

Automated facade control

David Metcalfe and Stephen Ledbetter



All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means including photocopying and recording without the written permission of the copyright holder, application for which should be addressed to the publisher. Such written permission must be obtained before any part of this publication is stored in a retrieval system of any nature.

Centre for Window and Cladding Technology
June 2008

Published by

Centre for Window and Cladding Technology, University of Bath, Bath, BA2 7AY
<http://www.cwct.co.uk>
cwct@bath.ac.uk

Sponsors

AON Ltd
Arup
Bovis Lend Lease Limited
Comar Architectural Aluminium Systems
Fenster Technik Brand (UK) Limited
Hydro Building Systems
Kawneer UK Ltd
Pilkington
Stonescreen Limited
Taylor Woodrow Construction Limited
University of Bath
Velfac A/S
Wintech Ltd

Cover picture courtesy of Velfac A/S

Introduction

This guide gives advice on the design, procurement, construction and operation of automated facades. It is intended for all those involved with automated facades including: clients, architects, M&E consultants, façade contractors, BMS contractors and suppliers.

Facades are automated to control ventilation and shading. They are essential for the realisation of naturally ventilated buildings on most commercial buildings, schools and the like. Automation can be used to optimise the shading performance through the seasons and allow it to distinguish between detrimental and beneficial solar gain.

This guide describes the components that are used to construct automated facades and how the processes of design, procurement and construction differ from those for simpler facades.

Emphasis is placed on; the need to take appropriate early design decisions, the need for both concept design and detailing to be carried out as concurrent design with all relevant parties involved and the need for early planning of the supply chain.

It is recommended that the reader also reads: 'Natural ventilation in non-domestic buildings' (CIBSE 2005) when designing and constructing naturally ventilated buildings, 'Design for improved solar control' (CIBSE 2006), and 'Solar shading of buildings' (Littlefair 1999) when designing shading systems for solar gain and daylight.

This report was produced by the Centre for Window and Cladding Technology (CWCT) for the DTI research project 'The use of BMS to control facades'.

Whilst every care has been taken in the preparation of this report, the Centre for Window & Cladding Technology cannot be held responsible or liable in any respect for the use to which the information in this report is put.

This research work was -funded by the Department of Trade and Industry under research contract number J3515F, and industry.

Partners:

Carillion Plc
Council for Aluminium in Building
Faber Maunsell Ltd
Max Fordham LLP
SE Controls Ltd
Skelly and Couch
Velfac Ltd

Contents

1	Summary	5
2	Why automate façade control?	7
	2.1 Drivers for change	7
	2.2 The role of automated control	8
	2.3 Disadvantages of manual control	8
	2.4 Advantages of automated façade control	9
	2.5 Natural ventilation	10
	2.6 Occupancy comfort and satisfaction	11
	2.7 Schools	14
3	Components for ventilation control	16
	3.1 Windows	16
	3.2 Other operable ventilation devices	26
4	Components for shading	28
	4.1 External shading devices	28
	4.2 Internal shading devices	30
	4.3 Mid-pane blinds	30
	4.4 Solar control glass	31
	4.5 Overall solar shading	32
	4.6 Advanced glazing	32
5	Control of automated facades	34
	5.1 Actuators	34
	5.2 Sensors	41
	5.3 Power and wiring	45
	5.4 Actuators and power supplies	47
	5.5 Battery back-up	47
	5.6 Wireless technology	48
	5.7 Control boxes	48
6	Strategies for ventilation control	52
	6.1 Control and ventilation strategies	52
	6.2 Ventilation strategies	52
7	Strategies for shading control	58
	7.1 Shading against solar gain	58
	7.2 Shading against glare	58
	7.3 Control of glare	59
	7.4 Shading for privacy	63
8	Intelligent facades	64
	8.1 'Dumb' windows	64
	8.2 Intelligent windows	64
	8.3 Intelligent buildings	65
	8.4 The need for a control box	66
	8.5 Functionality	66
	8.6 Simplicity or complexity	69
	8.7 Network based control	70
	8.8 Algorithms	71
9	Design, procurement, construction and commissioning	72
	9.1 Pre design decision making	72
	9.2 Design	75
	9.3 Procurement	76
	9.4 Detailed design	81
	9.5 Construction	82
	9.6 Commissioning	86
	9.7 Specification	88
10	Case studies	95
	10.1 BRE Environmental building	95
11	Further reading	101
12	Terminology	103
13	Standards	104

1 SUMMARY

The design and construction of automated facades requires collaboration between many designers, suppliers and contractors. It is the Client's role to ensure that appropriate designers are appointed and to develop an appropriate Client's brief. Increasingly Clients are employing building physicists and façade consultants to assist in the consideration of different building strategies and the development of the Client brief. The Client should be clear about why the façade is being automated and how it will be integrated into other aspects of the building including the BMS and possibly the IT systems.

It is possible to automate facades to give any action of shading or venting in response to any occupant instruction, environmental sensor or action of the heating and cooling systems within the building. Although functionality of the facade may be this highly interactive the associated complexity of performance is reflected in the complexity of design, procurement, construction and commissioning. At the other extreme a window may be under occupant control and give no benefits of reduced carbon emissions or comfort to the majority of occupants. It is necessary to decide the extent to which the control of the façade is to be embedded within the BMS and IT systems at the concept design stage or earlier.

The procurement process is equally important and has to recognise the need for early design inputs from suppliers and contractors. The Client has to develop a procurement strategy concurrently with development of the concept design. The design and procurement processes are described in Section 9.

Automated facades comprise windows, vents, shading devices, blinds and sensors in addition to the window or wall framing system. These will be supplied by different contractors or manufacturers and have to be selected to be compatible not only physically, in terms of geometry and force, but also electrically, in terms of cabling, power and signals. The compatibility of components and the interoperability of components and controls means that components cannot simply be substituted at a late stage in the construction process and it is necessary to appoint contractors and suppliers earlier if a facade is to be automated.

Windows have to be selected to give the required ventilation opening and pattern of air flow, but they also have to meet many other requirements including weathertightness, safety, security and so on. Some window types are easier to automate than others and the window geometry will often determine the size and appearance of the actuators required.

A secondary level of performance also has to be considered. It may not be possible to deploy shading devices on windy days or to lower blinds when windows are open. Windows may have to be closed if rain is being driven on to the façade or high winds cause draughts. Detailed descriptions of the components used in automated facades and their function are given in Sections, 3, 4 and 5.

The functionality required to give the primary performance of ventilation and shading control and the secondary performance requirements may need to be embedded in the system as rules or algorithms. The signal processing associated with these may be local to the façade in a control box, within a BMS or within the IT system of the building. Where the control is split between different areas, for example some functions being controlled local to the window, others centrally, it must be ensured that the controls are properly integrated so that they do not fight each other. The algorithms have to be agreed at the concept design stage so that the locations of sensors, cabling and control boxes are known at the commencement of detailed design. This knowledge enables the appropriate allocation of detail design responsibility and packaging of the work across the different specialist contractors. These aspects of façade automation are described in greater detail in Section 9.

Construction of automated facades need be no more complex than that of simpler facades with exception of scheduling of the work and commissioning. Scheduling of work may be complex and it requires good communication between specialist contractors to ensure that components are installed prior to cabling, that components and cables are correctly positioned and terminated and that components function before they are connected into the system. Commissioning procedures and responsibility for commissioning should be agreed early on as part of the procurement plan. The construction process is described in Section 9.

2 WHY AUTOMATE FAÇADE CONTROL?

The control of building internal environments is becoming ever more important in response to demands for buildings with lower carbon footprints. There is always a conflict between sealing and ventilating a building. Buildings are now far better sealed as a means of controlling energy loss and buildings are tested for whole building air leakage. Ventilation air is no longer provided by general adventitious leakage and a strategy for providing ventilation air is required. The mantra is 'seal tight and ventilate right'.

2.1 Drivers for change

It is widely understood that the Building Regulations (AD L2 2006) and the National Calculation Method (NCM) for carbon emissions make it easier to show compliance for air-conditioned buildings rather than naturally-ventilated buildings. However, air-conditioned buildings generally create greater carbon emissions than an equivalent naturally ventilated building.

The true benefits of naturally ventilated or mixed mode buildings over air-conditioned buildings are recognised in environmental grading schemes for buildings such as BREEAM and the 'Green Building Guide'. The UK Government proposal that new dwellings should be 'zero carbon' by 2016 and that all buildings should be 'zero carbon' by 2019 will also emphasise the benefits of naturally ventilated or mixed mode buildings. A more immediate driver is the emphasis placed on naturally ventilated buildings as schools. Guidance on ventilation in schools is given in Building Bulletin 101 Ventilation of School Buildings, DfES, July 2006.

Ventilation for air quality and energy efficiency requires that windows are opened only as far and for as long as required to admit fresh air and displace stale air from the building.

The requirements for energy efficiency and ventilation in England and Wales are given in:

Building regulations AD L2A 'Conservation of fuel and power in new buildings other than dwellings'

Building regulations AD L2B 'Conservation of fuel and power in existing buildings other than dwellings'

Building Regulations AD F 'Means of ventilation'

Technical Handbook Section 3 and 6 and Technical Booklets F2 and K cover the requirements in Scotland and Northern Ireland respectively.

A further consideration is that of predicted climate change through the life of buildings constructed today. The feature of climate change that concerns the control of facades is that of hotter peak summer temperatures and reducing cloud cover. The 2006 version of Building regulations AD L2 defined the UK, for the first time, as an area where summertime cooling of buildings was an issue. Until that date the UK had been regarded as a climate where only heating was required to maintain comfort in buildings.

The implications of regarding the UK as a cooling climate are the need to provide control of solar gain and a need for ventilation for cooling. Solar gain may be limited by the use of passive shading devices and environmental control glasses but these also reduce the level of daylight within a building. Active devices such as blinds and switchable glasses may reduce the need for more efficient artificial lighting but appropriate methods of controlling these are required.

2.2 The role of automated control

Automating the control of facades has advantages and disadvantages. Perceived and actual disadvantages include:

- Design complexity
- Procurement
- Initial cost
- Reliability
- Maintenance

There is also a latent resistance to change. The use of automated facades will require many clients and designers to apply knowledge and skills that are not yet commonly available in the industry.

However not automating a façade also has disadvantages:

2.3 Disadvantages of manual control

The primary disadvantages of manual control are:

- Control of the façade is dependent on the response of the occupants
- The façade is generally operated too late and only in response to selective stimuli
- Strategies for ventilation control are often counter intuitive, for example closing windows when the external temperature is higher than the internal.

2.3.1 Occupant response

Building occupants are only likely to adjust the level of ventilation or shading in response to discomfort in the form of poor air quality, overheating, chilling, lack of daylight or glare. This response is subjective with different occupants making different responses. Furthermore the response is likely to be a response to the greatest element of discomfort and may be an over reaction.

For instance a cold draught will probably cause the occupant to close a window fully rather than partially close it. This may lead to a deterioration of air quality and a subsequent response of opening the window.

In spaces occupied by more than one person there is the potential for each occupant to have different comfort thresholds and for windows to be fully opened or closed to the annoyance of other occupants.

2.3.2 Appropriate response

Timely operation of ventilation and shading requires a response to the correct stimuli in advance of discomfort being experienced by any of the occupants. There are several aspects to this:

Low level continuous ventilation can be as effective on-off ventilation at higher flow rates. However, ventilation should be provided before discomfort from air quality is experienced and occupants do not notice the need sufficiently early. Once the occupants do respond they are unlikely to know just how much ventilation is required and are likely to open windows further than is required. Once the air quality improves they are unlikely to close the windows unless there are cold draughts or the room temperature falls, yet fully or partially closing the window is necessary to save energy once the air quality is improved.

Once a room has overheated the occupants may open the windows wide to provide cooling ventilation but this will be less effective than if the windows were opened earlier in anticipation of the overheating.

Occupants are only aware of solar gain once a room has overheated. The response is then to open windows wide to provide cooling ventilation. The most advantageous response is to deploy solar shading devices or provide cooling ventilation before overheating occurs yet occupants are unlikely to anticipate overheating.

Blinds may be deployed to reduce an individual's discomfort from glare or to reduce temporary glare on a computer screen. The occupant is unlikely to be aware when the glare problem has been resolved by a change of the sun's position and the blinds will remain closed for too long, often with the lights on.

A particular problem is that occupants open windows wide in an attempt to cool a room even if the external air temperature is higher than the current room temperature. This is of course futile but it is an intuitive response in the UK climate. The appropriate response is often to open the windows early in the day when cooling is required to maintain the room temperature rather than to alleviate discomfort and to close the windows later in the day as external air temperatures rise.

2.4 Advantages of automated façade control

The use of automated facades that react to sensors (rather than human response to stimuli) under the control of smart algorithms (rather than un-smart occupants) can overcome many of the disadvantages described above. In particular algorithms may adjust the setting of the façade:

- In response to conditions of comfort as well as those of discomfort,
- In advance of discomfort being experienced by the occupants,
- To reduce energy use (carbon emissions).

2.4.1 Smarter control

Automated facades under the control of smart algorithms can also give a far more efficient response with less discomfort or nuisance. For instance rather than opening windows in an arbitrary pattern, windows may be opened on just the windward or leeward side of a building to allow stack-ventilation rather than cross-ventilation.

2.4.2 Additional functionality

Automated facades may incorporate additional functionality, for instance the ability to close windows for the purpose of securing the building or to secure the windows in a partially open position to provide night cooling of a building.

2.4.3 Image and value

As with brise soleil and other additional features of a façade, automated control may be adopted to create a façade that appears to embody 'high technology' or to be an 'environmentally friendly' façade even if it does not give reduced carbon emissions. This may be associated with the business occupying the building and may add value to the building through higher rental income or prestige for the owner occupier.

2.4.4 Essential functionality

Facades may be controlled remotely to allow operation of windows and shading devices that cannot be operated manually because of their inaccessibility. A strategy of automating the facade will overcome problems of operating façade components that are generally inaccessible or inaccessible/inoperable to the frail or disabled.

