **leaky building**, infiltration may reduce or, in extreme circumstances, totally negate any theoretical benefit from such systems.

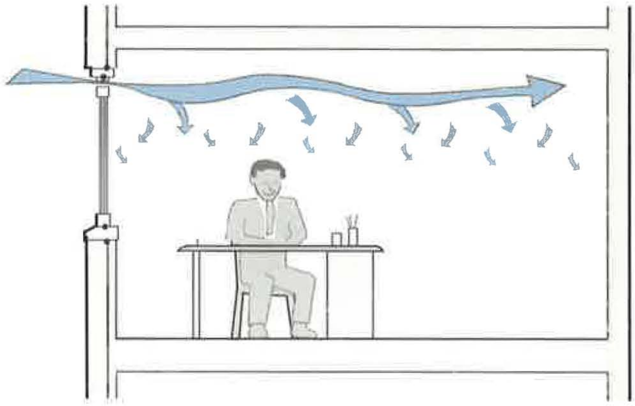
- Optimum start controls will not reliably ensure that the building reaches a comfortable temperature soon enough.
- Exfiltration of warm air through a leaky fabric will reduce the heat available to heat recovery systems and may depress their efficiency rating by over 20%.

Comfort

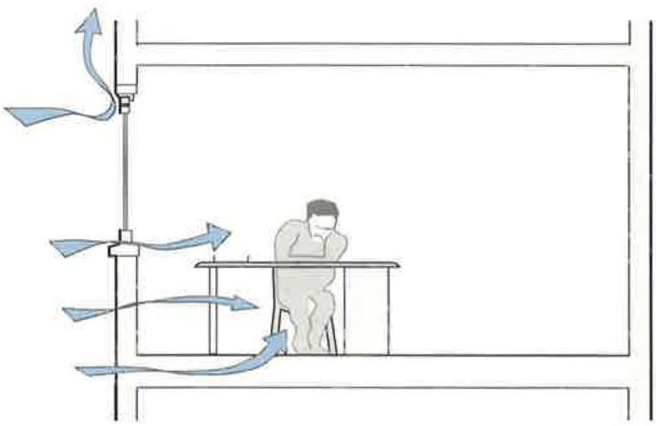
In a well-designed **tight building**, fresh air enters through controllable ventilation openings. This provides high level air movement in the room and a minimum of draughts around people.

Where infiltration is minimised, uniform ventilation and warmth is achievable and a good comfort level can be maintained. In more extreme weather conditions occupants have the option of part closing the ventilation openings to avoid discomfort.

In a **leaky building** the occupants, particularly those in corner rooms, may experience discomfort from draughts and localised cold spots. Closing the ventilation openings will not improve matters. In extreme cases, excessive infiltration may lower the average temperature in rooms to an uncomfortable level during severe weather. There are many examples where leaky facades have given rise to serious complaints about discomfort. Such complaints are difficult to resolve with occupants and remedies are often very expensive.



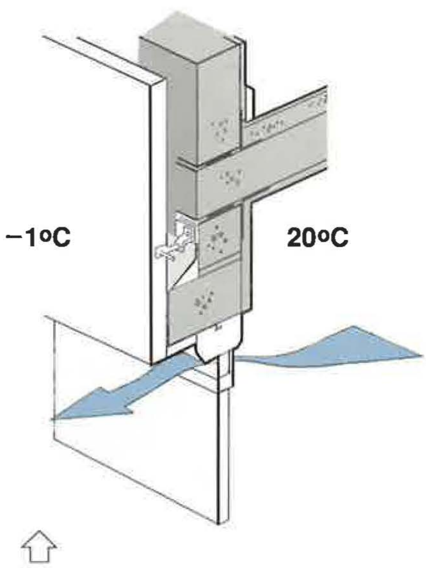
Build tight for comfort



Leaky facades make uncomfortable buildings

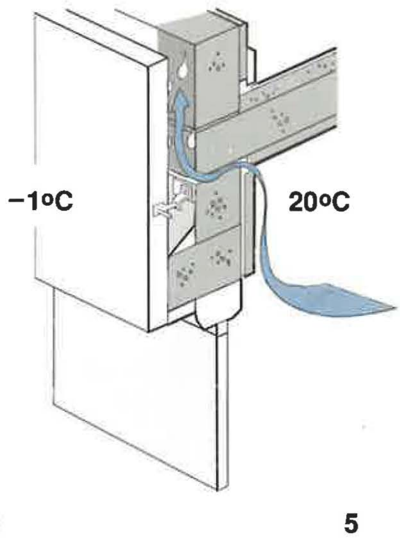
Reduced risk of deterioration

In a tightly built and well-ventilated building, excessive build up of moist air is less likely to occur. If the building has a leaky construction, exfiltration will tend to pull internal air (which is usually warm and moist) out through the fabric of the walls and roof. The walls and roof may not be designed to be tolerant of this airflow and there may be a risk of condensation and moisture accumulation. This may lead to deterioration of moisture-vulnerable materials and possibly to frost damage on materials positioned on the cold side of the wall insulation. The risk is greatest when exfiltration brings warm air in contact with cold external cladding or roofing layers, particularly thinner types.



Properly ventilated tight building - controlled routes for escape of moist air

Leaky construction - moist air enters the fabric and may condense on any cold surfaces



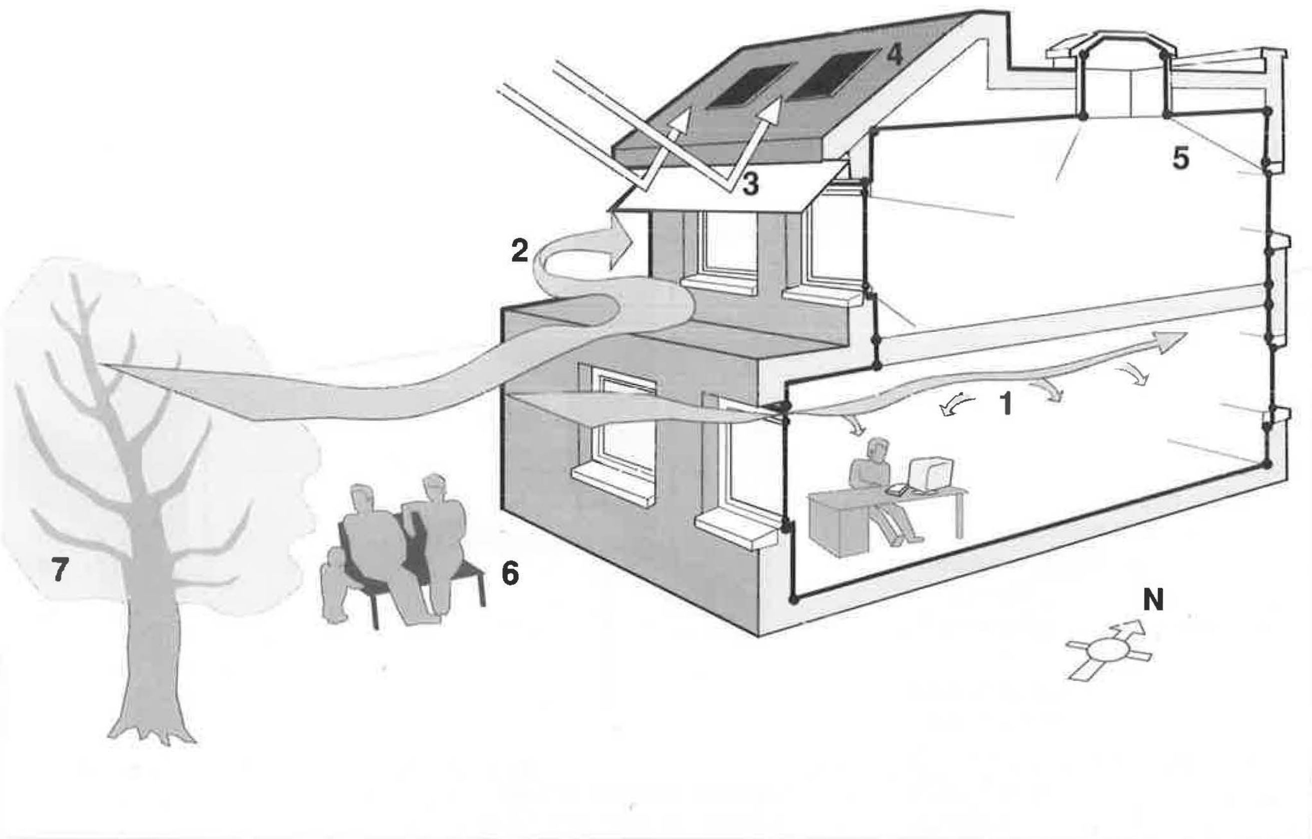
4 Infiltration and climate-responsive design

A tight building gives designers scope for more positive utilisation of the climate, in particular to optimise and integrate:

- Natural ventilation
- Daylighting
- Solar gain (space and water heating)

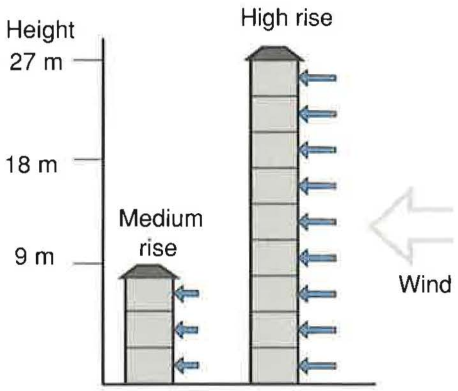
A building which is specified and constructed to minimise air infiltration has greater flexibility for incorporating and integrating design strategies which positively utilise the local climate.

For example, building orientation may be less critical in a tightly constructed building and it may be possible (figure below) to obtain full benefit of natural ventilation opportunities (1) by setting the long axis to face the prevailing wind. In such an example, the designer then calls upon additional strategies to minimise structural wind loading (2), minimise any risk of overheating in summer from solar gain (3), optimise solar water heating (4) and daylighting (5). At the same time the designer can take steps to ensure that there are no detrimental effects on the local exterior wind environment (6) and can recommend landscaping (7) which will enhance environmental conditions gradually in future years.

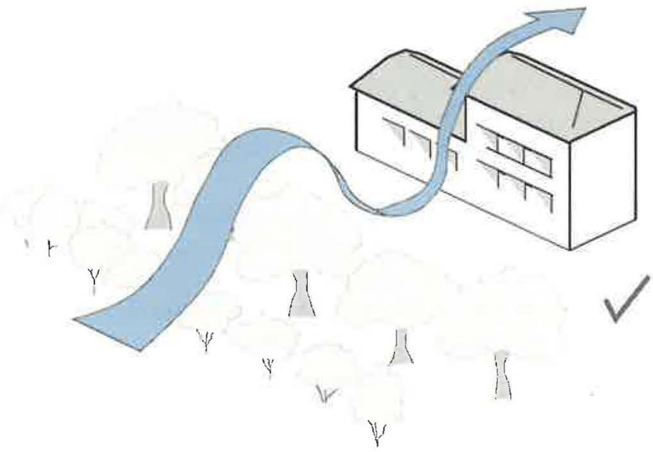


Designers opportunities for minimising infiltration

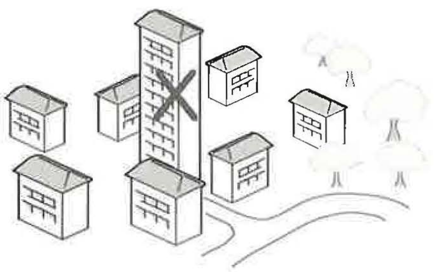
Shown below is a selection of design considerations which influence the wind microclimate around buildings and can contribute to low infiltration levels.



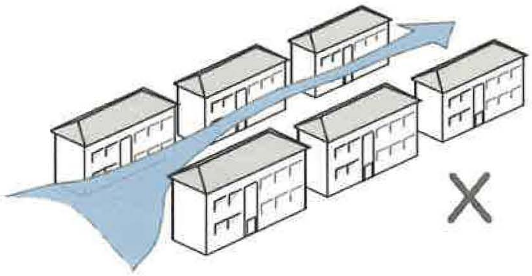
Reduce dimensions, particularly height
Wind pressure on high rise buildings may be as much as 50% more than that on medium rise. Infiltration control is technically more difficult on taller buildings.



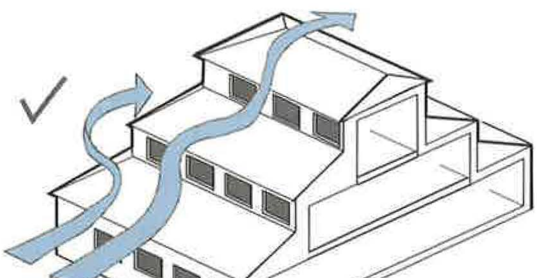
Provide windbreaks Built or planted windbreaks can reduce exposure rating significantly. Carefully planned tree and shrub planting can screen out wind without blocking light.



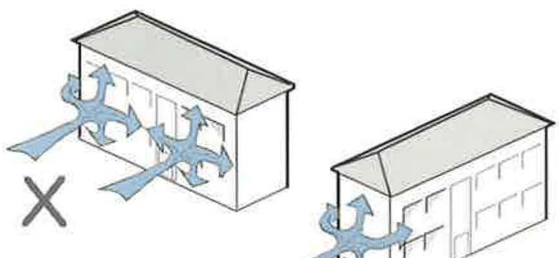
Do not mix different heights Mixing different building heights in close proximity causes complex distortions in wind flow patterns, and may result in stronger pressures on the lower buildings in a group.



Avoid wind funnelling Long, parallel rows of smooth faced buildings will funnel the wind. Try to incorporate some randomness in the arrangement of groups of buildings.



Staggered facades By staggering the facades of the building which face the prevailing wind, higher wind pressures can often be avoided.



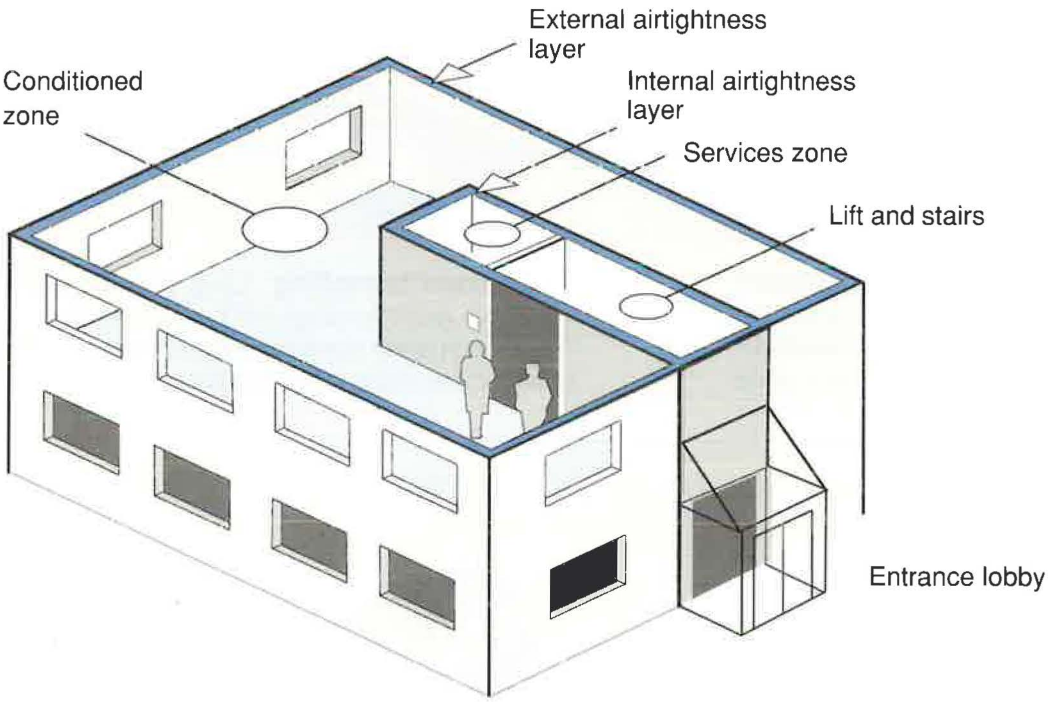
Orientation In exposed sites consider not orientating the main axis of the building perpendicular to the prevailing wind.

5 Identifying zones requiring protection

- Conditioned zones should be identified early in the design process.
- Provide an airtightness layer to separate conditioned zones from vertical shafts, entrances, delivery bays and services zones.
- Entrances need special consideration.

The zones of the building which require good protection from infiltration should be identified early in the project. Areas which are conditioned (ie. heated or cooled) need to be separated from unconditioned spaces, such as roof voids, boiler rooms, car parks and delivery bays, by means of an airtightness layer. Entrances and vertical shafts in the core of the building may need special attention.

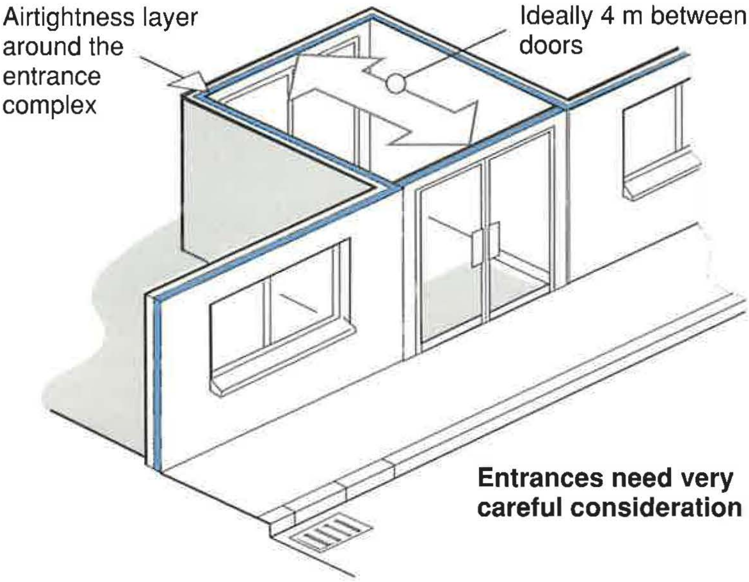
In an office building, the area where people work has to be heated in winter and may need provision for cooling in summer. This is known as the conditioned zone. The design team should define the conditioned zone at an early stage and identify the measures necessary to 'seal' this area and thus prevent uncontrolled infiltration from outside or from unconditioned areas in the building.



Consider where airtightness layers should be located to protect the conditioned zone

Entrances

Entrances are a well known source of draughts and therefore it is essential that areas around them should be protected. Lobbies can be effective in achieving this in low rise buildings. It is suggested that entrance/storm lobbies should have two doors set about 4 m apart so that one set of doors closes before the second set opens. In highly trafficked offices and in tall buildings revolving doors are preferable. The problem can also be solved by pressurising entrances (an air curtain) but this can have a fuel cost penalty.

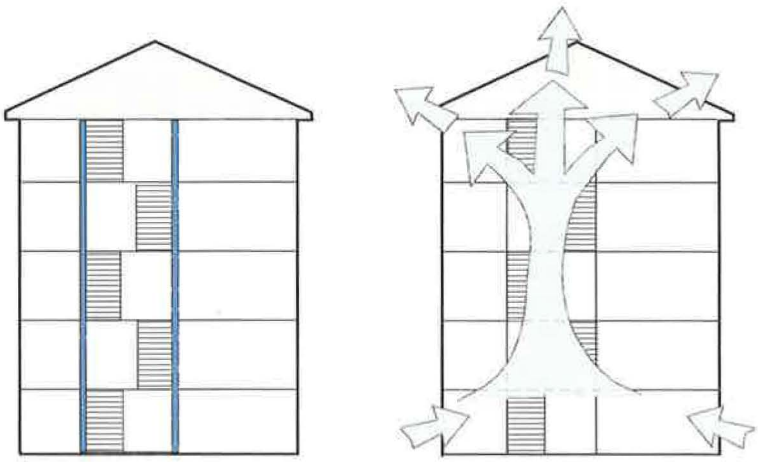


Entrances need very careful consideration

Stack effect

Tall buildings will have a significant stack effect in the core area where there are vertical shafts. This can result in high levels of air movement from the outer conditioned zones into the core. Partitions and doors between conditioned zones and core should be reasonably air tight. The area above false ceilings, especially, is often neglected.

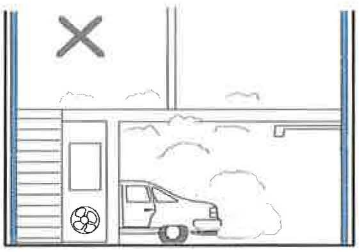
Many new office buildings are designed with pressurised staircases for smoke control. If masonry construction is used, stair enclosures should be plastered to ensure uniform airtightness performance (dry wall construction should be carefully specified and installed with all perimeter junctions sealed).

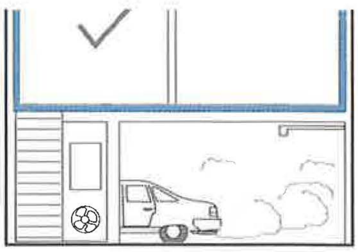


If you do not seal the stairwell, an unforeseen stack effect may be created, leading to draughts, particularly on the lower floors

Limits of the conditioned zone

Cold roof voids are normally ventilated to reduce condensation risk. An airtightness layer should separate these freely ventilated voids from the conditioned zone. An airtightness layer is needed around any sections of the roof space which will be occupied. Boiler rooms with conventional flue boilers will have large fresh air vents and should be separated from the conditioned zone. Car parks and delivery bays should also be considered as 'outside' spaces and under no circumstances should be incorporated as part of a conditioned zone.