2.5 Natural ventilation

The principal role for automated facades is to control the internal environment of naturally ventilated buildings.

It is important to note that natural ventilation cannot be used for all buildings. It depends very much on the location of the building and the internal gains within that building. It is much easier to design a naturally ventilated building in an out of town site, where the orientation of the building can be changed in order to reduce solar gain, and if the internal cooling loads are low, than it is to design one in an inner city area where the orientation is fixed and the cooling requirements are often high. Air pollution may also be an issue for naturally ventilated buildings in city locations, especially for the lower floors.

With naturally ventilated buildings the performance of the façade has to be much higher in order to ensure comfortable conditions within the building as there are no mechanical systems to remove any excess heat gain.

Experience has shown that often the designs with the best user satisfaction are mixed mode systems. Here the buildings are mainly naturally ventilated but also have mechanical ventilation to supplement this when it is required.

Whether a building relies solely on natural ventilation or is a mixed mode building the ability to control the façade is fundamental to the design and the efficacy of the control will determine the comfort levels and energy use of the building.

The issue of whether natural ventilation is the most energy efficient way to cool a building has to be addressed. There is an argument that mechanical ventilation with heat recovery might be a more energy efficient option; however this view is far from universal. Heat recovery is very effective when there are large differences between the internal and external temperatures, however it is less so when the differences are smaller.

There may be disadvantages to using naturally ventilated buildings. These include:

There is a lack of flexibility of use with naturally ventilated buildings. Open plan spaces are generally needed for natural ventilation, and there is always the danger that parts of the space might be turned into cellular offices. If the overall space was relying on air from that area for cooling then the whole design could fail because of this change. This is a particular concern for deeper plan buildings which rely on cross ventilation for cooling.

Concern has been expressed that naturally ventilated buildings are generally operating at their maximum capacity so there is little or no margin for error in design or operation. Therefore if external temperatures increase in the long term or higher occupancy densities are used the building will not be able to cope with the extra loads. It should be noted that this concern also applies to air-conditioned buildings which can overheat due to incorrectly sized plant.

It should be remembered that the values in the Building Regulations give the minimum standard required for compliance and a building may just satisfy the requirements to prevent overheating in the present climate. However; the Regulations state that it may be desirable to consider what might happen in the future. Until now most design climates have been based on historical data, and there is a clear argument that the data used in design should take climate change into account and so use values that are anticipated to be the norm in 20 to 30 years time. This data is available but whilst there is no compulsion to use it, it is unlikely many designers will do so.

2.6 Occupancy comfort and satisfaction

All buildings suffer from a common problem unless some form of manual control of the façade is allowed. This is occupancy disquiet at the inability to control their environment when facades are sealed or automated. Manual control, or manual override, may be provided for some windows to empower the occupants in controlling their environment. This may allow local variations in internal climate but will probably defeat the overall strategy for cooling and ventilating the building unless steps are taken to limit individual control of manually operated elements of the façade.

In all buildings the task of the building services engineer is a difficult one because every occupant has a different perception of comfort. Some prefer warmer temperatures whilst others prefer cooler temperatures and it is seldom possible to satisfy everyone within a space. Typically, the best that can be done is to keep ninety five per cent of people content, so in a building of 1000 people there will be fifty people who are not comfortable (too hot, too cold, not enough fresh air) and who may complain. In order to satisfy more people it may be possible to provide a range of conditions throughout the space rather than having a uniform environment. Providing the occupants are able to choose where they sit this could allow them to find a place that best suits their individual needs.

2.6.1 Thermal comfort

Thermal comfort has been defined as that state of mind in which satisfaction is expressed with the thermal environment. Put another way, comfort is the absence of discomfort. Thermal comfort is a very subjective matter. Different people will be comfortable under very different conditions, which means that designing a building for thermal comfort is very difficult. Ideally, each occupant should be able to control the thermal environment within his or her immediate locality. However, where a group of people is subject to the same environment, it will normally not be possible to satisfy everyone at the same time due to this variance. Therefore the aim is create optimum thermal comfort for the whole group, ie a condition in which the highest possible percentage of the group is thermally comfortable. When considering automated facades, manual overrides should be provided to alleviate discomfort quickly if it should occur.

Thermal comfort is primarily dependent on factors such as temperature differences, both air and radiant, between the human body and its surroundings, the humidity of the air, the air speed around the body, the degree of activity, the bodies metabolism and the degree of clothing.

2.6.2 Temperature

The issue of which temperature to measure and use is an important one, as it can have a large impact on the comfort within the building. There are several temperatures that can be measured, for example the air temperature, the radiant temperature and the dry resultant temperature.

The air temperature is simply the temperature of the air surrounding the body. This is also known as the dry bulb temperature.

Thermal radiation is the heat that radiates from a warm object. Radiant heat may be present if there are heat sources within an environment. The radiant temperature is more important than air temperature in terms of perceived comfort as it has a greater influence on how we lose or gain heat to the environment. Examples of radiant heat sources include the sun and hot surfaces.

The operative or dry resultant temperature is a further measure sometimes used to determine of the comfort of the space. This is defined as $\frac{1}{2}$ the air temperature plus $\frac{1}{2}$ the mean radiant temperature of the surfaces (this simplified formula assumes a low air velocity within the space, which will nearly always be the case).

Generally air temperatures are specified, as they tend to be easier to achieve. Radiant temperature sensors are available but are not widely used.

Whichever temperature is used it is important to fully understand the consequences of that choice. It is possible to design a building that models say will work but is clear will not be comfortable for the occupants. For example if a dry resultant temperature of 20°C was required and the mean surface temperature was 30°C the air temperature would have to be 10°C. This would obviously not provide a comfortable environment despite the maths saying otherwise. Similarly if there are large areas of glass present then the effects of radiant heat transfer can be significant, and therefore the set points for heating and cooling (if present) need to be considered carefully to take this into account.

2.6.3 Humidity

The humidity of a room is expressed in absolute terms, ie, the moisture content (the mass of water vapour per unit mass of dry air (kg/kg)) or the vapour pressure (partial pressure of water vapour (Pa)).

The relative humidity is the ratio of the vapour pressure to saturation vapour pressure at the same dry bulb temperature, expressed as a percentage (% RH).

The nature of the role played by relative humidity in the environment is less well defined than it is for temperature. In normal circumstances, humidity in the range 40 – 70 per cent is acceptable. Humidity has a significant effect on thermal comfort only at high temperatures.

2.6.4 Impact of the sun and overheating

There is the belief that some architects and consultants do not fully understand how to design the building to take account of solar control and how the sun can impact on the building. Because of this there is the possibility that the various facades of the building will not perform as intended.

The normal procedure is to design the building such that overheating on a clear, sunny day will be minimised. However this condition is not always the worst-case scenario. For example if the building contains a highly glazed area on the north façade, the gains will actually be higher for that façade when the sky is overcast. The gains could be up to 300 W/m² on an overcast day and only 100 W/m² on a clear sunny day. This is because when it is sunny there would be mainly direct components of sun's energy which would not be incident on the north façade, whereas when it is overcast there would be a higher proportion of diffuse components and therefore more solar energy incident on the north façade.

This sort of detail can easily be missed out of the design and so the internal conditions within the building might not be acceptable under certain conditions.

2.6.5 Air movements in the building

It has been stated that windows should be closed when the external temperature is higher than the internal temperature. This applies in theory, however in practice the situation can be different. Air velocity can be an important factor in thermal comfort because people are sensitive to it. Therefore, in warm conditions, although the air temperature may increase by keeping the windows open, the comfort of the occupants could be improved due to evaporation caused by the air movements. These draughts and air movements will have a negative impact in cooler conditions however, as they will greatly increase convective heat losses, leading to discomfort.

2.6.6 Air quality

The method for determining the air quality in a building will vary. The main ways in which this is done are by either using a CO₂ sensor or simply a temperature sensor. Providing adequate air quality is more of an issue in the wintertime. During warmer conditions it is

generally accepted that if there is sufficient ventilation for cooling purposes then the air quality in respect to the CO₂ level will also be adequate.

The use of CO₂ sensors combined with trickle/background ventilation may provide a good solution, however CO₂ sensors are often excluded due to their cost. This can result in wasted energy as the temperature alone is used as a measure of the air quality. This can lead to the situation where, because a room feels stuffy and uncomfortable, the windows have to be manually opened in order to ventilate the room, which would have a greater conflict with the heating and therefore be less efficient than if automated windows with CO₂ sensors were used.

2.7 Types of building

There are many common issues that must be considered in the design of any building employing natural ventilation and/or an automated façade. These include, amongst others;

- Location of building
- Orientation
- Thermal mass
- Depth of floor plan
- Internal heat gains
- Shading

These will be discussed throughout this document. As well as these, there are also considerations that are specific to certain types of building.

2.7.1 Office buildings

A major concern with the design of a naturally ventilated office is potential lack of flexibility they offer, especially when cross ventilation is used. This means that unless the design of the ventilation is very sophisticated, any partitions installed as part of the fit out or when a new occupant moves in will severely affect the performance of the building.

The high internal heat gains normally associated with office buildings due to large amounts of IT equipment and high occupant densities can make it difficult to provide the required amount of ventilation in order to cool the building. Natural ventilation can be shown to work in the current climate, however if temperatures rise as predicted this could become increasingly difficult in the future.

Naturally ventilated offices often make use of the stack effect through using atria/stacks/chimneys in order to provide sufficient ventilation for the building. In these situations particularly crucial are the air flows on the top floors. Here, the stack height and therefore the driving force is at a minimum. As a result, flow reversal could occur with lower floor warm air finding it easier to exit the building via the top floor windows instead of the atria openings.

A further concern with natural ventilation in offices is occupant comfort around the perimeter of the building. Cold draughts in the wintertime, excessive solar gain in the summertime and glare throughout the year can be an issue all over the building, but this is especially true around the perimeter.

2.7.2 Hospitals

One of the main problems with the use of natural ventilation in hospital wards is that the occupants are transitory and therefore they will not be familiar with the building and with the operation of the ventilation devices. This also means that nobody takes ownership of the windows and therefore does not operate them appropriately. These particular issues

can lead to an automated façade being used so that the control of the ventilation is handled without requiring an input from the occupants. However there can be concerns regarding cost and maintenance of such systems, particularly if the building is a PFI project.

A further concern with the use of natural ventilation in hospitals is that curtains and internal blinds are often used and these will restrict the flow of air into the building, especially if the window has a limited opening for safety reasons.

There are also concerns about the spread of infection due to air movements through the hospital and bacteria etc entering from the outside.

2.7.3 Schools

The design of schools is a major factor in the uptake of automated facades, primarily because the Government is setting low energy targets and encouraging the use of natural ventilation and there is a large school building programme at the current time.

Schools are particularly difficult to design as the requirements are so varied. Teachers and children want and accept different things so finding a compromise can be difficult and because schools are generally quiet and focussed environments, the occupants tend to notice being uncomfortable more readily. The Government is trying to push the use of natural ventilation in schools but generally teachers are not in favour of it. High temperatures are allowed (120 hours over 28°C in a year) which some believe are unacceptable. The use of opening windows for ventilation could be distracting to pupils (both the noise of the actuator itself and then any noise from outside) and therefore affect learning.

Occupancy densities have a huge impact on heat gains and internal temperatures. Can natural ventilation be made to work for higher densities? This is a particular issue for schools. Increasing use of IT equipment also adds to the heat gains within the space. Most classrooms only have windows on one side of the room so the options for the ventilation strategy are more limited.

There are some conflicts between the different parts of the DfES Building Bulletins that make it very difficult, if not impossible, for the design of a school to satisfy all the requirements. These include:

- Acoustics (both external to internal and between classrooms),
- Ventilation,
- Access,
- Security.

For example, for security and safety opening windows or those that only open a small distance are preferred, whereas for natural ventilation it is desirable to have as many openings as possible. Normally these conflicting requirements push the design towards a sealed envelope that is air-conditioned; however this is obviously not very energy efficient. Natural ventilation can be made to work but not all of the criteria can be met and so any design must be a compromise between many different considerations. Learning from past experience and accepting that there must be these compromises is very important.

BB101 uses the air temperature as the design criteria. It is usually much easier to achieve a satisfactory design with this measure, when compared with, say, the radiant temperature. There is currently a certain amount of debate within the Regulations/Standards over which temperature should be used.

Schools are designed to meet the Building Bulletins which only assume occupancy of that building during the school day, however the remit of most schools is achieve better

utilisation of their property, so they may well be opening them in the evening. If this is the situation what happens if a night cooling strategy is required to cool the building? If the building is still occupied until 9 or 10 at night (with all the additional heat gains that this would introduce) how is the building to cool down ready for the next day? Similarly more schools are being used throughout the summer for play schemes/holiday clubs, etc. when the buildings were not designed to be operated during these hotter months and with those loads.

3 COMPONENTS FOR VENTILATION CONTROL

Ventilation in a building can be achieved through a number of different components. These include windows, rooflights, dampers, trickle ventilators, automatic inlets, and through opaque panels in the façade or roof.

3.1 Windows

The choice of window in a façade will depend on many factors including appearance, and the servicing strategy of the building, and whether natural ventilation and automated openings are to be used.