Airtightness layer must be correctly positioned

6 Designing a tight envelope

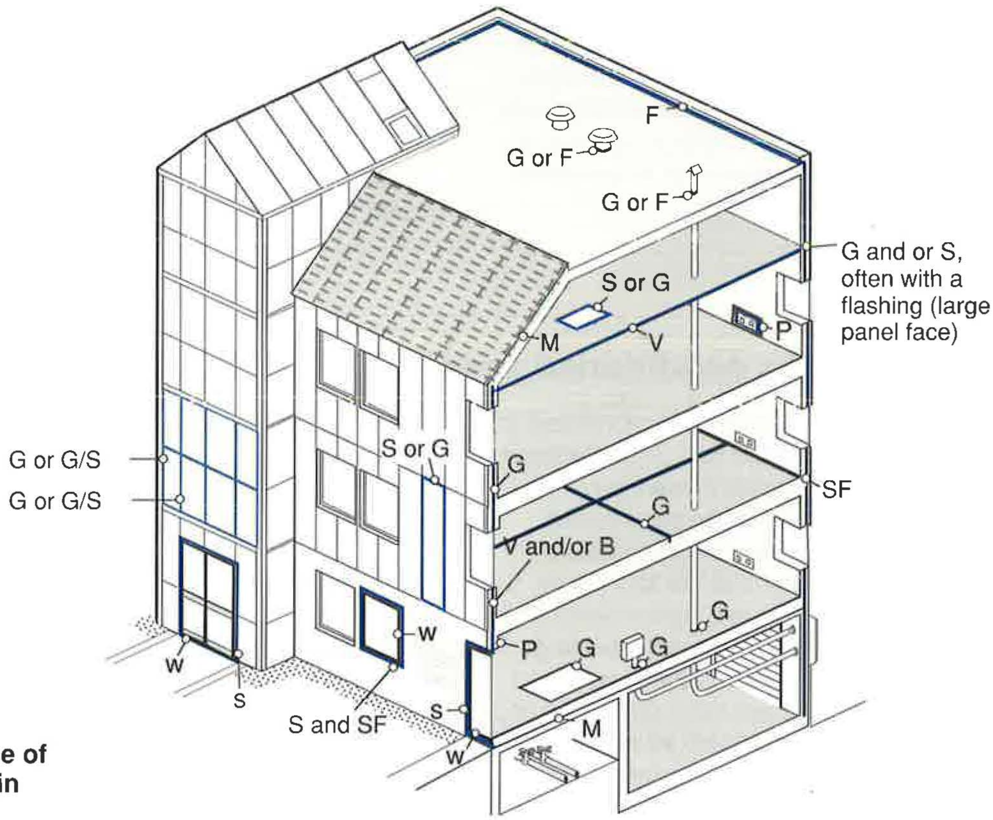
To be effective, the airtightness layer must meet the following criteria:

- Be made up of air-impermeable materials.
- Be capable of being made fairly continuous around the envelope.
- Have sufficient strength to withstand any pressures created by wind or stack effect and air control system.
- Be easily installed.
- Be durable and/or accessible for maintenance or replacement.

Overview

Wherever possible, designers should try to ensure an effective airtightness layer without the need for complex detailing. Consider the roles played by the components in the external envelope (see page 11) and try to avoid designs where the incorporation of a continuous airtightness layer at any overlapping wall configurations will cause practical difficulties for the building contractor. It is important to recognise that potential air leakage paths at junctions between elements, joints between components and at services entries, may require attention: some common situations are described on pages 12 and 13. For all potential points of air infiltration and in particular, at complex intersections and corners, and situations where site staff might not appreciate the role of a particular component of the airtightness layer, designers should provide explicit details and guidance for use on site.

A wide range of materials may be used as part of the airtightness layer (below and page 15). By selecting appropriate, durable materials, and incorporating these correctly and in a way which allows removal and replacement, good long-term airtightness can be achieved with minimal maintenance cost.

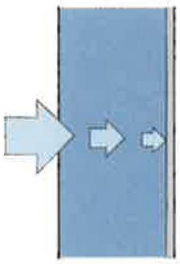


B Breather membrane
P Plaster adhesive
F Flashing
G Gasket
M Polymeric membrane
P Plaster
S Elastomeric sealant
SF Foam sealant
V Vapour control layer
W Weatherstrip (some are sealants or gaskets)

The extensive range and use of materials and components in minimising air infiltration

Types of construction

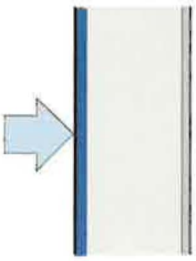
The roles of different layers in the building envelope vary between the main classes of construction, as shown below for walls. In some cases a cladding, or the external surface of the wall, may form part of the airtightness layer, but it is common for an internal layer to provide the main protection against air infiltration. Careful detailing is needed to ensure continuity of airtightness around openings and where different types of construction overlap on a building.



Homogeneous walling

- Concrete panel walling
- Solid block walling
- Masonry

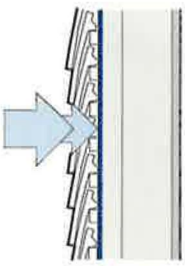
There may be reliance on the internal lining and vulnerability to air infiltration where linings have air gaps or are incomplete. All joints, including those in brickwork, allow some air leakage, particularly if construction is substandard.



External cladding with air seals

- Sealed metal-skinned panels
- Sealed exterior tile panelling
- Curtain walling

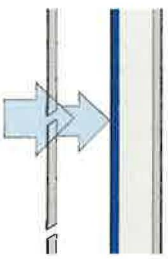
Little evidence of long-term air infiltration resistance of sealed tile panelling. With curtain walling, careful detailing, careful choice of materials and good workmanship is essential to ensure long lasting control of air infiltration at glazing joints and at junctions with the main structural elements.



Rain screens

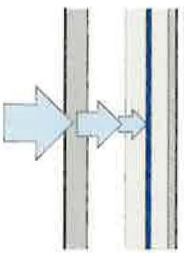
- Overlapping tiles
- Some overlapping metal sheet systems

The airtightness layer (often a breather membrane) is mounted immediately behind the outer skin, which provides the rain protection. The airtightness layer requires careful detailing and fixing and normally is required to be permeable to water vapour.



- 'Rainscreen walls', which range from drained and back ventilated types to pressure-equalised types

There are technical advantages with these systems, but the design mechanisms must be fully understood and detailed, particularly at corners and at intersections with other envelope constructions.



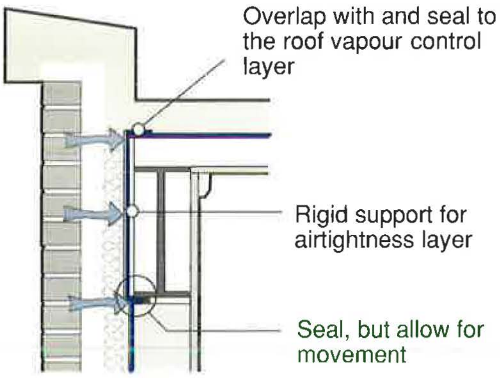
Internal airtight vapour control layer

- Lightweight panels on internal frame
- Masonry cladding

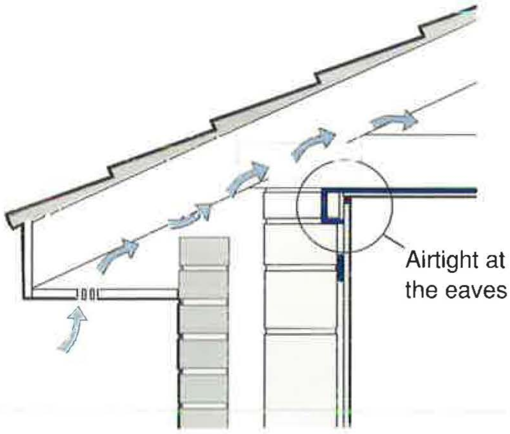
One layer (often a membrane) controls both infiltration and vapour flow. Care is needed to ensure it is continuous, properly supported and positioned to avoid condensation risk in the wall. Services penetrations need careful detailing.

Sealing junctions between elements: some typical details

Walls to roofs

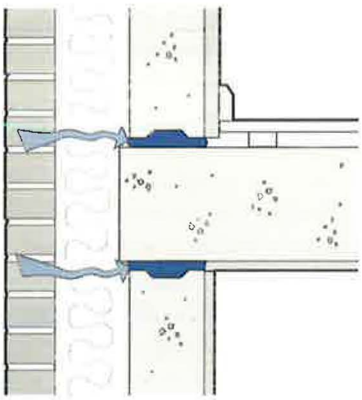


With steel frame, support the airtightness layer between flanges. Allow for movement between steel and infill wall below, and overlap with roof vapour control layer.



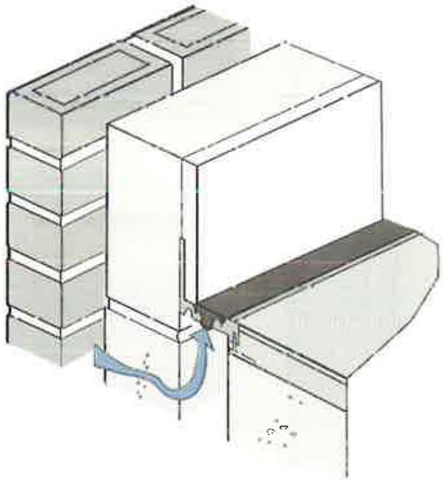
With pitched roofs consider how the eaves air flow will be prevented from entering the occupied area (insulation omitted for clarity). This example illustrates a solution for dry lined walls.

Walls to floors

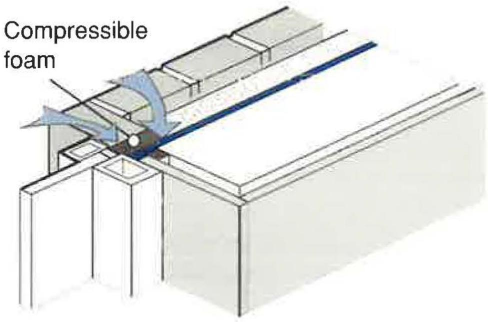


Foam sealants (left) may be used to provide continuity of airtightness between concrete infill wall panels and floor elements.

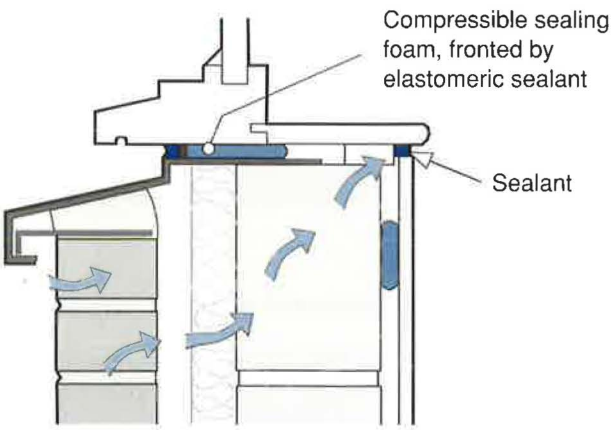
Proprietary gasket systems (right) can be used to reduce air leakage and allow differential movement between wall and floor elements.



Walls to windows or doors

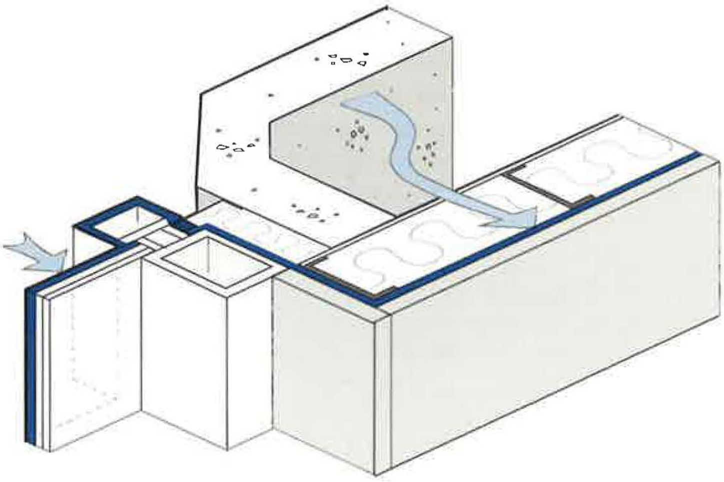


At jambs the airtightness layer must extend to the frame and be sealed to it. In the detail shown above, a strip of compressible foam insulation completes the thermal break at the jamb and supports the airtightness layer.