The following section discusses some of the other issues that have to be considered when opening lights are incorporated in the façade. These include;

- Ease of control
- Seal effectiveness
- Fine control
- Security
- Occupant security and safety
- Ventilation capacity
- Ventilation mode
- Weather protection
- Shading/blinds
- BMS control

Ease of control

- Some windows are difficult to move if too large/heavy
- Outward opening designs may have problems with required reach
- Straightforwardness of control should be considered
- Remote controls should be placed in obvious places

Seal effectiveness

- Need to avoid discomfort due to local draughts
- Need to avoid energy wastage due to air leakage in winter and summer

Fine control

- Essential feature
- Should allow precise setting of ventilation rate rather than fixed just open, closed or limited intermediate positions
- Friction stays on casements (side or top) provide variable control
- Fine setting is particularly important when ventilation is provided to supplement trickle vents

Security

- Most types of window can be fitted with a device to limit the opening (usually 100 mm)
- Smaller lights with limited opening are more secure
- Glass louvre windows may require steel reinforcing bars behind glass blades

Occupant security and safety

- Restrictors are required on upper floors
These will restrict air flow, especially when the window does not open beyond the reveal.
- Provision of anti-trap mechanisms
- Occupants hitting themselves on internal projections

Ventilation capacity

- Effect of angle of opening on ventilation flow
- Effect of size/aspect ratio of opening light
- Influence of the frame design and features such as cills and reveals

Ventilation strategy

- Single sided ventilation needs a large vertical opening or vertically separated openings to allow convective circulation (cool air in through lower opening, warm air out at top)
- Cross ventilation is possible with any type of opening
- Good draught free ventilation is achieved with high level opening lights

Weather protection

- Ventilation capacity is severely reduced if windows have to be closed due to rain
- Some designs are inherently more effective at reducing water ingress (eg inward opening hopper)

This is particularly important in intermittently occupied rooms

Shading when open if mid-pane blind used

- Some designs will let full sun in if opened (eg side hung casement)
- Others will still provide good shading (eg top hung)

Interference with interior blinds

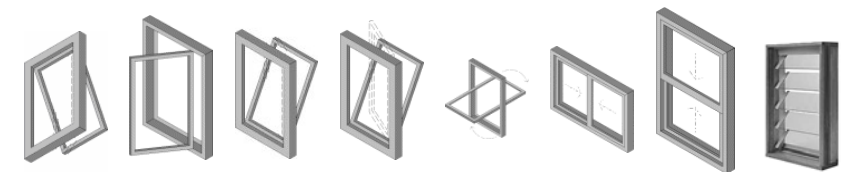
- Inward opening lights may have limited opening capacity when blinds are down
- Air flow may be restricted by both the opening and blind itself.

BMS control

- Actuators are available for most window types
- Provision of manual control should also be considered

3.1.1 Selecting different types of opening lights

The table below provides a checklist to allow easy selection of different types of opening light depending on the requirements of the project.



Function	Top hung casement	Side hung casement	Bottom hung casement	Tilt-and-turn	Horizontal pivot	Horizontally sliding sash	Vertical double sash	Louvre
Ease of cleaning				✓	✓			✓
Fine control								
Weather protection	✓							
Suitable for night ventilation	✓		✓	✓	✓			✓
Internal projections		✓	✓	✓	✓			

Function	Top hung casement	Side hung casement	Bottom hung casement	Tilt-and-turn	Horizontal pivot	Horizontally sliding sash	Vertical double sash	Louvre
External projections	√				√			
Limited size		√						
Desk level draughts		√			√	√		
Effectiveness of seals					X	X	X	X
BMS controllable	√	√	√	√	√	√	√	√

3.1.2 Advantages, disadvantages and general remarks regarding different types of opening light

There are many factors that influence the types of window/opening light that are used. The choice of opening light will depend on the functions that are required of it. For example, if the ventilation capacity is the highest priority a different opening light might be chosen rather than if security is the main requirement. The cost is a major consideration, as is the appearance, especially where opening lights might have to match existing products.

Commonly available opening lights, together with a note of the advantages and disadvantages associated with each type, are listed below.

Top hung, outward opening casement vent

Chain actuator commonly used



Advantages

- Good weather protection – slope of glazing directs rain outside the building
- Scoops upward air flow into building
- Secure night ventilation (if small)
- BMS controllable

Disadvantages

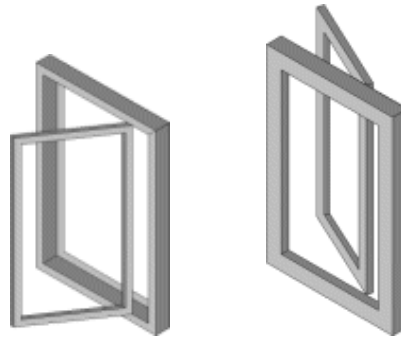
- May reflect noise into building
- Fine (manual) control difficult
- Subject to bird fouling

General remarks

- Not subject to distortion due to their own weight so large lights with small frames are practical
- Must have positive opening and stay mechanism else they bang shut or fully open due to the wind
- Different types of hinge are available ranging from simple butt hinges to various types of friction stay
- Provides cooling for occupants but poor thermal contact with the ceiling for night ventilation
- Windows on reversible stay arms are gaining in popularity. These have the advantage of both sides being able to be cleaned from the inside, but present a security risk if left open at night
- Ventilation may be limited if the window does not open beyond any cill detail or reveal that may be present

Side hung casement

Chain actuator commonly used



Advantages

- Tall opening for localised stack ventilation
- BMS controllable
- Simple intuitive design
- Good outside awareness

Disadvantages

- May lack fine ventilation control for winter
- Unsuitable for high wind speeds as there is a greater distance from the window edge to the pivot
- Size limited as the weight of the casement causes it to sink when open
- Lack of security when open
- Rain penetration possible
- Desk-level draughts

General remarks

- The limit to the size of the window means there will be a higher frame area percentage which cuts the unobstructed glass area. Therefore it is common to have a large fixed light with a small casement alongside and a ventlight above
- The relatively small window areas make cleaning laborious, although reversible/projecting stays are available so that windows may be cleaned from the inside

Window with bottom hung inward opening hopper or top vent

Chain actuator commonly used



Advantages

- Directs air at ceiling for night cooling
- No projections
- Secure night ventilation
- BMS controllable
- Direct sound to ceiling

Disadvantages

- Rain penetration possible
- May lack fine control for winter
- Could interfere with internal blinds

General remarks

- Not subject to distortion due to their own weight so large lights with small frames are practical
 - Must have positive opening and stay mechanism else they bang shut or fully open due to the wind
 - Different types of hinge are available ranging from simple butt hinges to various types of friction stay
 - Windows on reversible stay arms are gaining in popularity. These have the advantage of both sides being able to be cleaned from the inside, but present a security risk if left open at night
 - The airflow can be limited if the opening frame does not clear the window reveal
-

Tilt-and-turn

Chain actuators commonly used
(automatic opening in one direction only)



Advantages

- Easy access for cleaning

Disadvantages

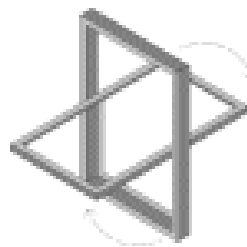
- Relatively expensive and complex
- BMS control in one orientation only
- Fine (manual) control difficult

General remarks

- Designed to provide limited ventilation in the tilt mode and access for cleaning and maintenance in the turn mode
 - Tilt mode may provide too much ventilation in the winter and insufficient cooling in the summer
 - Turn mode may be used for ventilation and a safety restrictor may need to be fitted. Devices are available to restrict the window entering turn mode
-

Horizontal pivot

Chain actuators commonly used



Advantages

- High ventilation capacity
- Upper and lower ventilation for stack flow
- Easy access for cleaning
- BMS controllable
- High air flow rates when used for single sided ventilation

Disadvantages

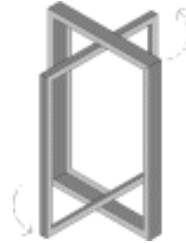
- May lack fine ventilation control for winter
- Angle of opening limited for safety
- Could reflect noise into the room
- Desk-level draughts possible
- Opening restricted by internal blinds
- Top seal difficult if control at bottom

General remarks

- Air entering at the top of the window (in cross ventilation mode) has good thermal contact with ceilings so makes night ventilation more effective
 - Window opens against action of friction pivots. These pivots may not be strong enough to resist wind gusts so some form of stay could be necessary
-

Vertical pivot

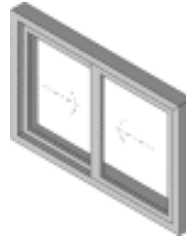
Chain actuators commonly used



- Similar in performance to side hung windows
-

Horizontally sliding sash

Linear actuator used



Advantages

- Relatively low cost
- Tall opening for localised stack ventilation
- Safe in high winds
- Unobstructed large open air flow
- Large panes
- No external projections
- No internal projections
- BMS controllable

Disadvantages

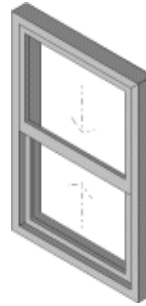
- Not secure for night ventilation
- Rain penetration possible
- Desk-level draughts
- Traditional arrangements difficult to seal effectively

General remarks

- The air leakage performance of modern designs has improved significantly. Sashes can run on wheeled track and are pile weatherstripped to the frame.
 - Sliding sashes are difficult to automate and is rarely done
-

Vertical double sash

Linear or chain actuators used



Advantages

- Good single sided ventilation
- No external projections
- No internal projection to interfere with blinds
- Unobstructed large open area for air flow
- BMS controllable

Disadvantages

- Difficult to seal effectively
- Rain penetration possible
- Difficult to clean both sides from inside the building

General remarks

- Need to be designed so top sash can be operated easily by occupants
- Sashes are hung so do not tend to distort due to their own weight which means that large sashes can be used
- Sliding sashes are difficult to automate and is rarely done

Louvre

Linear actuators commonly used for larger louvres, rotary actuators may also be used



Advantages

- BMS controllable
- Secure night ventilation
- Readily cleaned from the inside
- Greater free area for the same sized opening than a casement window and consequently will allow approximately twice the air flow

Disadvantages

- Difficult to seal effectively
- Relatively expensive and complex
- Could reflect noise into the room

General remarks

- Glazed or aluminium blades may be used
 - Security bars may be fitted inside so they can be used in night ventilation mode
 - The control of rotary actuators is straightforward and can therefore be handled directly by the BMS
-

Window hinge arrangements

The weight of the window is not the only factor that has to be considered when calculating the maximum size that can be used. The hinge arrangement is also significant. With bottom hung windows some designs of friction stay allow the window to drop slightly when it is opened, meaning the whole weight of the window must then be lifted when it has to be closed. Similarly for side hung casements on friction stays, the weight of the window can cause it to drop when opened. This can be overcome by using standard hinges, allowing for larger opening windows to be used.

Inward opening windows

Most windows in the UK open outwards and when automating the operation of windows this method is usually the easiest to perform. There are several problems with automating an inward opening window. If the actuator is mounted on the fixed frame then there can be interference due to the proximity of the ceiling. If the actuator is mounted on the opening frame there are issues with providing power to the motor as there would either have to be a cable trailing between the actuator and the ceiling and the wall, which is not a particularly elegant solution. Scissor stay actuators may be used for this type of operation, but generally window companies prefer outward opening.

There are some advantages to the use of inward opening windows when external shading is also used on the building. These windows have no external projections so will not interfere with shading devices such as Venetian blinds or shutters, and can therefore remain open when such devices are deployed.

Free opening areas

The free opening area of a window will primarily depend on the size and type of the window; most only have one ventilation opening per window, however some, such as sliding and pivot windows and louvres, have more. These all provide multiple openings per window and are able to provide an increased ventilation rate. Pivot windows generally have the best overall performance as they can be sealed effectively, whereas both sliding windows and louvres struggle in this area. Framed louvres are available that seal better, but the increased frame area means that the U-value is significantly worse and they may not be able to be suitable in some applications.

Airflow versus opening distance

There is a misconception amongst building designers, managers and occupants that windows need to be opened large distances in order to allow enough airflow through them. These large openings can cause acoustic problems for the building users as well as being a potential security risk and are one of the main reasons people may choose not to make use of natural ventilation.

Testing has been carried out that suggests large opening distances are not required for cooling and ventilation in most cases. The following results were obtained by testing different types of window in a wind tunnel to determine the airflow rate at different opening distances.

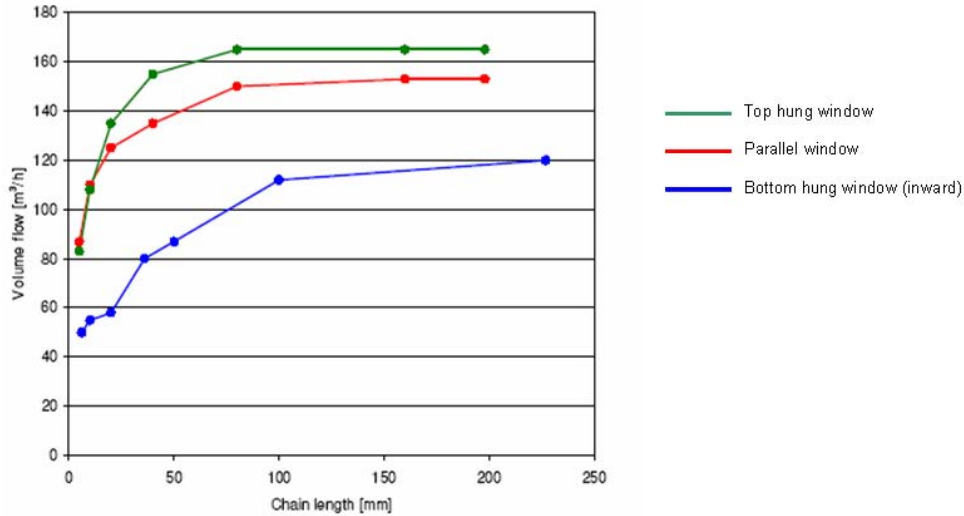


Figure 3.1 Airflow versus opening distance (VELFAC/WindowMaster)

Results for the top hung window suggest that 60 per cent of the maximum airflow is in the first 10 cm of opening and 90 per cent is in the first 50 cm.

At these small openings the acoustic performance of the window is still reasonably high. The following single figure values are calculated in accordance with BS EN ISO 717-1, 1997.