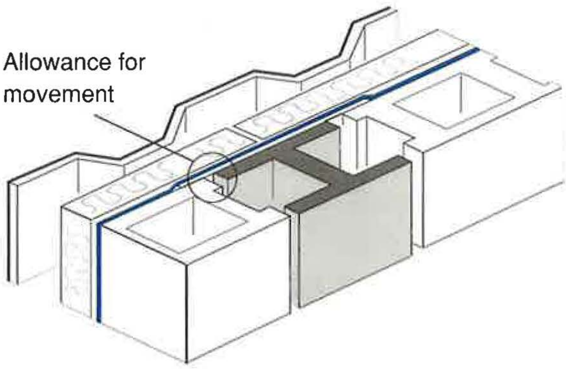


Sill detailing should not allow air penetration between frame, sill or wall. The plasterboard must be sealed against the window sill if, as in this case, it is designed to contribute to airtightness.

Sealing joints between components: some typical details

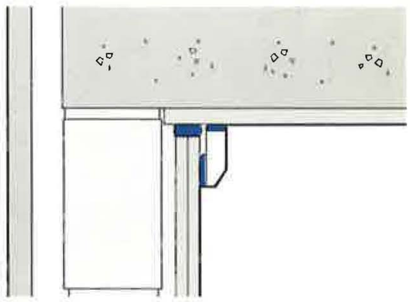


Continuity between components of differing function In the curtain walling example shown above, the airtight glazed facade must be carefully detailed to be continuous with the airtightness layer (which also serves as a vapour control layer) behind the pressure-equalisation zone of the concrete clad section.

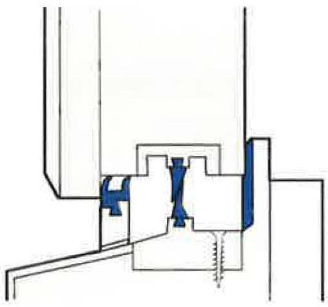


Continuity where allowance for movement is needed The airtightness layer must be supported and detailed to allow for differential movement, which might be quite large at boundaries between some wall components with very different thermal movement coefficients.

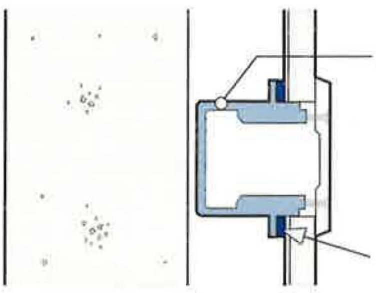
Continuity between components of identical function For example, where wall plasterboard (below) is part of the airtightness layer, specify laying to break joint, sealing tape at corners and a seal to the ceiling plaster; performance can be further improved by sealing a coving unit to the plaster, as shown.



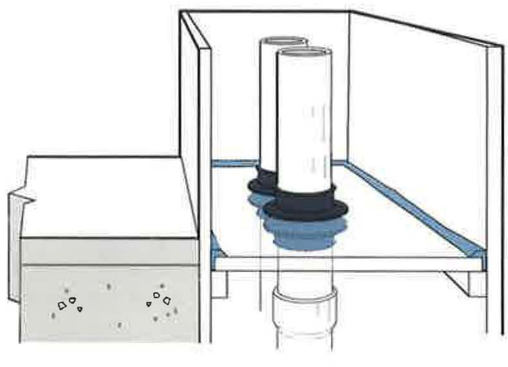
Continuity at openings A range of window and door designs with highly effective seals between frames and opening parts are available. Window design should allow easy replacement of the sealing materials.



Sealing holes at services entries



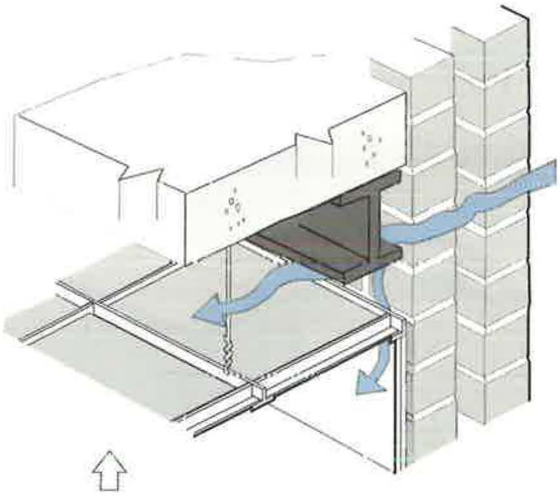
Seals are important where **electrical services** penetrate the airtightness layer, particularly in construction where the plasterboard or a vapour control layer forms part of the airtightness layer. Airtight electrical boxes are now available.



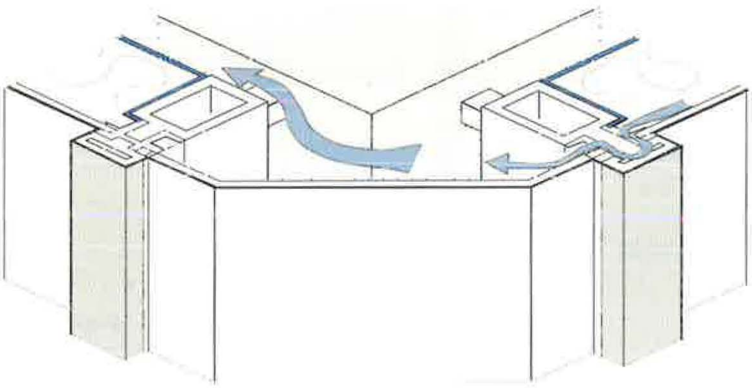
Waste services routes and penetrations should be carefully detailed to be airtight and, where necessary, to have the required resistance to fire spread.

Provide explicit detailing

A carefully worked out airtightness strategy may prove ineffective if the details are not clearly identified and explained on the plans. Often, the detailing is most poorly explained at the more difficult joints, junctions and corners. These locations, in particular, require very careful design consideration to ensure continuity of airtightness, thermal insulation and rainproofing; the detailing should not be left to chance.



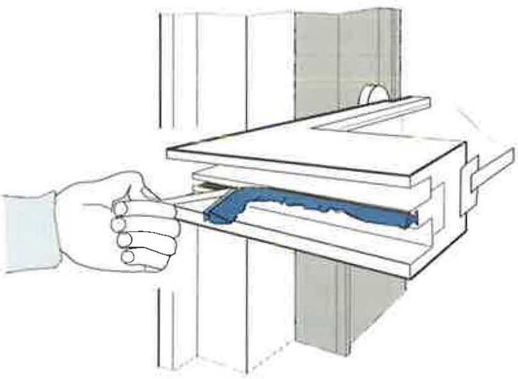
Site staff may not appreciate that plaster (or roughcast render) forms part of the protection against infiltration and should be continued above false ceilings and made continuous with other airtightness measures.



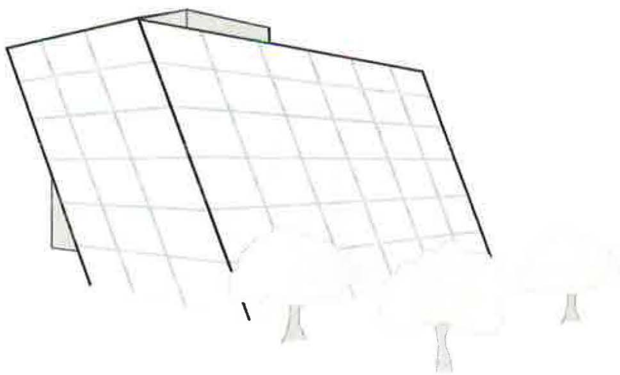
A route for excessive air infiltration. Behind this external corner panel there should have been a rigid airtightness layer (and insulation) linking with the vertical and horizontal mullions

Designing for access to the airtightness layer

The airtightness layer will need to be checked and maintained/ replaced during the life of the building. Designers should consider how this might be achieved.



At the component level A fully rotatable window with an easily replaceable weatherstrip: minimising future costs for maintaining a moving component which will inevitably wear with age.



At the building level Consider access for maintenance and repair of the airtightness components. If access is likely to be difficult on your design, specify that all airtightness components are as durable as possible.

Choice of materials for infiltration control

Sealants

Gun applied sealants (Elastic and elastomeric types). These sealants are commonly used in external joints and as bedding materials for glazing and on curtain walling. They may be expected to keep out rain and minimise infiltration at joints. To be effective, sealants must be resistant to cyclical movements at the joint and must maintain adhesion to surfaces, despite wetting during rainfall. Some are also used in positions where they are exposed to the degrading effects of UV light. The more commonly used Elastic or elastomeric sealants for joints are shown in the table. If properly applied to a well designed joint, which does not exceed the movement capability of the sealant, all these types can be expected to have a life of up to 20 years on a building, but much less in very exposed situations. Failure occurs rapidly for incorrectly specified or poorly applied sealants. Although formulations are continually being improved, much is expected of the sealant component in external joints and it is a good design that anticipates and allows for easy replacement during the life of the building. Designers should always seek advice from sealant manufacturers on life expectancy, optimal joint design and correct joint primers for **specific** sealant types.

Site applied foam sealants (usually supplied in a pressurised canister). These are usually 1-part polyurethane formulations. They are often used for sealing around curtain walling sections and gaps that are too wide to be sealed with elastomeric sealants. BRE advises that they are not used as a sole means of fixing an object to a framework. The ability to seal large and irregular gaps (the sealant rapidly expands by up to 15 times its initial volume) makes these sealants very popular for use in remedial control of airtightness. At present there is little authoritative information on the durability of these materials and it is advisable to ensure that when installed they are protected from direct exposure to the weather.

Elastic and elastomeric sealants with an expected life of 20 years

Type	Movement tolerance*	Typical uses	Practical considerations
1-part polysulphide	25%	Movement joints in heavy structures	Slow curing; vulnerable to damage until cured
1-part polyurethane	30%	Movement joints between lightweight wall components	
2-part polysulphide	30%	Movement joints between heavy or lightweight wall components	Mixed on site so must be used within 'application life'. Maintenance costs low
2 part polyurethane	30%		
1-part silicone (low modulus)	50%	Joints between plastics and metal components	High initial costs. Careful surface preparation needed

* as a percentage of the joint width

Gaskets for movement joints

Neoprene and silicone gaskets are used extensively for sealing the external envelope against rain and air penetration. They feature in many proprietary curtain walling systems and are used for joints between concrete and lightweight cladding panels. Very little is known about the long term performance of gasket systems on exterior facades of buildings and in external joints. With gaskets it is essential that adequate compression is achieved at construction and maintained in service; for joints in large panel construction, this is difficult to achieve and there have been some associated problems related to water and air penetration. Some joint systems have gaskets and baffles which are not intended to be airtight; a backing strip and/or a flashing strip may be required to ensure good airtightness. It is important to indicate how the flashings should be sealed to close the joint and how they should be supported in position. Designers should anticipate the need for gasket replacement at some stage of the building's life by opting for designs which allow easy access, removal and replacement of gaskets and any associated flashings.

Gaskets are a logical choice for seals around hatches and services penetrations, at joints between large structural floor units and at other internal positions where some differential movement will occur between elements. They must meet special requirements if penetrating the fire barriers between two compartments of a building.

Choice of materials for infiltration control

Draughtstripping

Windows make up a large proportion of the external envelope and poorly draughtstripped windows can represent one of the major routes for air infiltration. In a high performance window, typical of that used for office buildings, draughtstripping is an integral part of the factory finished unit, which has probably been tested to meet a performance level for air infiltration (eg. to BS 6375). Modern draughtstrips are manufactured from resilient and durable materials, commonly a synthetic rubber (to BS 4255 Part 1) or a thermoplastic elastomer (to BS 7412) and may be expected to have a long life compared with earlier generations of materials. The performance of draughtstrips in controlling air flow varies with the profile of the seal and the level of compression that the closed window places on the seal. In general, tubular seals appear to have benefits in allowing a good seal with less compressive force. The resilience of all draughtstrips may be reduced by high temperatures on the building facade, chemical changes associated with moisture uptake, UV degradation, effects of pollutants, the effects of cleaning detergents and solvents which may be used for cleaning and maintenance, and paints which might inadvertently be applied. Like sealants and movement gaskets, draughtstrips should be accessible for replacement; designers should bear in mind the likely future availability of draughtstripping, particularly those of complex section.