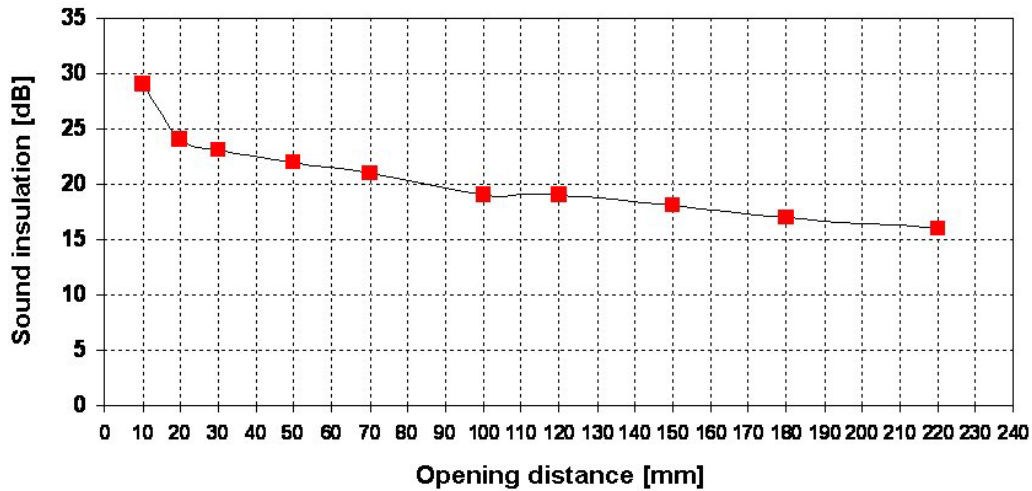


Figure 3.2 Sound insulation versus opening distance (courtesy VELFAC/WindowMaster)

These test results, together with information from actual projects, show that small opening distances will generally be sufficient for the cooling requirements of most buildings. The data below is from a primary school and shows the opening distances of windows and rooflights in four different zones as a percentage of their total opening.

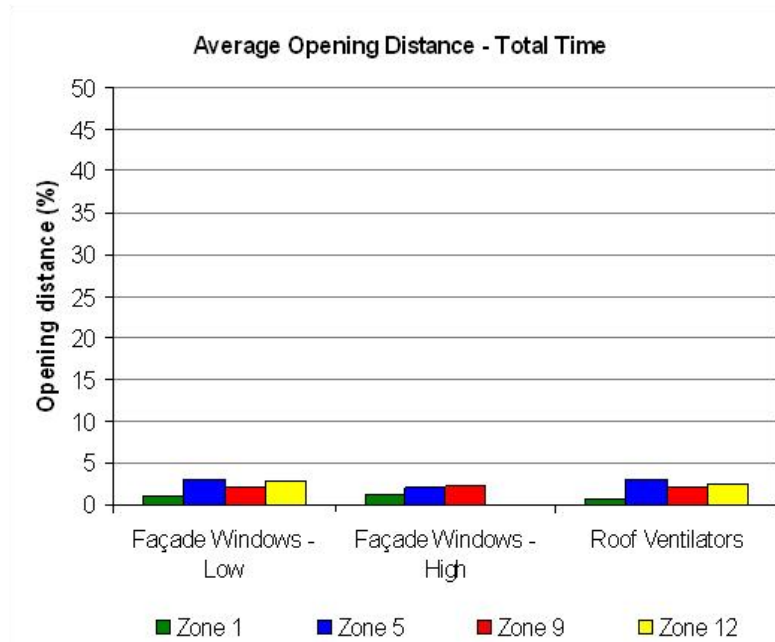


Figure 3.3 Average opening distance (courtesy VELFAC/WindowMaster)

These results demonstrate the advantage of having automated control of the windows. Building occupants tend to either fully open or close the windows. This may cause the building to be either over- or under-ventilated. Automated control allows the windows to be open small amounts whilst still providing the correct level of ventilation, which is less distracting and obtrusive for the users.

Despite these results windows with very large opening distances are often still specified. There may be several reasons for this. Firstly M&E consultants have to design the ventilation based on a still day, which is very rarely the case. Secondly the calculation methods that are used can be quite basic, resulting in larger openings than necessary.

Security and fire egress are two aspects of performance that require greater consideration.

Security

Windows offer a potential way into a building so security is very important. One third of all domestic burglaries are through rear ground floor windows, but it is also issue for non-domestic buildings.

Windows are only a security risk if they offer a credible entry route and therefore inaccessible high-level windows are not a concern for security. Where possible it is desirable to avoid operable windows in vulnerable locations.

The use of externally exposed hinges or pivot fixings should be avoided if possible. Where they are used they should be of the non-removable type to minimise risk of intrusion.

In order to prevent people getting through a window, the largest dimension in any direction should not exceed 125 mm and a maximum area of 0.05 m² is recommended. This is different from the regulations regarding fire egress windows (see below) so careful planning is required.

Intruders may enter a building through windows if they are left open (intentionally or otherwise) after cleaning. Windows that are linked to a global control that can, for example, lock all the windows at the end of the day offer better security in this instance.

Where necessary catches should limit the opening of any window to an aperture of not more than 100 mm. To permit the windows to be opened wider, the catches should be capable of being unfastened by means that are not readily operable by small children. The catches should re-engage automatically when the window is closed.

Any security measures fitted should not hinder or delay the occupants' escape in the event of a fire.

Fire and smoke

The requirements for fire egress windows differ greatly from those where ventilation is the only priority. The regulations state that there must be an unobstructed opening area of 0.33 m² and that the window must be at least 450 mm by 450 mm. Furthermore the bottom of the openable area should be no more than 1100 mm above the ground (and no less than 800 mm). Windows should be designed so that they remain in the open position without needing to be held by a person making their escape.

Windows suitable for means of escape should operate in the following sequence:

- Release window handle
- Release of any restrictor
- Window fully open to egress position
- Window move to any other position, eg for cleaning.

Any restrictors that are fitted to egress windows should be readily identifiable and should be capable of being released by an adult without prior instruction. Restrictors should be designed specifically to operate on the types of windows on which they are being used. Clear written information on the operation of safety restrictors, and any potential risks or limitations in use, should be provided to owners and occupiers by the window installers.

There appears to be some conflict between the advice given in Approved Document B of the Building Regulations and BS 8213-1. AD B states that locks (with or without removable keys) and stays may be fitted to egress windows, subject to the stay being fitted with a release catch, which should be child resistant. BS 8213-1 states that lockable handles and restrictors released by removable keys or other tools should not be fitted to opening lights suitable as means of escape in case of a fire.

3.2 Other operable ventilation devices

3.2.1 Rooflights

Rooflights can play an important role in the ventilation of buildings. There are two main types available - glass rooflights (essentially windows in a different orientation) and dome/pyramid types. The choice will depend on the design and performance requirements of the building as well as the desired aesthetics.

Rooflights can be used for smoke ventilation (or specific smoke vents can be used). Rooflights can be incorporated in the system to create a smoke free layer above the floor by removing smoke from the building. The natural buoyancy of the hot gases is used to exhaust them through high-level vents, with low-level vents allowing fresh air in. There are various control strategies that are suitable ranging from a stand-alone system to one that is fully integrated with the BMS for maximum control.

The openings required for smoke ventilation are generally larger than the areas required for comfort ventilation. Therefore vents designed for the control of smoke may also be used for ventilation, with this dual purpose approach popular.

3.2.2 Dampers

Dampers may be used to provide manual or automatic control of airflow for natural ventilation. They are usually used for the air intake below a false floor and at the main exhaust points.

As with louvres the main issue with dampers is providing an effective seal when closed and thus minimising energy losses from air leakage.

To achieve effective control a significant proportion of the available pressure differential must occur across the damper to provide control authority.

3.2.3 Trickle ventilators

Trickle ventilators are designed to provide a minimum fresh air rate, particularly in winter. To minimise cold draughts they should be placed at a high level (1.75 m above the floor level).

Trickle ventilators are usually used in conjunction with other types of ventilation opening as they are only intended to provide background ventilation. Where greater levels of ventilation flow are required opening the windows for a short time or the use of mechanical ventilation are necessary.

In order to minimise the resistance to air flow, the main air passage through a trickle ventilator should have a minimum dimension of 5 mm for slots, or 8 mm for square or circular holes. Trickle ventilators can be part of the window frame, part of the glazing unit or separate from the frame (usually placed immediately above it).

The equivalent area has been introduced into Approved Document F instead of the free area for the sizing of background ventilators (including trickle vents). Equivalent area is a better measure of the airflow performance of a ventilator. Free area is simply the physical size of the aperture of the ventilator but may not accurately reflect the airflow performance which the ventilator will achieve. The more complicated and/or contorted airflow passages in a ventilator, the less air will flow through it. Therefore two different ventilators with the same free area will not necessarily have the same airflow performance. As an approximation, the free area of a trickle ventilator is typically 25 per cent greater than its equivalent area.

3.2.4 Automatic (variable area) inlets

Some air inlets respond automatically to various air quality and climate parameters. These products are generally used with passive stack ventilation systems.

Temperature sensitive vents

The area of the vent reduces as the external temperature reduces. This limits the impact of stack ventilation and prevents a rise in airflow rate as the stack pressure increases.

Humidity sensitive vents

These vents open when the humidity in the room increases in order to aid the removal of moisture.

Pressure sensitive vents

The driving pressures for natural ventilation are usually very low (~10 Pa) so reliable operation of pressure sensitive vents is not guaranteed. Vents that operate with a pressure difference as low as one Pa have been developed. This allows an almost uniform flow rate to be achieved throughout a wide pressure range which gives good control of natural ventilation.

4 COMPONENTS FOR SHADING

There are many different types of shading device available. The choice will depend on a number of factors including whether glare control, solar overheating or privacy is the major concern and cost, appearance, façade orientation, and maintenance amongst others.

The orientation of the facade plays an important role in establishing what type of shading device is most appropriate.

- North-facing windows only receive sunlight in early mornings or late evenings so are not a major concern.
- South-facing windows receive the most sunlight, however in the summer overhangs can easily block this, as the sun will be high in the sky. This means that overheating can be minimised, however glare can still be an issue due to low angle sun during the winter.
- West- and east-facing windows only receive sunlight for half of the day. When the sun is opposite the window it tends to be fairly low in the sky, even during the summer. This makes it difficult to shade against it without completely covering the window. They are also exposed to more sun in the summer than the winter.

For these reasons it is easier to shade a building if its major openings are orientated in a north-south direction, as opposed to an east-west direction.

For this study the different shading devices are divided into three categories: external, internal, and mid-pane.

4.1 External shading devices

External shading devices are the best for controlling solar overheating as if designed properly they can completely stop a proportion of the incident solar energy from entering the building. This compares with internal and mid-pane devices where the solar energy enters the building, after which a proportion will be reflected back out of the building and some will be absorbed by the shading device and re-radiated into the internal environment. External shading devices lose heat to the outside by convection currents and through longwave radiation. The issue of longwave radiation emission can be a particular issue in hot climates where the shading device may store a large amount of heat, which can then radiate back into the building, adding to the internal gains.

There are several concerns regarding the use of external shading devices which may limit their appeal; the first of these is maintenance and cleaning. Regular cleaning is essential when reflective properties of the shading device are used to reflect light into the building and to protect surfaces and finishes. Any projections from the façade make routine cleaning more difficult and time consuming and external shading devices may limit access to the façade for the replacement of glazing units. There have been instances when the whole shading device has had to be removed in order for this to happen.

A further consideration when using external shading devices is the effect of the wind, especially with tall buildings. The shading devices and their fixings should be suitably robust, or the device should be retractable in order to protect it during periods of high wind. In addition to the structural performance, the noise caused by the wind flowing over external shading devices can be an issue and should be considered during the design.

4.1.1 Overhangs, awnings and canopies

There are many options for overhangs and canopies. The choice will depend on the desired external appearance and whether it is a retro-fit solution or not. Compared to a fixed overhang, a moveable canopy has few environmental benefits; the main advantage is that it can be protected from the wind by retracting it.

These devices are most effective when the sun is high so work best for south facing facades and at low latitudes. If glare is an issue extra shading may be required for low-altitude winter sun.

For UK conditions the depth of the overhang should be approximately the same as the height the window to provide optimum summer shading.

Disadvantages of these types of shading device are that they can collect dust and other debris, provide a place for birds to nest and can make window cleaning difficult.

4.1.2 Light shelves

Light shelves consist of a horizontal baffle which provides shade below, and reflects light up into the building off its upper surface. They are usually fitted part way up a window (above 2 m to provide a good view out of the building and to reduce glare for the occupants). They work best with a high ceiling and can be external, internal or both. The top surface should be as reflective as possible to maximise daylight reflection.

Studies suggest an external shelf of depth equal to its own height above the desk works well, although at high latitudes, or with an east or west facing façade, even a very deep light shelf will allow some direct daylight through.

4.1.3 Fixed and moveable louvres

External fixed or moveable louvres possibly provide the best control of incoming solar gain. A wide variety of different types are available with different façade orientations requiring different types.

For a south facing façade horizontal louvres are best. For a south-west, or south-east facing façade, louvres that are fixed horizontally will tend to block most of the incoming solar gain whilst still allowing some view out. For east and west facing facades louvres with a diagonal slope are most effective.

With the correct design external louvres are able to reject sunlight completely in the summer and reflect it into the space during the winter, however there will always be a compromise between view, admission of daylight and glare. For example at high latitudes and with east or west facing windows, it is very difficult to obtain an acceptable view out without some daylight penetration. Opaque louvres can be used as these can provide reasonable glare control whilst letting in some light. As with other external shading devices maintenance can be difficult.

4.1.4 Shutters

External shutters are a traditional way to control solar gain; however they do this at the expense of the view out. They can be especially useful in rooms that are unoccupied during the day where this drawback does not matter. Their operation may be automated. Insulated shutters are also available to reduce heat loss at night.

4.2 Internal shading devices

Internal blinds tend to be a lot simpler than external devices. They offer a degree of user interaction which is a very important feature. Studies have shown that when occupants have control of shading/ventilation they tend to accept higher internal temperatures than they would if they had no control of the space.