Choice of polymer based draughtstrips and glazing gaskets

	Weather resistance	Resistant to air pollution (ozone)	Resistant to acids and alkalis	Comment
Synthetic rubbers:				
EPDM	Good	Yes	Yes	Low resistance to oils
Silicone	Good	Yes	No	Often used for glazing for plastics components, against which it does not react. Colours other than black available
Chloroprene	Moderate	Yes	No	Resistant to oils
Thermo-plastic elastomers*:				
PVC nitrile	Good	Yes	Yes	Can be co-extruded with rigid PVC. Colours other than black available
Acrylic	Good	Yes	No	Colours other than black available

* Thermo-plastic elastomers are currently more widely used for static applications like glazing gaskets.

Mineral wool

Although used mostly for thermal insulation and fire protection, mineral wool (glass fibre or rock wool) can be used to provide air seals in some situations. 'Sealing fibre' (mineral wool in a polyethylene tube) is used between larger construction elements /components. 'Jointing fibre' (strip of mineral wool with a polyethylene film on one side) is used between wall and framing components. These materials may not retain a good seal between components which are expected to show differential or cyclical movement.

Preformed flexible foams

These can be used to seal joints between components. The degree of compression in the joint determines the effectiveness of the seal. manufacturers should be consulted over the ability of these materials to retain a long term seal in particular joint types. Some of these seals are supplied in a pre-compressed condition, expanding to seal a joint after insertion.

Films

Polyethylene film is almost universally used when a sheet vapour control layer or airtightness layer is needed. All film should be of a type which has been stabilised against UV degradation and oxidation. Elevated temperatures accelerate degradation of film; metal foil should be fixed behind any radiators to prevent high temperatures occurring in any film located on the warm side of the wall insulation.

Polyethylene film is usually fixed by staple gun using zinc plated steel (or stainless steel) staples. Plain steel or copper staples may cause localised aging and should not be used. Although 500 gauge polyethylene is used, 1000 gauge is preferable, being much more resistant to accidental damage, before and after construction. Designers should consider use of reinforced films or polyolefin films in situations where additional robustness is needed.

Careful sealing of overlaps is essential. Heat welding is the most effective, but still not that commonly used. A strip of butyl sealant provides an effective join. There is some uncertainty over the long term performance of adhesive tape for joins; some of these may dry out with time and lose adhesion. If tape is to be used, seek guidance from manufacturers on the type(s) which will provide acceptable service life under the proposed conditions of use. **Simple overlapping is not acceptable.**

Care is needed with airtightness details where services penetrate the film. For electrical services, specify how the service will be supported and sealed. In Canada and Scandinavia, proprietary sealing boxes are used universally for electrical services penetrations. These are now starting to be available in the UK.

Special electrical services seal, as used in Canada. Similar seals are now available in the UK

Breather membranes

The primary role of breather membranes is to protect a structure against rainwater penetrating the outer skin. They are vapour permeable and allow the escape of moisture generated within the building. In some construction types they are used as part of the airtightness layer. As yet, breather membranes cannot be specified against airtightness criteria, but designers can ensure that a membrane has adequate tear resistance. Specify corrosion-resistant fixings for the membrane, frequency of fixing, overlap for vertical and horizontal joins and how the membrane should link with adjacent airtightness components, particularly around openings. The overlaps between sheets should be sealed carefully, preferably with a continuous bead of flexible sealant.

7 Building Specification

Specification and sitework

- Precision is needed in specification writing in order to ensure that the main contractor is fully responsible through the specialist sub-contractors for constructing to predetermined performance criteria.
- During work on site, awareness is needed at all site management levels of the care required for achieving specified maximum levels of infiltration.

1 Specification - specialist subcontractors

On many office projects, construction of the main elements of the building envelope will be undertaken by specialist subcontractors. In most cases the specification will define the required performance of the element, including airtightness, but not its detailed design or construction. The specification should also define methods of checking that the performance standards are being met; this should include reference to test procedures and specifying who is responsible for carrying out, supervising and paying for the tests. Procedures for remedial work and retesting must also be set out.

2 Specification - traditional construction

Standard specifications do not, at present, emphasise methods which are relevant to airtightness. It is usually the responsibility of the building designer to ensure that adequate airtightness provision is included in the specification and that areas critical to air infiltration are clearly spelt out in contract documents.

3 Coordination of trades

The problem of coordination of trades or specialists must be tackled during specification. It is where trades meet that 'loose ends' occur; for the minimisation of infiltration these loose ends are all important. Sealing around pipe entries, for example, is seldom clearly specified and is often dealt with as an afterthought or neglected entirely. It is recommended that the building designer should identify all the problem areas and spell out responsibility for finishing off in the contract documents.

4 Sitework stage - designers duties

The building designer should consider how all involved on site can be fully briefed before sitework starts. A member of the design team should then check that the sitework is being carried out according to the specification, giving particular emphasis to work that will be concealed later in the building process. This will normally be done by visual inspections, although in some projects (see the case study on Wansbeck Hospital on Page 25) a more rigorous approach may be chosen.

5 Sitework stage - contractors duties

The main contractor is responsible for coordination and supervision on site and must make sure that all specialists are fully aware of how their components relate to others and that there are no unsupervised 'gaps' between specialists. Training of contractors' supervisors and labour is equally important although beyond the scope of this guide.

6 Specification and sitework - summary

Appendix 1 outlines the typical stages involved in a building project and highlights the areas where infiltration should be considered.

Data for specifiers

- Regulations
- Performance standards
- Ventilation standards

Regulations

Approved Document L, *Conservation of Fuel and Power* (1995 edition), which supports the Building Regulations (England and Wales) requires that infiltration is reasonably controlled in buildings. The Approved Document refers to this BRE Report as a primary source of information on practical ways of compliance. The Regulations also require that adequate ventilation is provided and the Approved Document F *Ventilation* indicates the levels of ventilation required. The Building Standards (Scotland) Regulations, 1990, and the Building Regulations (Northern Ireland), 1990, contain similar requirements.

The Workplace (Health, Safety and Welfare) Regulations, together with the Approved Code of Practice, also require effective and suitable provision to ensure that every workplace is sufficiently ventilated.

Performance standards

BS 6375:Pt.1:1989: *Performance of Windows*, describes air permeability standards for windows for five categories of exposure. These standards are not very onerous and the Standard refers to a stricter limit on air leakage which can be chosen 'when stringent levels of performance are required'; this allows roughly a quarter of the air leakage of the standard categories. BS 8200 also refers to air permeability measurements and the need for testing of wall claddings. For practical reasons, test methods in British Standards concentrate at the component level rather than whole facade or building level, and few are appropriate for overall assessment of infiltration. Currently there is very little guidance for architects on likely airtightness performance for specific forms of construction and differing standards of construction.

Ventilation standards

Minimum rates for supply of fresh air are required to satisfy safety and health criteria for the occupants of a building, as discussed in Appendix 2. Guidance is also provided in BS 5925: 1991: *Code of Practice for ventilation principles and designing for natural ventilation* and the CIBSE Guide A.

While casual air infiltration could provide potentially useful fresh air, it cannot be designed for. Consequently, fresh air provision is conventionally designed assuming zero casual infiltration, to ensure adequate supply at all times. Infiltration rates should therefore not be related to fresh air demand and all infiltration during the heating season can be seen as wasteful.

8 Inspection during construction

- Once the building is completed, it may be very difficult to examine the airtightness layer.
- Inspection is an opportunity to ensure that the construction team has a clear understanding of the importance of the airtightness layer and how it will be incorporated.
- Inspection should concentrate on ensuring **continuity** of the airtightness layer, particularly parts that will be hidden in the completed building.
- Key inspection points may differ depending on the type of construction.

Except in some forms of curtain walling, inspection during construction may be the only way of ensuring that a continuous airtightness layer is incorporated correctly. The main objective in inspection should be to ensure that there is an adequate understanding on site of the airtightness requirements at joints, intersections and junctions of different wall types, and to ensure that the airtightness specification has been met. The design team (or more rarely the Clerk of Works) may wish to be involved in (or lead) this training process, which should include careful briefing of operatives (see also Appendix 1). If there is any uncertainty over detailing or materials, this should be checked with the building designer.

Guidance notes for Site Representatives and Building Control Officers

1 Common inspection locations for all types of construction

Check that the airtightness layer is continuous at:

- **Foundation/ground floor level.** Wall and floor dpcs may have an airtightness function, but often a separate airtightness layer is needed as well.
- **First floor and intermediate floor level.** With concrete floors there should be a seal which links the plasterboard with the floor (ie a gasket or sealant, which can tolerate any movement). Any voids under floor finishes or for services runs should be sealed to prevent infiltration of external air. With timber floors, a seal should be incorporated (polyethylene sheet) to prevent any air penetration parallel to the line of joists; this sheet will need to be supported between joists.
- **Eaves level.** There should be continuity between the wall and ceiling airtightness layers.
- **Junctions between parapets and roof/wall junctions.** Correctly installed dpc and flashing systems alone may not always provide adequate airtightness.
- **Windows and doors.** Check that the frame to wall junction is properly sealed and continuous with the wall airtightness layer, particularly at sills. With all windows and doors check that an appropriate weatherseal is provided between the opening unit and its frame.
- **Boundaries between different wall envelope systems.** This is where many mistakes happen. Check carefully that all wall systems represented on the structure have an airtightness layer and that the design allows for these to be formed as a continuous layer.
- **Services penetrations.** Check for proper seals at services entries to buildings, services ducting and conduit and at the points where services enter conditioned zones.
- **Ceiling level below the roof space.** Check that an airtightness layer separates any deliberate roof ventilation from the conditioned zone. Check detailing to avoid infiltration at the eaves. Services penetrations and hatches must be properly sealed if they penetrate the airtightness layer.
- **Lift shafts and services cores.** Where present, these should be separated from the conditioned zone by an inner airtightness layer and draughtproofed access doors.
- **Main Entrances.** Check that the whole entrance complex is separated from the conditioned zone by an airtightness layer, and has a door layout consistent with likely traffic.
- **Delivery entrances/car park areas etc.** These must be separated from the conditioned zone by an airtightness layer.

2 Some key inspection points for four major construction types

Brick/block construction

Masonry

○ Check quality of construction as work proceeds. For Brickwork and blockwork a full mortar bed is needed, and carefully 'buttered' end joints. There should be no gaps or cracks in the finished work. Check external **and** internal leafs.

○ Check that any services which penetrate the masonry are properly sealed.

Dry lining

○ Check that the plasterboard is continuous and that airtightness measures have been incorporated at ceiling and floor levels.

○ Check that the plasterboard (or internal rendering) is continuous above false ceilings and linked to the airtightness layer at the true ceiling/roof level.

○ Check that the plasterboard is correctly detailed at joints, corners, reveals and window sills to prevent air penetration. Mount plasterboard on ribbons of plaster or adhesive rather than on dabs.

Concrete frame construction

○ Where the concrete panels constitute a waterproof shell, make sure that the joints are properly fabricated (check in particular for proper detailing at junctions and intersections and boundaries with other walling). Note that most joints are expected to have a flashing which provides airtightness on the inner face of the joint. If sealants are used, check that these have been correctly applied and that the joint width is acceptable. If gaskets have been used, check that these have been installed with the right degree of compression.