The performance of any shading device is not only dependent on the type of device, but also the materials used, especially fabrics. These include:

- Transmittance – a fabric with a high transmittance may become very bright when the sun is incident upon it. This source of glare may cause a particular problem for people with computer screens. CIBSE recommends a transmittance of less than 0.1 for these cases.
- Weave – open-weave fabrics allow some view through. However they do not provide full control of glare from direct sunlight. Close-weave blinds are recommended where glare is important.
- Reflectance – light coloured blinds are recommended to avoid harsh contrast at night between the blind and the surrounding wall. For solar control the side of the blind facing the window should be light coloured and preferably silvered to reflect the incoming sun.

A major concern with the use of internal blinds is that they can severely affect the airflow through an opening window. Firstly the blinds will mean that the window can only be opened a limited distance which will restrict the airflow due to the reduced free opening area. Secondly the blind itself will further restrict the airflow. Therefore the ventilation strategy of a building that uses internal blinds needs to take these reductions into account by adjusting the openings of windows where blinds are raised for example.

4.2.1 Venetian blinds

When properly designed internal Venetian blinds offer excellent glare control and privacy. However they are very bad at controlling solar heat gain as the heat that is absorbed by the blind mostly stays within the building.

The blinds should be easy to operate and to understand so that they are not simply left closed which would increase the use of artificial lighting. They should not interfere with the window opening and any window furniture.

4.2.2 Vertical louvre blinds

Many of the observations for Venetian blinds also apply to vertical louvre blinds.

They are most suitable for east and west facing windows where the sun is often at an oblique angle to the glazing.

4.3 Mid-pane blinds

Various types of mid-pane blind are available, depending on the type of opening to be shaded. Typically blinds can be installed in the air gap of double windows, in the cavity of a double skin façade, or inside sealed double-glazed units.

An advantage of mid-pane blinds over internal blinds is that they do not conflict with the ventilation through opening windows. As the blind moves with the window it will not restrict its opening or the airflow through it.

4.3.1 Mid-pane fixed reflective louvres

These types of blind offer seasonally varying shading performance; in the summer light is reflected outside the building, while in the winter the light is admitted and redirected by the blind. The main problem with these fixed systems is that they only deal with the sun for particular range of solar altitudes. Slat design is a compromise between view, daylight admission and glare. For example at high latitudes, particularly with east or west facing windows, an acceptable view out is difficult to obtain without some daylight penetration. Similarly the more the louvres protect against solar glare, the less diffuse daylight they will admit.

4.3.2 Mid-pane Venetian blinds

These blinds have similar properties to internal Venetian blinds. They offer better protection from the sun's heat as the heat absorbed is more likely to be emitted to the outside rather than to the inside of the building. They do not take up any space within the building and do not get dirty as quickly as they are in the sealed unit.

They are subject to some problems, mainly to do with access and maintenance due to their position. There could also be a performance issue when the window is open. Some blinds have limited functions (tilt only, not retractable) that will affect the overall performance.

4.4 Solar control glass

The alternative to using shading devices to control solar gain is to use a solar control glass. This works by either absorbing or reflecting the solar radiation in order to stop it entering the building. Absorbing glass tends to be tinted and heats up when the sun is on it, and this can contribute to the overall heat gain entering the building. Reflecting glasses are coated and are usually better at rejecting incoming solar gain, however they may cause unwanted dazzling for people outside the building. Coated glasses admit significantly more daylight than tinted glasses, and have a lower heat loss in winter. Films, typically used as a retro-fit measure, that absorb or reflect incident shortwave solar radiation are also available.

Environmental control glasses are often specified by their total solar energy transmittance, solar factor, or g-value. This is defined as the sum of the direct solar transmittance and the absorbed radiation entering the room by long wave radiation and convection from the glass.

Due to the nature of the solar spectrum it is not possible only to block out the short wave solar radiation which is responsible for heating. Half of the power of solar radiation lies in the visible spectrum and therefore by cutting down the incident short wave infrared, the visible part is also affected.

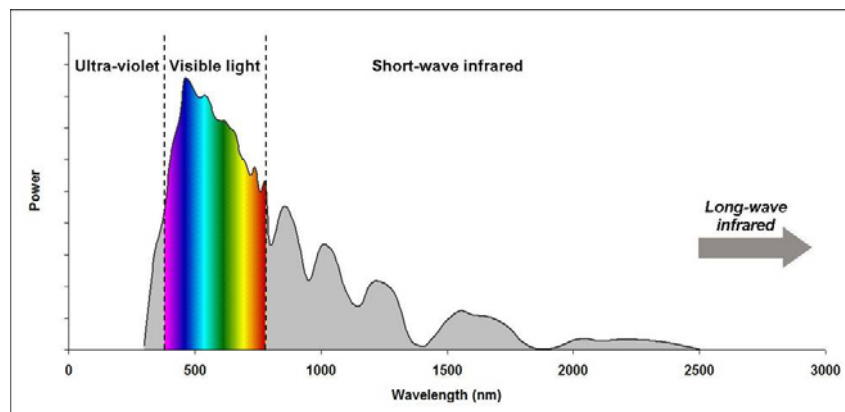


Figure 4.1 Spectrum of solar radiation

Solar control glasses, unlike other shading devices, can be made to be spectrally selective, that is they only restrict part of the spectrum. Whilst they cannot be designed only to cut out the short wave infrared, they can be designed to allow a higher proportion of visible light through into the building. This selectivity is a measure of the efficacy of a control glass and may be defined as the light transmittance divided by the g-value. A glass described as 67/37 would have a light transmission of 67 per cent and a total solar transmittance of 37 per cent.

Solar control glasses are a passive form of solar shading and cannot be adjusted to change their properties. This means a glass selected to reduce solar heat gains in the summer will also reduce them in the winter.

The configuration of the glazing unit is another important factor in the overall performance. For example tinted glasses and high absorptance coatings will get warm and should be used as the outer pane of a unit. Similarly reflective coatings should be orientated to reflect solar radiation outwards, and will become warmer if both the incident and reflected radiation passes through the glass. Therefore they should also be used as the outer pane. In both cases a low emissivity coating may be used on surface three (the side facing the cavity on the internal pane) to reduce the amount of energy radiated inwards from the outer pane.

If blinds are to be used, careful consideration should be given to the glass specification. For example if mid-pane blinds are used a low emissivity coating should be applied to surface three, as this will reduce the radiation transfer from the hot blind to the internal environment. If internal blinds are used then the risk of solar overheating is increased as the incident solar energy will have already entered the building before hitting the blind. Therefore a reflective solar control glass may be used for the outer pane to reduce the shortwave infrared radiation entering the internal environment.

Thermal fracture of annealed glass may occur if a sufficiently high temperature differential is created across the glass. The greater the absorptance of the glass the hotter it is likely to become. Coatings and films may also increase the temperature of the glass if they reduce heat loss by reducing radiation from the surface or if they reflect radiation back through the glass.

4.5 Overall solar shading

The overall solar shading of a window or façade will be a combination of the properties of both the glass and external shading device used. The shading co-efficient is defined as the amount of solar radiation excluded by the shading device and glass combined and may be defined as the shading factor multiplied by the solar factor of the glass. The shading factor is the effective proportion of the glass that is shaded and will vary throughout the day with altitude and azimuth of the sun. More details may be found in CWCT Technical Note 50.

4.6 Advanced glazing

There are several glasses available that change their appearance in response to an external stimulus. These include electro-chromic (where electricity is the stimulus), photo-chromic (light), thermo-chromic (heat) and liquid crystal (electricity). Of these electro-chromic glass has the most potential for use in buildings. Typical current figures suggest that shading coefficients of between 0.67 (bleached) and 0.20 (coloured) are achievable. In theory this means that a single variable transmission product would be able to reduce the incoming solar gain in the summer whilst allowing beneficial solar gain in the winter. The control of this could be automated in order to ensure the optimum conditions result. Currently these glazings are not available on a large scale commercial basis, and there are concerns regarding their performance, these include the size of

panes that can be produced, the colour (currently tend to be blue), the speed of switching between the different states, and the overall durability of the technology. Whilst not currently viable, these glazings could be incorporated into buildings in the future if the technology progresses.

5 CONTROL OF AUTOMATED FACADES

5.1 Actuators

Window actuators comprise an electric motor that operates a chain, piston or spindle mechanism in order to open and close the windows or operate the shading device.

Control may be by individual switches or remote control and several opening lights can be linked together. The alternative is for the actuators to be sensor-controlled and linked through the building management system. Windows may be linked through sensors for temperature, humidity, daylight, rain and wind speed.

The following issues should be considered in the selection of an appropriate actuator:

- Cost
- Robustness
- Appearance
- Physical size
- Type of opening light
- Protrusion into the room
- Noise
- Security
- Stroke (the maximum opening distance)
- Operating pressure
- Battery or mains power supply
- Energy use

The different types of actuator for opening and closing windows are described below.

5.1.1 Actuator types

Chain actuators

Chain actuators provide a compact fitting on to a window frame. They are available in styles that can be mounted directly into the window profile. When the chain is completely extended it is rigid so that even large external pressures will not affect its stability. When the window is closed the chain recedes into the actuator profile. Actuators attached directly to the frames are easier to access than those within the profile and maintenance is easier with this method of fitting, although concealed actuators may also be designed to allow access when required. A disadvantage of using actuators attached to the frame is that they may be subject to abuse and vandalism, especially in buildings such as schools.

The electric chain operator is supplied either with a chosen stroke or with an adjustable (multiple position) stroke. They are available in various sizes to handle different loads. Depending on the size of the window it may be necessary to use more than one actuator.



Figure 5.1 Chain actuator (courtesy SE controls)

Scissor stay actuator

Scissor stay actuators also provide a compact fitting to the window frame. They are generally supplied with an adjustable stroke so that the correct pressure is applied to close the window. Manufacturers suggest they are capable of providing a driving force of between 1200 N and 3000 N.

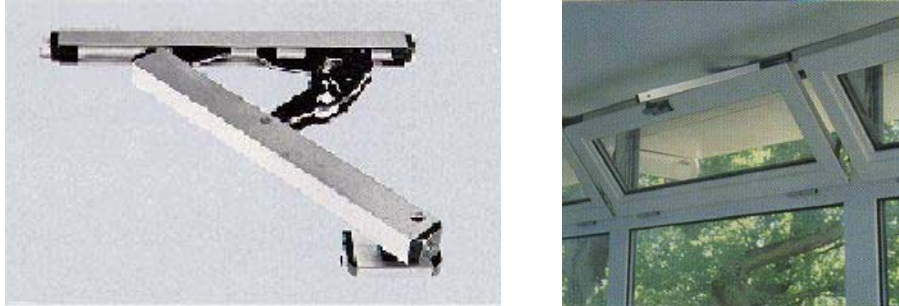


Figure 5.2 Scissor stay actuator

Rack and pinion actuator

Rack and pinion actuators have similar applications to the linear type actuator. They are available in a variety of standard travel lengths ranging from 170 mm to 750 mm; typical quoted thrusts are up to 650 N with a travel rate of 8 mm/s. They have the advantage that more than one window can be operated from a single actuator. These actuators are mainly used in the roofs but may also be used for blinds/blades.



Figure 5.3 Rack and pinion actuator (Climate Controls)

Electric linear actuator

Electric linear actuators protrude into the room and are more noticeable than a chain or scissor stay actuator. They typically come with thrusts of 200, 300 or 700 N (can be as high as 1500 N) and with a range of strokes up to approximately 1000 mm. They may be used to operate more than one window but they are usually used to operate a single window as shown in the diagram below.



Figure 5.4 Linear actuator (courtesy SE Controls)

5.1.2 Control

All of the above actuators are available with either 230 V AC or 24 V DC motors. 24 V actuators have the advantage that they are safer to work with, especially where there is a danger of water ingress or where vandalism is a concern. Window actuators have to be placed inside the building, as they are not designed to work in wet conditions. Specific actuators to control adjustable louvres and brise soleil are available that can be used externally.



Figure 5.5 Actuator for a shading device (courtesy SE Controls)

Some actuators use an end-of-travel microswitch to cut power when the actuator has reached the end of its travel. Others incorporate overload protection so that if there is an obstruction (such as a finger) as the window closes the power to the actuator is cut off.

By regulating the amount of time that the power is applied to the actuator it is possible to provide step control.

The compatibility between the actuator and the control system has to be ensured. Factors such as the voltage, current and system configuration have to be considered in order to optimise the design.

5.1.3 Smoke ventilation

Actuators that are to be used for the operation of smoke ventilators need to be capable of maintaining their open function whilst subjected to high temperatures. They also have to be capable of operating under the anticipated environmental loads. Actuators and the complete system of products (controllers, wiring etc) should be tested according to BS EN 12101-2 when they are to be used for smoke ventilation. These actuators are often powered using 24V DC so that battery back-up can be used when there is a mains power failure.

5.1.4 Natural ventilation

Actuators that are used in natural ventilation systems are required to have a high duty cycle, higher than that for smoke vents. Actuators should be tested to ensure they are suitably robust. If the actuator selected is not suitable for the intended use, then the life of the actuator may be considerably shortened.

5.1.5 Actuator reliability

Actuator technology is fairly established. Most of the advances in the control of automated components now come from developments in the software that is used to operate them.

Actuator reliability is generally very good, however problems can still occur. They are tested by manufacturers to ensure they operate for many cycles (commonly 10000), so they should last for a sufficient time once they are installed in a building. If there are problems with actuators, access can be difficult, especially if the actuators are external. Access and maintenance should be considered during the design stage as part of the CDM regulations.

Generally reliability issues occur when actuators are wrongly specified or not used in their intended way. In one example studied there had been problems with the actuators used to operate external louvres. The actuators had been installed upside down to enable connection to the louvres. As a result, the electrical supply entered the actuator from the top and the wiring seal did not provide the same degree of weathertightness. Subsequently the actuators were installed the correct way round and the reliability is believed to have improved.

The algorithm used to control the actuators can affect their reliability. There have been instances where actuators have been worn out in a matter of months simply because the algorithm was trying to adjust the position of the windows several times a second. This is far too often (a few times a day is a more common operation frequency) and caused the actuators to burn out very quickly.

Similarly, actuators used in applications other than those for which they were designed will cause problems. An example of this might be the selection of an actuator based on the forces required to operate a vertical opening light, but then being used to operate the same window in an inclined orientation. The loads on the actuator will be much greater in this configuration and are likely to lead to premature failure.

Although these issues are not directly a fault with the actuators it is often seen that way and clients and designers may have a lack of confidence in the reliability of actuators. It is for the manufacturers and suppliers to ensure this is not the case. Establishing relationships with designers and working together early in the project, so that actuators and controls are properly specified, would help to ensure that the chosen actuators perform as desired.

5.1.6 Actuator movements and forces

Actuators are available in many different specifications to cater for various ventilators from skylights and glazed windows to louvres and doors. When designing the following should be taken into consideration: the forces required moving the opening, the distance

the vent is required to move, whether the window is open-in or open-out, the forces required to compress the gaskets, how the actuator is attached to the window and the power supply required to the actuator.

For added safety in certain circumstances, especially in bottom hung windows, a restrictor device is included; when the actuator is disconnected for servicing or repair, or during installation, the vent will not swing down and damage itself or the panel below.

Actuator sizing will depend on the expected loading. This is related to the window style (for example if a window is on a sloped roof the actuator will have to lift the window as well as cope with any wind and snow loading effects). Windloading depends on the location of the building (height, exposure etc). Opening and closing forces will often depend on the weight of the vent.

5.1.7 Weathertightness

When selecting actuators the requirements of the window system designers have to be taken into account. For example, depending on the size and shape of the window, multiple locking points may be required to ensure the window still performs as intended with regard to weather resistance and security. Multiple locking points (on a manual window this may mean two handles or an espagnolette lock) will require either multiple actuators fitted to each vent, or a drive actuator and a separate locking actuator connected to the window's multipoint locking mechanism.

The addition of automation to a window could affect its weather performance. Different actuators operate in different ways and it is important to understand these differences.

The feedback used by the actuators is another factor. Some actuators have a magnet on the chain which, when it passes a reed switch, turns the motor off. With this kind of actuator there is no guarantee that it is really pulling the gasket tight enough to provide the necessary seal. To ensure that it does there is a fixing on the chain that has to be adjusted when the window is installed. Over time the gasket will loosen and the window performance will drop. Therefore regular maintenance will be required to ensure the window is always pulled sufficiently tight.

Other actuators are switched off by means of an internal limit switch. They continue to pull until the window is shut tight at which point the current drawn by the actuator will increase significantly as it tries to close the window but cannot move any further. The increased load draws an increased current that causes a switch to turn it off, and so with this type of actuator there is a much more consistent compression of the window's seals and therefore a more reliable weather performance. There is much less maintenance required when compared to the other type of actuator, which can be very important.

It is also very important to ensure that the actuator does not try to close the window too much, which can result in damage to both the gaskets and the frame. Some more sophisticated actuators that use limit switches close the window tightly and then back-off very slightly in order to ensure this does not happen. Furthermore when internal limit switches are used it is important to adapt the load-sensing cut-off to the particular type of window, again so damage does not occur.

5.1.8 Multipoint locking

Larger windows may require multipoint locking to ensure that the window meets the relevant performance and security criteria. If an automated window requires multipoint locking an additional actuator is required to operate the locking mechanism. There has to be some kind of link between the actuators responsible for the locking and the movement of the window to ensure that windows are not damaged, for example the window trying to open whilst still locked. This is achieved by one of the actuators being the master and the other the slave. The sequence of events in opening a window with multipoint locking would be the controller (or BMS) sends a signal to the locking actuator which, after it has

unlocked the window, sends a signal to the other actuator informing it that the window may be opened.



Figure 5.6 Multipoint locking actuators (courtesy SE Controls)

5.1.9 Multiple actuators on a window

In addition to multipoint locking, larger opening windows may require more than one actuator to operate them. These multiple actuators must be synchronised so that the window is not damaged. If the actuators are not synchronised the opening frame may become twisted. This integration may be provided in several ways. Firstly intelligent actuators may be used to give feedback to the controller, so it will know exactly where each actuator is, and will be able to make adjustments as necessary to keep them moving at the same rate. Alternatively 'standard' actuators may be used, with an extra module attached to the two actuators, which sends information on their relative positions back to the controller. The final method is to set one of the actuators as the master and the other as the slave. The master actuator takes the signal from the controller and then operates itself and the slave actuator.

5.1.10 Actuators for different windows

The type of hinge and the size of the window are very important considerations in the selection of window actuators. If the height of the window is quite low and it is mounted on butt hinges, the leading edge of the frame will move in quite a tight radius. If the actuator is fitted rigidly to the frame the chain of the actuator has to curve to that tight radius which it may not be able to do. Therefore the actuator might have to be fitted on a pivot to allow a similar curvature of the chain. Similarly if the window is mounted on friction stays the initial movement of the chain will be slightly downwards which means that it could contact the edge of the fixed frame if this is not taken into account when fitting the actuator.

As there are many different types of window available a considerable amount of information is required in order to choose the correct actuator (size, heights, type of hinge, opening/closing forces, path of the leading edge of the window as it opens, the cill detail etc). It is essential that advice is sought from the actuator supplier and/or window supplier in order to ensure the correct choices are made.

5.1.11 Anti-trap mechanisms

There is a firm requirement in BS EN 60335-2 103:2003 that a risk assessment be undertaken to ensure entrapment in an automatically operated vent is avoided. The basic solution is that vents should have no moving part lower than 2.5 metres from the finished floor level.

There are several different methods for ensuring protection from entrapment. An actuator and control system that uses motor drive speed sensing and load sensing will provide adequate protection but only along the edge of the vent to which the actuator is attached, usually the leading edge. However, should an object become trapped along the sides of a window thus protected, there is a scissor action in operation where very large forces are possible. The actuator and control system will not detect these high loads, only sensing a

much smaller load or reduction in speed. The result is a false and dangerous perception of safety.

A far more precise form of protection is a sensor strip placed along all of the pinch points on the window that detects if anything touches it. This is similar to the rubber strips found on automatic closing lift doors or bus doors. It may be costly, unsightly and more time consuming to install.

Alternately, microwave curtains or passive infrared detectors may be used to detect the presence of anyone close to the vents. These signal the controllers, which temporarily stop any movement until the person has moved away. Again costs can be significant.

5.1.12 Noise

The noise of actuators during operation is often a potential concern for clients and building occupants. There is a range of actuators available that can be selected to overcome this. However, in general the noise from window actuators is not significant, and within a week or so of people being regularly exposed to the noise, they tend to become accustomed to it and 'tune it out'. This is as much the case in schools as it is in offices and public buildings.

If the noise is deemed to be excessive (for example in a library where any noise could be seen as distracting) then some controllers can be adjusted to slow down the opening/closing speed of the actuators. With the speed of the actuators reduced to around 30 per cent of their maximum, their operation is practically silent. Two-speed operation is also possible with some systems, whereby under automated control the actuators move at slow, near silent speed, and under manual control they operate at higher speed. This gives the occupant opening or closing the window an obvious connection between pressing a button and something happening, which is important psychologically.

Noise from the external environment entering the building through windows and vents can be a concern. With this in mind the windows can be programmed to open only during the periods when the external noise levels are low or are unlikely to be a problem. For example this could be at break/lunch times in a school, before the start of the working day, not during rush hour times. Depending on the sophistication of the control system and actuators, windows can be set to only open a few millimetres in order to provide adequate background ventilation, and in this mode still perform reasonably well acoustically, providing typical sound reductions of around 25 dB. This compares to a sound reduction in the order of 28 – 32 dB for a typical double glazed window and 10 dB for a window with a fully open vent.

5.1.13 Simple and advanced actuators

Actuators can be broadly grouped into simple and advanced types. In general the type of actuator used will dictate the overall sophistication of the automated control system.

As an example a simple actuator will simply open/close a window while it is being signalled by the window controller. This means that it is possible for the system to lose track of the exact position of each window as factors such as wind speed and the stiffness of the hinges will affect how far it actually opens for a given signal period. Therefore in order to accurately adjust the position of a window that was already open, it must first be fully closed and then opened to its new position. This procedure could prove distracting to the building occupants as well as using up the life of the actuator more quickly.

An advanced actuator is more sophisticated in its operation and integration with the building's control system. This intelligence could take the form of feedback between the actuator and the BMS/window control system, so that its exact position is known at all times, or the actuator could have its own control logic embedded within it. It could then take input signals from relevant sensors and act according to its own algorithm.

5.2 Sensors

Sensors are an essential part of any system. The number and type of sensor incorporated into the systems will determine the functionality and degree of control possible for the façade. The different sensors available are described below.

5.2.1 Temperature

Temperature is the most commonly measured parameter in building energy management as it provides a good indication of thermal comfort and is relatively cheap and easy to measure.

Internal temperature sensors have to be positioned carefully to ensure they give representative temperatures within the room. Therefore they should be placed several metres into the room where the incoming air will have mixed with the air in the room. Similarly, they should be away from heat sources, other major draughts and convection currents.

Buildings are often divided into zones consisting of spaces with similar heat load characteristic throughout. In this way the different requirements for cooling, based on building orientation or operating hours, for example, can be met.

The air temperature (or dry bulb temperature) is the most common measurement; however other forms of temperature measurement may be incorporated. These include radiant temperature, comfort temperature and slab temperature.

Mean radiant temperature sensors use a thermistor placed behind a black bulb to measure the radiant heat pattern within a space. Comfort temperature sensors do the same but combine the results with the air temperature to give an environmental or operative temperature.

Slab temperature sensors measure the temperature of the floor slab close to the ceiling surface. These sensors are useful when night time cooling is used in order to understand better the building's response to different heat loads. As with air temperature sensors, the position of sensors in the floor slab is important.

Sensors used are typically based on platinum resistance thermometers or thermistors. Both of these both have an accuracy of within 0.5°C , which is usually sufficient unless a specially controlled environment is required.

A single external temperature sensor will usually be used. This should be weatherproof, fitted with a radiant head shield, allow a constant flow of air across the sensor and be placed away from sources of heat, such as solar gain. They will typically be placed on a north facing area of the building. As with internal temperature sensors, an accuracy of 0.5°C is usually sufficient.

5.2.2 Light sensors

To control the amount of artificial light within a room it is necessary to use sensors that measure both the internal and external lighting conditions. Sensors can be categorised into two types; pyranometric and photometric.

Pyranometric sensors measure the solar radiation from the whole hemisphere of the sky. They measure the flux density in W/m^2 from both the direct solar radiation and the diffuse sky. Sensor types tend to be photovoltaic cells (simple and inexpensive) or thermopiles (accurate and expensive). Due to the way the sensor responds to different forms of incident light, pyranometers tend to be configured under specific light source conditions and therefore must only be used within those applications. Mostly the configuration conditions are unobstructed natural daylight.

Photometric sensors measure illuminance (in lux), which is the light radiation as the human eye sees it. Although characteristics of the human eye vary between different people there are standard weighting curves available which photometric sensors can match within five per cent. Photometers usually consist of a photo diode and a filter that corrects for the response of radiation at different angles of incidence.

The primary purpose of an internal light sensor is to ensure that there are appropriate levels of light on the working plane. Therefore the majority of internal light sensors are ceiling mounted photometric sensors pointing vertically down so as to measure the illuminance of the working surface. If a daylight top-up system is being used it would be necessary to have more than one internal light sensor, so that the lights closer to the façade can be controlled separately from those further back.

When measuring the internal light level it is important to be able to distinguish between what is natural daylight and what is light from artificial sources. This is necessary to ensure the artificial lights are not being switched on and off excessively, which would cause annoyance to the building occupants.



Figure 5.7 Internal light sensor (courtesy SE Controls)

The main purpose of the external light sensor is to know the external sky conditions and therefore the external light levels. External sensors need to be waterproof and should have a range of 0 to at least 30000 lux. There are several different methods of providing this reading.

Global sky sensors can either be pyranometer or photometric sensors. There are a number of different types available enabling either horizontal or vertical orientation. Diffuse solar sky sensors are placed on the roof of a building away from any obstructions. They use pyranometers or photometric sensors to measure the daylight contribution of the sky. This is done by having an adjustable band that shades the sensor from the direct solar component. When used in conjunction with a global sensing element the difference between the total power and the diffuse power measured is the direct component, which can be used to determine when the sun is shining (as opposed to being behind a cloud). The third type are called sky scanners; they are the most sophisticated external light sensors and provide information about the luminous distribution of the sky. They can be linked to lighting and blind controllers to classify various sky conditions and match them with preferred lighting conditions. There are several different types available.

5.2.3 Solar gain

Solar gain sensors (pyranometers) may be used to indicate periods of high solar gain, enabling the control system to open vents to provide increased ventilation. This gives the advantage of a time lag between high solar gain and the resulting increased temperature within the space. Opening vents in response to high solar gain anticipates this potential for overheating. Sensors must integrate the gain over a period of time to avoid hunting during periods of patchy cloud for example.

5.2.4 Wind sensors

Wind speed

A wind speed sensor (anemometer) can be used to maintain a nominal constant ventilation rate by reducing window openings as wind speeds increase. They may be used in conjunction with a rain sensor to give an indication of the possible entry of wind driven rain.

Typical anemometers use a reed switch to make and break a contact once per revolution of a rotor to indicate wind speed. More sophisticated anemometers work by the rotating shaft cutting a light beam to generate a pulse with a frequency directly proportional to the wind speed. In cold climates a heating element should be supplied to prevent the shaft from freezing.

Wind direction

A wind direction sensor can be used to increase the amount of air flow within the building; it can be used to open vents on the leeward side and shut vents on the windward side of the building.