○ If the panels are designed to provide a rainscreen, and have a pressure-equalisation void, there usually needs to be an airtightness layer installed behind any insulation included. In these situations the airtightness layer needs careful detailing at junctions with windows and other cladding, like curtain walling and at corners.

Steel frame construction

○ Check that there is an airtightness layer behind the cladding, and that it is correctly positioned (usually on the warm side of the insulation).

○ Check that the airtightness layer is continuous within the wall, between the steel frame and any infill walling materials.

○ Check all locations where structural steel members support floors and roofs. Check that differential movement gaps are correctly sealed to prevent infiltration and that rigid support is given to any airtightness layer adjacent to and traversing the flange of the steel member. If the steel member is set back from the face of the wall, make sure that the airtightness layer (eg plaster-board) continues up behind the steel section or is sealed to airtightness provision around the steel.

○ Check that there is continuity of airtightness at windows and doors and at junctions between structural frame and curtain walling.

Curtain walling

The mullions which hold the facade units in place often have ventilation slots to allow pressure equalisation and free drainage in non-vision parts of the wall. Inspection should confirm that airtightness is continuous at the boundaries between vision and non-vision areas, and at difficult details like the corners of buildings and junctions with other cladding/walling systems.

Junctions between individual curtain walling components are often factory made and will have been tested to specified airtightness performance levels. Joints between curtain walling units and any structural framework with an exposed face will not necessarily have the same accuracy of jointing; inspect carefully the details and site workmanship at these locations.

9 Diagnosis and testing

- New buildings will require expert testing of components or finished sections.
- Existing buildings may require specialist diagnosis and testing to sort out problems.

Pressure testing

In this method whole buildings can be pressurised or depressurised by a large fan. At first this technique was used only for domestic buildings but in recent years larger test rigs have been constructed and it is now possible to test whole office buildings. A number of specialist agencies carry out this kind of testing (see Appendix 3).

Pressure testing a whole building

Tracer gas

Small quantities of inert (tracer) gases are dispersed inside a building and the falling concentration of gas is monitored as infiltration occurs. From the rate of change of gas concentration it is possible to calculate the infiltration rate. This technique does not distort the airtightness performance and can be conducted in occupied buildings. Until recently this was a specialist technique but BRE have devised a simplified technique, BRESIM, to determine approximately the infiltration rates of large and complex buildings. It is a complete and easy to use package comprised of robust, inexpensive equipment together with a protocol for its use, designed to allow non-specialists to carry out assessments of the infiltration performance of buildings. The procedure involves dispersing a tracer gas within the building, and taking samples of air in the building after two time intervals. The sealed samples are then sent to a laboratory for analysis.

Tracer gas monitoring equipment

Observation

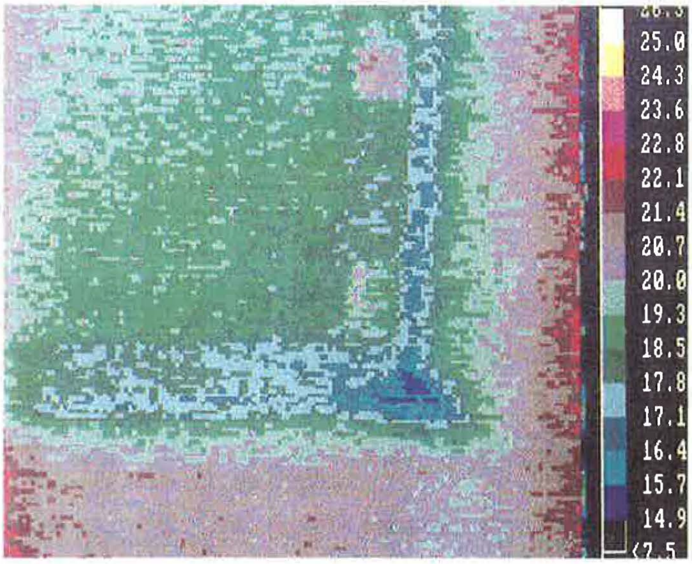
Some useful diagnosis can be made by on-site inspection without expensive equipment. Visual inspection can reveal defects and gaps; the use of a smoke pencil in windy conditions can reveal potential problems, indicating the need for more sophisticated investigation.

Simple observation with a smoke pencil

Photograph by courtesy of Building Sciences Ltd

Thermography

The use of cameras sensitive to infra-red radiation is common in identifying weak spots in the thermal envelope of buildings. Thermography can also be used to identify warm air escaping from gaps and cracks in the building. The method is best used in conjunction with pressurisation which will amplify these effects. Thermography needs to be undertaken at night when there is little incoming sky radiation and when the surface of the building has cooled down from any warming up during the day. It is best carried out in the winter when there is heating within the building and when insulated surfaces are cold on the outside. Specialist companies who can undertake thermographic surveys are listed in Appendix 3.

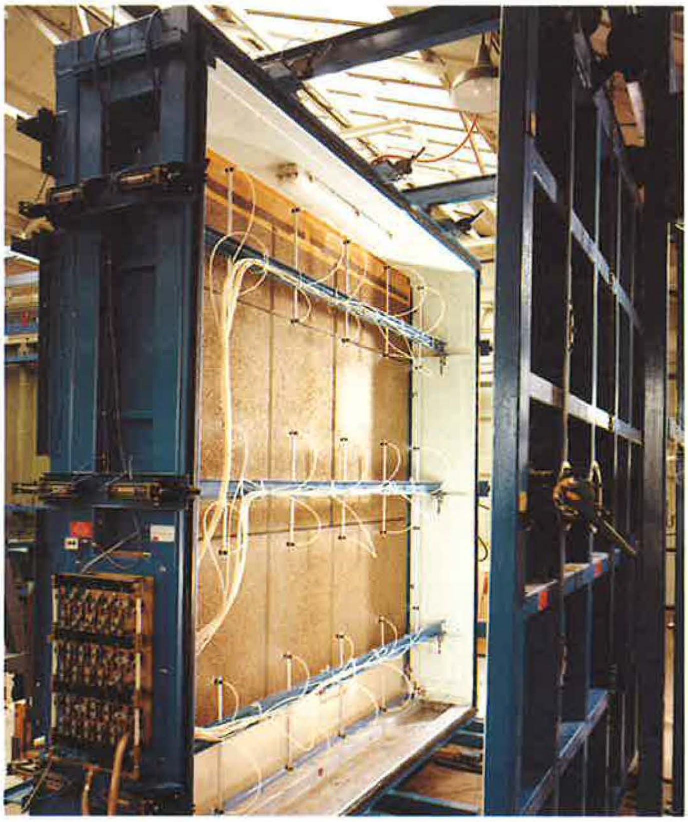


Air leakage (purple/blue) around the window frame is clearly highlighted in this IR thermography scan

IR scan by courtesy of S J-M Dudek, University of Newcastle, Department of Architecture

Test rigs

In major buildings, testing of one or two storey high sections of cladding is essential to ensure compliance with specified performance standards. There are a limited number of test facilities (see Appendix 3) which have rigs of sufficient size. Pressure testing for airtightness invariably accompanies testing for water penetration. Testing of components does not obviate the need for testing of whole buildings although this is still very rare: the case study of Wansbeck General Hospital (see Page 25) shows how the comprehensive testing of a building can be achieved.



A weathertightness test rig for panels up to 4 x 4 m

10 Case studies - new buildings

- BRE Low Energy Offices, Garston, Hertfordshire.
- Wansbeck General Hospital, Ashington, Northumberland.

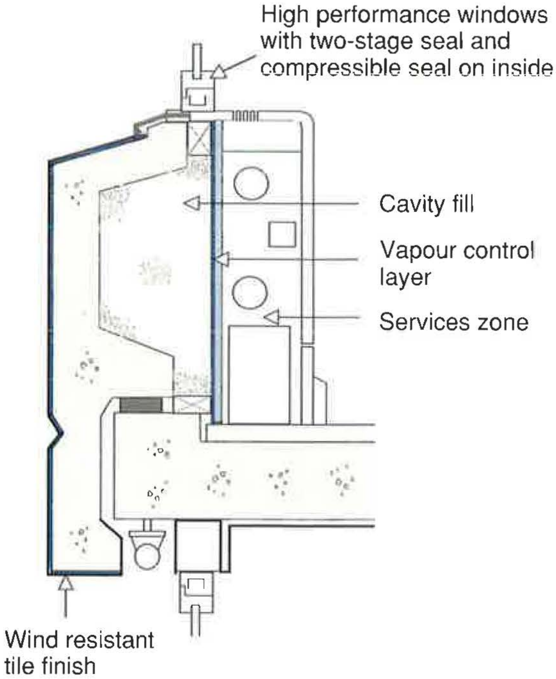
BRE Low Energy Offices

The BRE Low Energy Office

Project objective These offices were completed in 1978. The three storey building has an in-situ concrete frame with pre-cast concrete panel cladding. Unusual for the time of construction, energy conservation was a key design objective. The design team, supported by BRE energy experts incorporated and attempted to integrate established energy saving technology. This included some considerable care to minimise infiltration through the fabric. A measured infiltration rate of 0.2 air changes per hour was achieved on the unmodified building. Later improvements, which included replacement high performance windows, improved airtightness by 9%.

Project management The architect and his assistant, plus key supervisory staff were on site during the course of construction. They in turn had access to BRE energy experts, who as future occupiers of the building had a vested interest in achieving a good internal environment. The high level of supervision and rapid availability of advice on site meant that solutions to any production difficulties could be developed rapidly without delaying the overall project. Perhaps not unexpected was the finding that the levels of supervision needed to achieve a highly energy efficient, state of the art building was higher than would be expected for an equivalent conventional building.

Some airtightness features The building envelope has high performance windows, which on opening parts incorporate overlapping and compressible draughtstripping. The walls have a wind-resistant outer cladding with an internal vapour control layer, acting as a secondary barrier to air infiltration. Care was taken around entrances, which have well-sealing, double sets of doors. Services areas were well sealed from the conditioned zone. In addition the facade facing the prevailing wind was staggered and existing and planted trees reduce the wind load on the building.



Section through wall to floor intersection, showing airtightness features

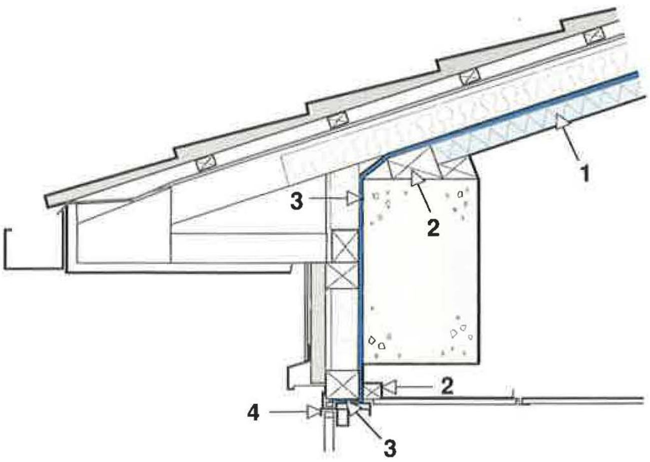
Wansbeck General Hospital

Project objective This example, although not an office building, is of a similar scale and probably represents the reasonable limits for airtightness in the UK. As the hospital was to be a prototype low-energy complex, the client demanded a high airtightness performance from all the buildings, especially at the junction between the clad wall and the roof. The structure has been made as airtight as possible by the use of a 0.5 mm reinforced polyethylene vapour control layer, carefully sealed at laps. The design aimed to reduce the number of air changes per hour to 0.3 - quite an achievement for a large building complex, situated on such a windswept site. Performance to this level was checked by large scale testing during the course of construction.

Project management A full size mock-up of a typical 'slice' of the building construction, including all penetrations through the envelope, was constructed off-site. It was tested for thermal insulation, cold bridging and air infiltration as well as general buildability. All the tendering contractors were invited to inspect the scheme and were also shown a video of the work involved. The successful contractor selected a group of 15 workers who alone carried out the work on the airtightness layer. The contractor was required to commission tests under both negative and positive pressure to prove that the specified standards were being achieved on site.

View of part of the Wansbeck General Hospital

Photograph by courtesy of Powell Moya Partnership



Simplified section through wall to roof junction

1 Woodwool } Providing a rigid base for
2 Battening } the vapour control layer

3 Vapour control layer carefully overlapped and sealed at joins and openings

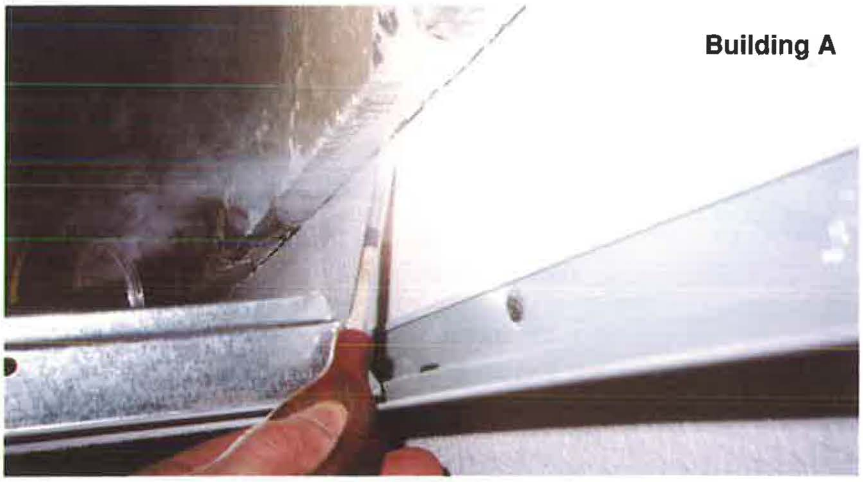
4 Double glazed casement windows with thermal break and draughtstripping

Some airtightness features Opening windows all have compressible seals and gaskets. The roof and wall construction was designed to provide a firm supporting substrate for the polyethylene vapour control layer; on the roof the woodwool decking provided a firm, flush surface for fixing the polyethylene and in the walls it was fixed against the inner blockwork and carefully restrained by battens and protected by non-compressible insulation. Particular care was taken to ensure that the polyethylene was sealed against all frames at openings.

11 Remedial work on existing buildings

- Many existing UK office buildings have poor or only moderately good infiltration control.
- Quite simple remedial measures using, in particular, the wide range of commercial sealants available, can often be introduced to control infiltration caused by airtightness imperfections.
- Checks of air quality should be considered after remedial measures have been carried out, to ensure controllable ventilation provision is adequate to provide sufficient fresh air for occupants.
- Infiltration may be providing fortuitous 'ventilation' to components within the building fabric. The provision of adequate designed ventilation to the fabric should be checked during remedial work.

Results from a recent Canadian study on whole buildings indicate that retrofit sealing of the fabric can achieve significant reductions in infiltration of up to 43%. The example remedial measures shown in this section are from UK buildings. Each was part of wider infiltration control package and contributed to achieved noticeable improvements in the performance of the respective buildings. They are all simple solutions which can make up for lack of continuity in the airtightness layer. An absent or grossly defective airtightness layer will normally require more substantial remedial work. Targeting infiltration control in remedial situations is not easy; there is some evidence that correcting one leakage path encourages greater infiltration at other, previously unidentified, airtightness deficiencies. Architects should advise their clients that effective control of infiltration on leaky buildings may not be achievable at the first attempt, particularly with more complex construction.



Building A

Building A **Concrete structural frame with brick cladding**

Office staff complained of discomfort and difficulty in maintaining the balance of air handling systems. An examination revealed that although the plaster had been extended above the false ceiling to abut the ring beam, no airtight seal had been provided at this position. The situation was made worse by differential movement between the structure and the lining. The cracks which resulted allowed excessive air infiltration at the base of the ring beam.

Remedy: an appropriate gap filling (non hardening) sealant was gunned along the joint to provide a lasting and flexible continuity between plaster and concrete.

Building B **Steel frame with brick and blockwork walls**

Again discomfort was experienced by office staff. The main cause was air infiltration at the wall to floor junction; air passing through the wall and into the gap behind the plasterboard and then gaining access to the offices through a perimeter gap between lining and the floor slab.

Remedy: a perimeter seal (a two part expanding polyurethane foam sealant) was applied between the back of the lining and block wall at floor level.


Building B


Building C

Building C **Steel windows**

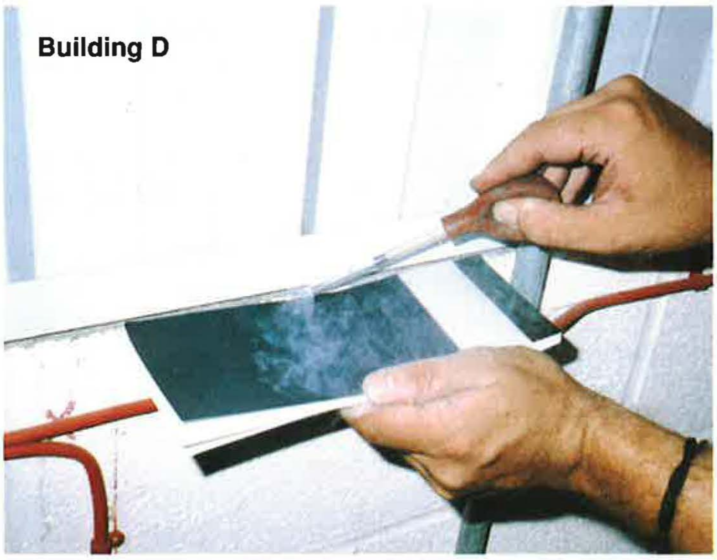
Cold draughts were experienced around the perimeter of this building. Typical of office blocks, windows formed a large part of the envelope and, in this case, a large amount of air infiltration was occurring between the windows and their frames.

Remedy: high performance silicone draughtstripping was applied to the window perimeters.

Building D **Steel frame with variable cladding**

This building was uncomfortable and expensive to heat. Deficiencies in the airtightness layer were identified at the wall to roof junction and at the boundary between the brick/blockwork section of wall and the steel panelled wall above. The joints between the individual steel sheeting units also allowed air leakage.

Remedy: gunned sealant was applied to cracks and smaller gaps. Larger gaps were sealed with expanding foam sealant. Careful sealant specification was needed to ensure compatibility with the various joint surfaces involved and the movement expectations at the joints.


Building D

Photographs of Buildings A to D by courtesy of Buiilding Sciences Ltd

Further reading

General

Building Research Establishment
BRE Digest 350 Parts 1,2 and 3. Climate and site Development. 1990.
BRE Report. Thermal insulation: avoiding risks. BR 262. 1994.
Chartered Institute of Building Services Engineers (CIBSE) publications:
Building Energy Code 1981. Calculation of energy demands and targets for the design of new buildings and services.
CIBSE Guide Volume A : Design Data
A1 Environmental criteria for design. 1978
A4 Air infiltration and natural ventilation
Elmroth A and Levin P. Air infiltration control in houses - a guide to international practice. Swedish Council for Building Research. 1983.
Energy Efficiency Office
Best Practice Programme. Energy Consumption Guide 19: Energy efficiency in offices. 1991.
A list of publications related to energy conservation and management in factories, warehouses and offices is available from BRECSU at the Building Research Establishment.
Ince M E. Energy saving measures for municipal and other office buildings, a research report. GLC Energy Group. 1980.
Liddament M W. Air infiltration calculations techniques an applications guide. AIVC. 1986.
Limb M. Air infiltration and ventilation glossary. AIVC. University of Warwick Science Park. 1992.
Persily A K. Envelope design guidelines for federal office buildings: thermal integrity and airtightness. National Institute of Standards and Technology. US Department of Commerce. March 1993.
Taylor B A. Natural ventilation and the PSA Estate. Natural Ventilation by Design. PSA. 1982.

Case studies and tests on buildings

Blosterberg and Eak. A low energy passive solar multi-family building in Sweden and the GRF. World Renewable Energy Congress, Reading, 1990.
Brunsell and Fossdal. Infiltration in Norwegian houses (and other buildings). Building Physics in Nordic countries. Trondheim, 1990.
Crisp V. The BRE low energy office. Building Research Establishment Report, 1984.
Gabrielson et al. The Ekono building, cost effective energy design. 7th International Congress of Heating and Air Conditioning, Budapest 1980.
Grot R A. Air infiltration and ventilation rates in two large commercial buildings. National Bureau of Standards, Washington.
Hestad T. Case study of retrofitting a 14 storey office building in Oslo. AIVC Conference 1983, Elm, Switzerland.

Remedial work

Building Research Establishment
BRE Information Papers 8/86, 9/86, 10/86 and 15/86: a series of papers discussing the recognition of leakage problems and possible remedies on large panel systems.
Shaw C Y, Reardon J T and Cheung M S . Changes in air leakage levels of six Canadian office buildings. ASHRAE Journal. February 1993.

Appendix 1

RIBA plan of work and air infiltration

RIBA Plan of work		Air infiltration considerations
Stage A	Inception	
Stage B	Feasibility	Survey to take note of microclimate of site. Possibly test existing buildings.
Stage C	Outline proposals	Consider the causes of air infiltration. Decide on form of construction adopting principles for minimising air infiltration.
Stage D	Scheme design	
Stage E	Detail design	Pay attention to materials and details with regard to minimising the various paths of infiltration. All members of the design team to coordinate their work to eliminate infiltration routes.
Stage F	Production information	Select sub-contractors for specialist works eg cladding, windows. Careful specification of components, membranes, and materials. Emphasise methods for airtightness and correct material handling. Spell out responsibilities in specifications for dealing with potential 'loose ends'.
Stage G	Bills of quantities	Define contractors' responsibilities for coordinating work sequences on site.
Stage H	Tender action	
Stage J	Project planning	Brief all involved in areas critical to air infiltration before work starts. Notify Building Control of project timetable.
Stage K	Operations on site	Preparation of samples, training and testing. Coordinate Building Control Officer inspections.
Stage L	Completion	Architect should ensure that all critical construction which is going to be concealed later is inspected by himself or the clerk of works. Possible training of contractors' supervisors. Visual inspection on completion, and testing as required.
Stage M	Feedback	Obtain reports from occupants regarding comfort and energy consumption. Carry out remedial work if necessary.

Appendix 2

Ventilation requirements

Reasons for ventilating

Fresh air requirements

The first requirement for ventilation is to provide sufficient oxygen and the second is to dilute the concentration of carbon dioxide produced by occupants and combustion to acceptable levels. The requirement for oxygen supply is far smaller than that for carbon dioxide dilution. This requirement in turn is less than the air needed for dilution of body odours and much less than the ventilation necessary to dilute tobacco smoke to acceptable levels. These requirements are illustrated in the chart (right).