The most common and least expensive method of monitoring wind direction employs a lightweight vane which orients itself parallel to the wind. The electrical output of such a vane can be either a discrete signal for each direction, or an analogue voltage output proportional to the orientation.

These vanes only give a true indication of the wind direction under steady conditions. During gusty conditions the wind vane will oscillate about the true direction, and it may be necessary to average the readings over a period of time in order to obtain a more stable result.



Figure 5.8 Wind speed and direction sensor (left), wind speed and rain sensor (right) (courtesy SE Controls)

5.2.5 Rain sensors

A rain sensor can be incorporated into a natural ventilation strategy to ensure that window openings are reduced during rain storms to avoid water ingress into the building. This can be linked with a wind speed and direction sensor so that only windward vents are closed.

The position of the sensor is very important. It is likely to be positioned on the roof of the building where the rainfall will be unimpeded. For large buildings it may be necessary to have more than one rain sensor so that incoming rain from any direction may be detected

before the risk of ingress occurs. Alternatively it is possible to have a rain sensor for each window or façade of the building.

Two typical types of rain sensor are available. The first works on a tipping bucket principle. A small bucket collects rainfall and tips over at a certain level, generating a pulse, the frequency of which can be used to determine the intensity of the rain. In cold climates a heater should be incorporated to prevent the system freezing.

The alternative is to use an electronic sensor. This is a device whose capacitance changes as the area of moisture on its surface increases. When a preset limit is exceeded a pulse is sent instructing the control system to act. The sensor should be fitted with a heater which is activated when it starts raining so that at the end of the period of precipitation the sensor dries quickly. The heater should also be activated when the ambient temperature drops below 4°C so that falling snow may be detected. This type of sensor is less expensive than the tipping bucket type, and is usually sufficient for buildings as the exact amount of rainfall is not required, only that it is above a certain intensity.

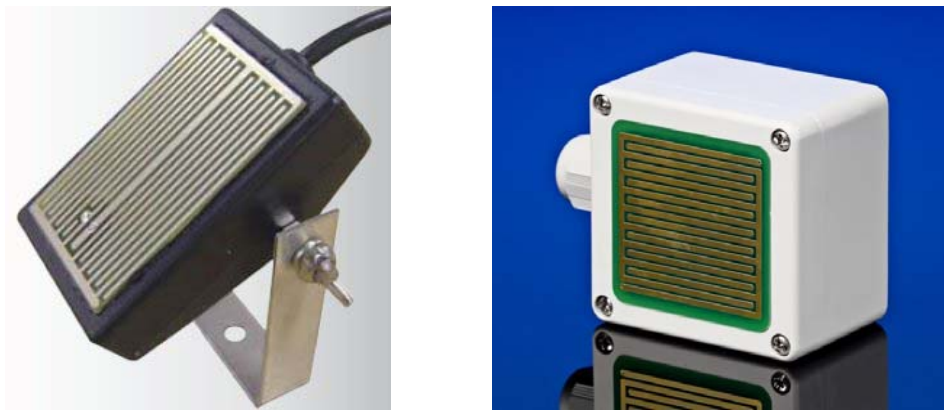


Figure 5.9 Rain sensors (courtesy SE Controls left, WindowMaster right)

5.2.6 Air quality sensors

A number of different approaches to measuring the air quality have been used. These usually rely on taking a particular pollutant as an indicator for the overall air quality. CO₂ and humidity sensors have commonly been used, the former in commercial buildings and the latter in residential buildings where condensation is a more serious problem.

High indoor CO₂ concentrations are an indicator of poor ventilation conditions that can lead to the build up of other trace gases and 'sick building syndrome'. In building ventilation control a threshold of 1000 ppm (compared with ambient air containing ~380ppm) is often used as a point to start ventilation.

Carbon dioxide concentrations are calculated by measuring the absorption of infrared light (at a wavelength of 4.26 microns) by carbon dioxide molecules. As CO₂ levels rise, more infrared is absorbed. CO₂ sensors incorporate a special source of infrared radiation, a detector, and electronics to detect the absorption. The sensors require annual recalibration which can be done at the factory or using special calibration gas kits.

5.2.7 Occupancy sensors

Comfort is only a concern if the room is occupied. Therefore if there is no one in a room the heating, lighting and ventilation controls can be adjusted to take this into account and save energy. Various types of occupancy sensor exist including passive infrared (PIR) sensors and ultrasonic and microwave sensors.

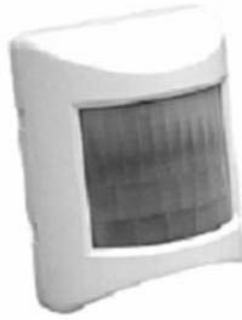


Figure 5.10 Occupancy sensor (courtesy SE Controls)

5.2.8 Security

Sensors can be used as additional security measures for opening windows. These include vibration sensors that are triggered by someone shaking the window or breaking the glass, and magnetic switches that can detect when windows and doors are opened. Microwave curtains are available that when placed close to the inside of a window, will detect if anyone tries to break in.

Some windows may also have a reed switch between the opening and fixed frame as a further security measure and is used to prove that the window is properly shut. Clients and building managers have concerns that actuators may be detached from the windows and that the system would think the building is secure, whereas this may not be the case.

5.2.9 Other issues

There is a large variation in the cost of sensors. The more expensive ones tend to use more advanced technologies and maybe more accurate and reliable; however for most applications the accuracy of the less expensive sensors will be adequate. This appears to be a particular concern with CO₂ sensors, where there have been concerns regarding their reliability in the past.

This leads to the question of whether lots of cheaper sensors or one more expensive one should be used in the building. This will depend on the application. For example a single temperature sensor maybe used in an atrium whereas it would be more appropriate to use multiple sensors within a space that requires closer control. Similarly for external light sensors where there are several options that could be used. Firstly a single sensor could be placed on the roof that takes both a global measurement and values in the direction of each façade. Alternatively separate sensors on each façade, or even sensors on each individual window, together with a global sensor may be used.

Maintenance of sensors is also has to be considered and therefore access is important. Certain sensors, such as light and rain, will have to be cleaned on a regular basis and provision should be made for this when they are installed. Some sensors will need to be annually calibrated which must also be allowed for. Finally access will also be required to control panels and the ease of this is something that should be considered

5.3 Power and wiring

24V DC is the preferred power supply to actuators for natural ventilation. It is safer to work with as well as giving the opportunity to use a battery backup that can be used in the event of mains power failure. This feature is essential when the automated system is used for smoke control. 230V AC power is still needed for the local controller. Actuators are grouped in zones according to the requirements of the strategy. An appropriate controller is then selected to control the zone and meet the current demand of the

actuators. The current capacity of a controller is often linked to the cost of the device, the larger the capacity of the controller's power supply, the higher the cost.

Wiring to the actuators is typically twin core, though more complicated multicore controlled actuators exist. Field cabling to the actuators is typically carried out by the electrical contractor on site, who will provide a junction box close to the actuator. The window controls specialist will then connect up to this junction box. The other end of the field cabling is glanded into the local zone controller, and again the window controls specialist will connect it as they must ultimately be responsible for their own equipment and are best placed to carry out such commissioning.

Other field cabling is required between the controllers and the sensors, between the manual override switches and the controllers, provision of mains power supply to the controllers and, if included, a network cable between all relevant devices. The electrical contractor would usually connect the mains power supply into the controllers, but the signal cables are usually glanded into the control panels by the electrical contractor, and connection to the panel made by the window controls specialist during commissioning.

Careful selection of the cable for each application is important, either as a safety issue with power cables, or to ensure a high quality signal with communications cables. With network cabling attention must be paid to how and where the cable is installed; if the network cable is positioned close to certain electrical plant (for example inverter driven machinery), the network signal may be seriously disrupted. Therefore network installation 'best practice' must be followed.

Ideally all wiring should be concealed. This is not only an aesthetic issue but also reduces risk of damage. With punched-hole windows in a solid wall this is easier – the wires can simply be 'lost' in the construction of the reveals. With glazed curtain walling it can be more complicated as the wires have to be routed within the frame. Some companies produce special profiles that allow this whilst others may require a series of pull through wires to help route the cables. If any holes are drilled in a mullion or transom for threading cables it must be ensured that the structural performance of the curtain wall is not affected. Sharp edges around the drilled hole could easily damage cables resulting in a short circuit and, if 230V actuators are being used, in electrocution. Therefore appropriate cable protection must be fitted to drilled holes. Access to wiring concealed in this way is very difficult so it is critical that it is installed in a way that will not cause damage to the wiring as it cannot be inspected. Other methods are available for concealing wiring to actuators. Internal cover caps that attach to the back of the curtain wall frame and contain all the cabling are possibly a better solution due to easier access for maintenance and replacement. All these considerations add extra cost and complexity to a project.

One potential issue regarding cabling is whether the window being connected is for ventilation purposes or whether it is a smoke/fire window. Issues can arise where the purpose of the window has not been identified. This can be especially true if there are lots of automated opening vents (AOVs) in the building. The choice of cabling between standard PVC coated or silicone coated depends on whether it has to be fire-rated, and there is a huge difference in the cost of the cables. Fire-rated cable will not be installed unless it is necessary and specified. The information required to make this decision is not always available early enough, and therefore it is very important to establish exactly what is required as soon as possible. This is particularly important for windows systems where the motor is fitted with either standard or fire-rated cable in the factory during the fabrication of the window. In this case the information will be required at the point of ordering the window, and it is vital that the correct part is fitted.

If these distinctions are not properly established before installation and it is found that the incorrect cabling has been fitted, especially if standard cable has been used instead of a fire-rated type, then it will have to be removed and replaced with cabling of the correct specification. This will be both very costly and time consuming for the contractor responsible for the mistake.

5.4 Actuators and power supplies

The power supply used for the actuators is an important component in the automated window system. Despite this it is an area where contractors think savings can be made by using cheaper alternatives. Contractors are generally not aware that the power supplies can be so crucial to the project's performance and success.

The power supply needs to be matched to the performance of the window and the actuator otherwise it may not operate correctly. The use of non-approved, incompatible power supplies can not only affect the performance of the automated components, but may also void the warranty of the window. Some companies will only offer a warranty covering the performance and operation of the window if their own power supply is used (or one that meets their technical brief).

The difference between a low price and an expensive power supply is essentially in the quality, and consistency of the signal it sends to the motor. Cheaper supplies can be subject to large spikes and troughs in the signal and a 24V dc signal could be providing anything between 12V and 32V. This can result in motors burning out and inconsistent opening of windows, which may severely affect the performance of a project. As an example, a project was discussed whereby the window actuators and their power supplies had been provided by different companies, with little/no co-ordination between the two. The school in question had so many problems with this combination (motors burning out and windows in the same room opening different distances due to the supply being so poor) that after two years they simply disconnected the motors and manually operated the windows.

A simple solution might be to specify the window actuators and power supplies together to ensure compatibility. However because of the way that the packages are usually split up (ie the motors with the window contract, the power supplies with the M&E contract) this does not always happen. The M&E contractor may simply source the cheapest power supplies possible (as he is not contractually responsible for the actuator performance) and the client will have motors that are not warranted.

230V AC or 24V DC actuators can be used, with the lower voltage ones being favoured for safety reasons. However BMS contractors prefer 230V actuators as they are easier for them to control as voltage drops along the cabling from the controller to the actuator does not have to be considered. These safety concerns are especially important when the actuators are installed into curtain walling due to the large amount of exposed metal that could become 'live' if a short circuit should occur. To address this there are additional regulatory requirements that must be met when 230V actuators are used and 24V actuators are usually the simplest option.

5.5 Battery back-up

The use of 24V DC actuators allows battery back-ups to be used to power the actuators in the event of a power failure. This is an essential function for windows with a smoke and fire function but also desirable for windows for natural ventilation.

The natural ventilation system can be used for night time cooling during the warmer months of the year. During these months there is an increased risk of thunder storms so having a battery backed-up system provides protection from the possibility of a power cut as a result of lightning during a rain storm. A mains dependant system would not be able to close the vents thus allowing rain to enter the building, and with no one on site during the night, damage may ensue.

A further advantage of a battery backed-up system is the separation from other systems and their possible failures. If the BMS system or the mains power supply fails, the natural ventilation system can continue to operate independently.

5.6 Wireless technology

Wireless communication between control boxes, actuators and sensors is a potential way to reduce the amount and complexity of wiring required linking all the various components together.

In the case of actuators this technology does not have a benefit as they would still require a power supply and would have to be wired to control box. There is a case for wireless communication between sensors and the control box, as sensors can more easily be battery powered. However this simplification of the wiring needs to be assessed against the added complexity and cost of the sensor and control box and the additional maintenance that would be required due to the batteries having to be regularly checked.

5.7 Control boxes

The necessity for a control box will primarily depend on the complexity of the system. A very simple system may be directly controlled by the BMS, whereas a more complex one may require its own controller.

The task of the control box is essentially to process the incoming data from the various sensors around the building and, according to the built in control algorithm, send signals to the different actuators to control their positions.

The type of control box required will depend on many factors including the number of actuators to be controlled, their power requirements and the level of sophistication needed. Commonly control boxes may be local to room/façade or they may be more centralised and control multiple rooms.



Figure 5.11 Local and centralised control boxes (courtesy SE Controls)

The level of control, such as allowing very precise openings, may be removed if the control of the actuators is dealt with by the BMS. There is also the potential for compatibility issues between controllers and actuators. Best practice is for the actuator supplier to supply the control boxes as well so these problems can be resolved.