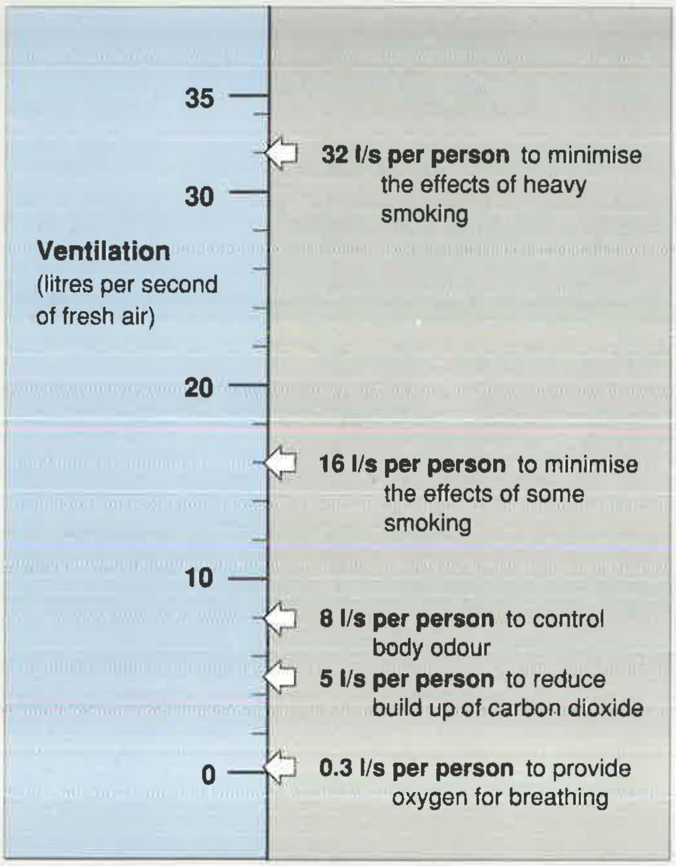


Chart showing minimum fresh air requirements for a sedentary person in an office

Note. Ventilation is not usually the preferred solution for control of other air contaminants (local extract ventilation may be more practical).

Indoor pollution

Pollutants generated within buildings can include:

Naturally occurring gases, eg.
carbon dioxide,
body odour,
water vapour,
ozone,
methane.

Products of combustion, eg.
carbon monoxide,
oxides of nitrogen and sulphur.

Volatile organic compounds, eg.
formaldehyde.

Particulates

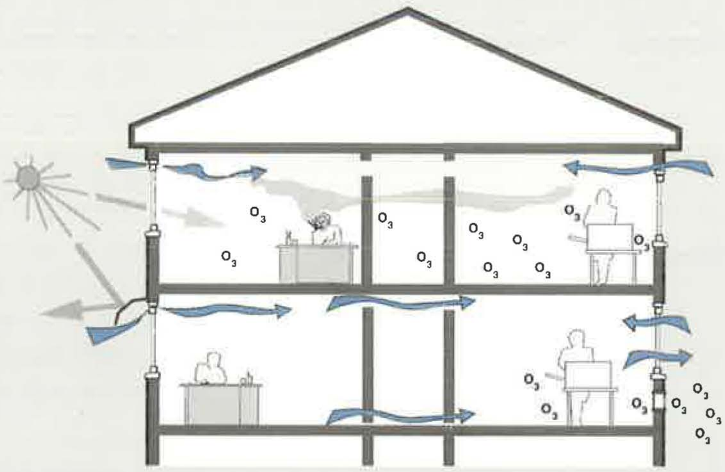
Microorganisms

Fibres.

In the working environment the Health and Safety Executive provide guidance on the acceptable limits of most common pollutants.

Ventilation to remove products of internal activities

In the United Kingdom, ventilation requirements vary according to the type of use and level of occupancy. Smoking, for example, can drastically change fresh air requirements. Buildings should be designed with zones for the more heavily polluting activities and to provide enhanced local ventilation (or extract ventilation) to control levels of pollutants in these zones and to control the spread of pollutants to other areas in the building. Further guidance can be obtained from the CIBSE Guide.



Removing products of internal activities

Top floor - no ventilation strategy

Lower floor - a positive ventilation strategy

Providing ventilation

Natural ventilation

Natural ventilation is usually provided by means of openable windows and/or controllable trickle vents. Since the mechanisms driving natural ventilation (wind and buoyancy) are variable, window openings should have a large range of opening positions, with fine adjustments for the smallest apertures. For housing, the building regulations provide simple rules for the sizing of opening windows as a ratio of floor area, but there are much more sophisticated methods for designing ventilation. BS 5925 1980 provides a detailed method of designing for natural ventilation. A new BRE Digest, giving a simplified approach, is under development for publication in 1994.

There are many advantages in using natural ventilation methods, where the form of the building allows. Capital costs, maintenance and running costs are low enough to be disregarded, and it is easier to give local control.

Mechanical ventilation

Mechanical ventilation systems in office buildings are usually designed with a variable amount of recirculation of air within the building. In the heating season or when air conditioning is needed the fresh air input is kept to a minimum in order to reduce fuel costs, at other times the proportion of fresh air is increased dramatically (to around 10 air changes for example) to provide 'free' cooling. The distribution of air needs to be carefully designed so that at times of minimum fresh air intake ventilation requirements are being met in all spaces. Ventilation systems may also include energy saving measures such as air to air heat recovery systems.

In mechanically ventilated buildings a recently developed technique to control fresh air is by monitoring indoor air quality using Carbon dioxide as an indicator of fresh air requirement. This approach is capable of providing adequate air quality whilst minimising the heating of fresh air and so achieving the most energy efficient solution. This approach is valid providing the dominant pollutant is carbon dioxide: if other pollutants dominate (eg. tobacco smoke, combustion products from gas appliances), ventilation by this method may be inadequate.

Carbon dioxide monitoring to establish fresh air requirement

Photograph by courtesy of Solomat Ltd.

Appendix 3

Organisations providing testing services

Large scale testing

BRE Technical Consultancy

Building Research Establishment,
Garston,
Watford,
Herts, WD2 7JR.
Telephone 0923 664800

The 'pressurisation' rig **BREFAN** is available for measuring the airtightness of non-domestic buildings such as offices. BREFAN is designed to carry out air leakage tests on the whole building envelope. BRE provides a BREFAN measurement service to other organisations concerned with the provision and control of ventilation in buildings

BRE supplies **BRESIM**, a simplified measurement technique to determine approximately the infiltration and ventilation rates of large and complex buildings. It is a complete and easy to use package, designed to help non-specialists carry out assessments. A BRESIM measurement service is available specifically for those concerned with the provision and control of ventilation in buildings.

For verifying the airtightness performance of a cladding or curtain walling system, BRE can test samples up to 11.3 m by 3.5 m high.

Taywood Engineering Ltd

Taywood House,
45 Ruislip Road,
Southall,
Middlesex, UB1 2QX.
Telephone 081 578 2366

For verifying the performance of a cladding or curtain walling system, the **Taywood rig** can accept a test sample up to 13.5m wide by 10m high. Small scale testing of components off site can also be carried out for clients.

On site services for establishing the performance and safety of installed systems include an air permeability evaluation (which requires access to the interior only for inspection purposes) and a wind resistance test (which requires the erection of a wooden chamber on the inside if the curtain walling). Consultancy services giving advice on remedial works and maintenance and inspection programmes are also available.

The Building Services Research and Information Association (BSRIA)

Old Bracknell Lane West,
Ventilation and Special Projects Section,
Bracknell,
Berks, RG12 4AH.
Telephone 0344 426511

Fan rover is available for air leakage testing of large enclosures. It is a positive pressurisation technique, which uses a self-contained mobile test facility capable of flow rates up to 30 m^3/s.

Blower door is a method for measuring air leakage in small buildings.

Additional services include measurement of air change rates using either carbon-dioxide or nitrous oxide as a tracer gas with concentrations detected by infrared gas analysers.

Welsh School of Architecture

University of Wales College of Cardiff,
The Bute Building,
King Edward VII Avenue,
Cardiff,
CF 1 3AP.
Telephone 0222 874000

Fan pressurisation leakage tests on whole buildings up to 10,000 m^3. This work can be coupled with air quality assessment using (CO_2) sample point measurement.

Whole-building tracer gas decay assessment using sampler jets.

Examination of individual infiltration paths using infra red thermography.

Small scale testing

The following are some of the larger organisations that offer small scale testing, eg. testing of components or individual rooms.

British Standards Institution (BSI)
Services Division,
Maylands Avenue,
Hemel Hempstead,
Herts, HP2 4SQ.
Telephone 0442 230442

Provide test rig facilities for the testing of individual components, doors and windows, for infiltration.

Wimpey Environmental Ltd
Beaconsfield Road,
Hayes,
Middlesex, UB4 OLS.
Telephone 081 573 7744

Evaluation of air infiltration in individual rooms using depressurisation and identification of possible air leakage paths using infra red thermography. Also facilities to monitor the decay of an introduced tracer gas, directly related to the natural ventilation rate of a building.

Building Sciences Ltd
Birchwood,
PO Box 238A,
Surbiton,
Surrey, KT7 0UA.
Telephone 081 398 2390

Air leakage identification and quantification on buildings and small enclosures such as halon/CO_2 protected rooms and pressurised clean rooms.

Other services

Most of the organisations listed left also provide diagnosis services; there are many more firms and consultants able to carry out diagnosis but who do not have their own testing facilities. Up-to-date lists of suitable consultants can be obtained from:

Chartered Institute of Building Services Engineers (CIBSE),
Delta House,
222 Balham High Road,
London, SW12 9BS.
081 675 5211

Royal Institute of British Architects (RIBA),
66 Portland Place,
London, W1N 4AD.
071 580 5533

Royal Institute of Chartered Surveyors (RICS),
12 Great George Street,
London. SW1P 3AD.
071 222 7000

Building Research Establishment (BRE)
Garston,
Watford,
Herts, WD2 7JR.
Telephone 0923 894040

Appendix 4

Standards and Regulations

British Standards

BS 4255: Rubber used in preformed gaskets for weather exclusion from buildings: Part 1: Specification for non-cellular gaskets. 1986.

BS 4315: Methods of test for resistance to air and water penetration: Part 1: Windows and structural gasket glazing systems. 1968.

BS 4873: Specification for aluminium alloy windows. 1986

BS 5368: Methods of testing windows: Part 1: (EN42). Air permeability test. 1976

BS 5925: Code of practice for design of buildings: ventilation principles and designing for natural ventilation. 1980 (under revision).

BS 6375: Performance of windows: Part 1: Classification for weathertightness (including guidance on selection and specification). 1989.

BS 6510: Specification for steel windows, sills, window boards and doors. 1984.

BS 7412: Plastics windows made from PVC-V extruded hollow profiles. 1991.

BS 8200: Code of practice for design of non-loadbearing external vertical enclosures for buildings. 1985.

International Organisation for Standardisation (ISO)

ISO 6589: Air permeability of joints, watertightness.1981

ISO 6613: Air permeability of tests on windows and doors. 1980

Both available from British Standards Institution

Building Regulations

Conservation of fuel and power

England and Wales. Approved Document L. 1995 edition.

Northern Ireland. Part FF of the Building Regulations (Northern Ireland). 1990.

Scotland. Part J of the Technical Standards for Compliance with the Building Standards. 1990.

Ventilation

England and Wales. Approved Document F. 1995 edition.

Northern Ireland. Part K of the Building Regulations (Northern Ireland). 1990.

Scotland. Part K of the Technical Standards for Compliance with the Building Standards. 1990.

Chartered Institute of Building Services Engineers (CIBSE)

Building energy code. Part 2(a) Calculation of energy demands and targets for new built, heated and naturally ventilated buildings.

Offices, Shops and Railway Premises Act 1963.

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