Automated façade control

Device	Location	Purpose	Notes
Rain sensor	On each facade	Detects rain driven on to that façade and may be used to close windows in a single facade	Should be positioned to detect rain driving on to the façade (should not be protected from the rain). On long facades should be positioned near the middle of the façade or duplicated at each end.
	On roof	Detects rain and may be used to close all windows or may be combined with wind direction sensor to close selected windows	Should be mounted to detect rain from all directions (should not be protected from the rain). On large buildings the sensor should be duplicated at the different extremities of the building.
Wind speed sensor	On roof	Measures wind speed so that vents may be shut or the opening reduced as the wind speed increases	Should be positioned in an unsheltered location so that a representative wind speed is measured.
Wind direction sensor	On roof	Can be used to increase the ventilation rate by shutting windward, and opening leeward vents. Used in conjunction with the wind speed sensor to close or reduce the openings of the affecting vents only when the wind speeds are high.	Should be positioned in an unsheltered location so that a representative wind direction is measured. Only gives true indication of wind direction under steady conditions, so readings may have to be averaged to gain a more reliable result.

Automated façade control

Device	Location	Purpose	Notes
Anti-trap sensor	On each window	Used to detect if anything (object, person etc) gets trapped in an automated window	Sensor strip placed along all pinch points on the window and as such is a very precise form of protection. Is in addition to the regular gaskets so as not to affect the weather performance etc.
	Centralised control	Used to detect if anything (object, person etc) gets trapped in an automated window	Control system uses motor drive speed and load sensing to provide protection. Is only effective if an object is trapped along the edge which the actuator is attached so does not provide adequate protection if something becomes trapped along the sides of the window
CO ₂ sensor	In room	Used to detect the build up of CO ₂ as a general indication of the overall air quality.	For best control and lowest energy use there needs to be a CO ₂ in every room. However, often a single sensor is used for a number of adjacent rooms.
Internal temperature sensor	In room	Used to measure the internal temperature. Used together with the external temperature to control the opening windows for cooling.	Need careful placement so that representative indication of the space temperature is recorded. Several sensors will be required in the building is split into zones with different requirements. Slab temperatures can also be measured which is useful when night cooling is used.
External temperature sensor	External	Used to measure the external temperature. Used together with the internal temperature to control the opening windows for cooling.	Should be located away from any sources of heat gain, typically on a north facing area of the building.

Automated façade control

Device	Level of control			
	Single window	Room of windows	Façade of windows	Whole building of windows
Rain sensor	On the window	On each façade or on the roof	On each façade or on the roof	On each façade or on the roof
Wind speed sensor	On the window	On each façade or on the roof	On each façade or on the roof	On each façade or on the roof
Wind direction sensor		On the roof to measure representative wind direction.	On the roof to measure representative wind direction.	On the roof to measure representative wind direction.
Anti-trap sensor	On the window	On each window	On each window	On each window
CO ₂ sensor		In the room	In each room	In each room
Internal temperature sensor	In the room	In the room	In each room	In each room
External temperature sensor	On the building and shaded to measure air temperature.	On the building and shaded to measure air temperature.	On the building and shaded to measure air temperature.	On the building and shaded to measure air temperature.

6 STRATEGIES FOR VENTILATION CONTROL

6.1 Control and ventilation strategies

The strategy used to cool a building will depend on many factors and include

- The type of construction (lightweight or heavyweight);
- The location;
- The building use;
- The internal design (open plan or not, single occupier in each floor etc).

6.2 Ventilation strategies

Three common strategies for ventilation will be discussed: single-sided ventilation, cross ventilation and ventilation through roofs and thermal stacks.

6.2.1 Cross ventilation

The principle of cross ventilation is simple; under most circumstances there will be a positive pressure on the windward face of a building and a negative pressure on the leeward side. This pressure difference will promote airflow through the building. In practice it can be more complicated, and there are many issues that have to be considered.

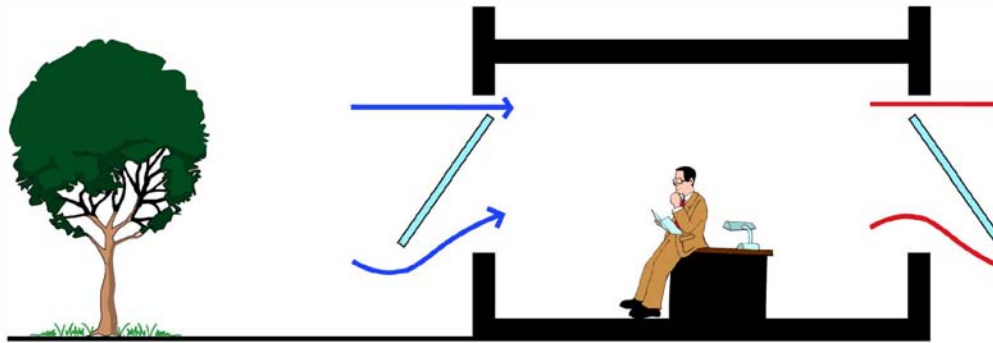


Figure 6.1 Cross ventilation (courtesy WindowMaster A/S)

The effective depth of room that can be cooled in this way is approximately five times the floor to ceiling height of the opposing facades.

To be most effective the design should aim to suck air out of the building (and subsequently draw air in the other side) as opposed to the air being pushed in (and it being forced out). With this in mind there should be more openings on the leeward side of the building than the windward side. This is primarily to avoid cold draughts.

A major concern with cross ventilation is that the path for the airflow through the building may be blocked. This usually occurs when spaces are partitioned either to create a number of cellular offices within an open plan space, or if the building is rented, having more than one tenant in a particular floor. If this partitioning has not been taken account of in the design then it can result in a building that has insufficient ventilation. It is a sensible to consider, during the initial design, what may happen if the building is partitioned, so that if it is partitioned at a later date it will still function adequately.

Manual overrides for the windows are essential in order to satisfy occupant demands for individual control but this may complicate the strategy further. What happens to the airflow if any one occupant closes a window on one side of the building? Is another window opened to compensate? This may be required if the necessary ventilation is still

to be provided, but this could annoy the occupant as their desire to close a window has essentially been ignored. These conflicts need to be considered fully during the design of the building and its strategy.

To make best use of cross ventilation the control strategy has to link the façades on either side of the building. This ensures that the correct windows are opened in each façade according to the external wind speed and direction.

6.2.2 Single-sided ventilation

Single-sided ventilation, where only one exterior wall has operable windows or vents, is also possible but this tends to be less effective, since air speed (along with its cooling effect) is typically lower than in cross-ventilated buildings.

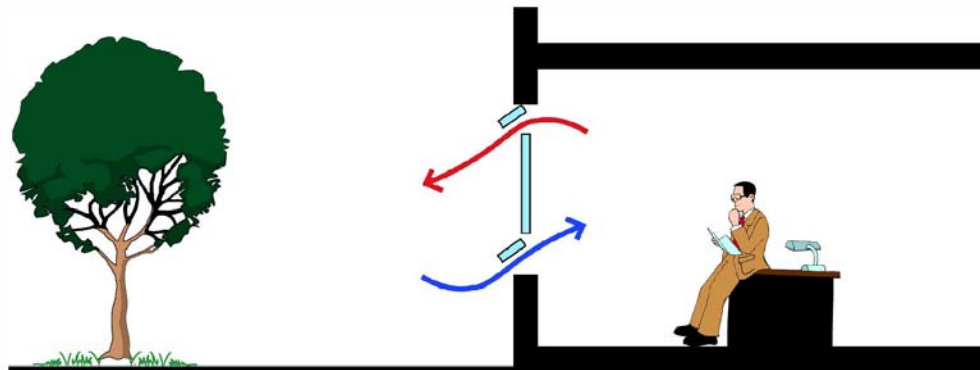


Figure 6.2 Single sided ventilation (courtesy WindowMaster A/S)

With a single operable window or vent, natural ventilation relies on wind turbulence and buoyancy, rather than the higher pressures differences available from the wind. In single-sided ventilation, airflow through a low level opening is heated within the space, and flows out at the top of the same opening, or a second opening at a higher level. In general, the greater the height difference between the top and bottom of the opening(s), and the higher the temperature change, the greater the airflow.

Single-sided, single-opening natural ventilation is effective to a depth of approximately twice the ceiling height. Having two separate openings, one at a high level and one at a low level can increase this depth of effectiveness to approximately 2.5 times the floor to ceiling height.

The control strategies used for single-sided ventilation can be simpler than those for cross ventilation. Control maybe at a façade level, as opposed to a whole building strategy because the amount of ventilation is not dependant on, and does not affect other areas/spaces with the building,

Ventilation through stacks and thermal chimneys

Passive stack ventilation can be the most effective natural ventilation strategy as it uses a combination of cross ventilation, buoyancy (warm air rising) and the Venturi effect (wind around a high level opening creating suction).

Warm air inside the building (from solar gains, the occupants, IT equipment, etc) rises. Provided the warm air can be exhausted from the building, it will draw cooler air into the building, thus creating a natural airflow. Windows in the roof are used for letting the used, warm air out, while windows at the lower levels take fresh ambient air into the building. This flow can be increased if the extra pressure reduction is created at the top of the stacks or the roof by the external airflow over them. The stack effect requires a certain height difference between the windows used for air inlet and outlet.

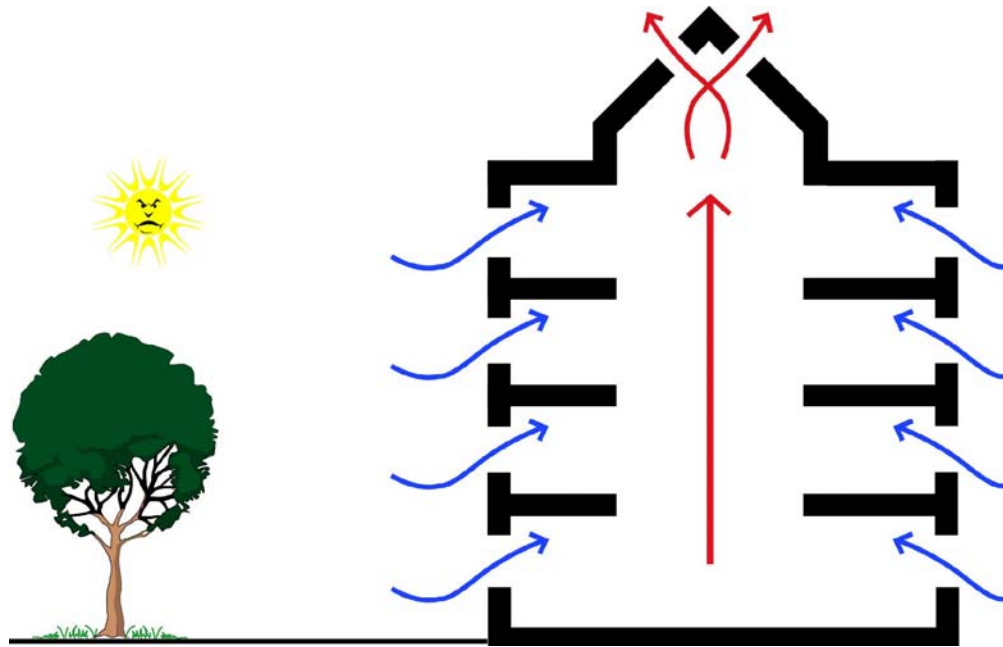


Figure 6.3 Stack ventilation (courtesy WindowMaster A/S)

Passive stacks can comprise stairwells, atria or ductwork to take the warm air from within the building to exhaust outlets at high level. A stack can be located in the middle of the building and can therefore ventilate buildings with twice the width possible with traditional cross ventilation. It can also provide effective night cooling, as the difference between internal and external temperatures at night is greater and tends to increase the buoyancy effect.

The amount of ventilation through thermal stacks and chimneys is generally calculated assuming a still day, however when the wind is blowing the suction at the top of the stack will be greater and the openings at the top of the stack need close control to avoid over-ventilating the building. These openings should be linked to the windows at lower levels so the level of airflow can be closely controlled. A whole building approach is therefore necessary for the control of the automated openings in order to provide the optimum conditions.

The area of effective ventilation is similar to that for double sided ventilation, i.e. around five times the floor width to that of the floor to ceiling height

6.2.3 Ventilation timing

By providing ventilation at particular times the effects on cooling and air quality can be enhanced.

Night cooling

Night cooling is a common way to cool a building. Night cooling refers to the operation of natural ventilation at night to purge excess heat from occupied spaces. It takes advantage of the lower overnight external temperature to reduce the temperature of the building fabric. A building with sufficient thermal mass that can be exposed to night time ventilation can reduce peak daytime internal temperatures by 2-3°C.

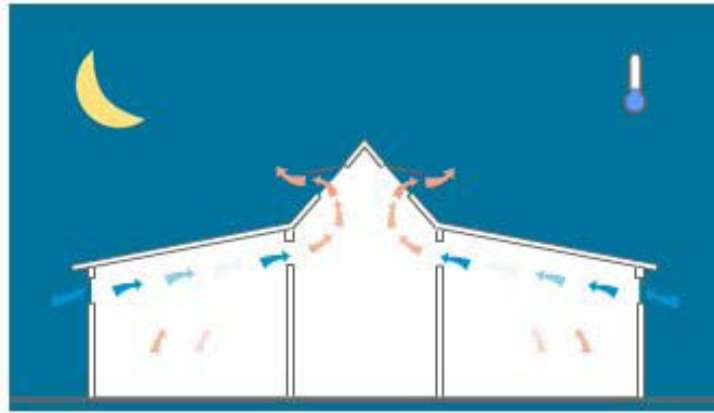


Figure 6.4 Night cooling (courtesy SE Controls)

There are several issues associated with night cooling; security is perhaps the most important. Windows have to open at night and it is essential that they are secure and cannot be forced open, especially at lower vulnerable levels. This threat can be reduced by using only high-level windows for night cooling, or by using inward opening windows/panels that have grids or bars in front of them. It is important to be able to predict how far to reduce the temperature. Good control of night cooling is required in order to achieve maximum free cooling whilst avoiding overcooling and subsequent re-heating or thermal discomfort the following day.

Thermal mass is crucial if night cooling work is to be successful. The thermal mass needs to be present in order to store the 'coolth', so this method is not as effective with lightweight buildings. Retrofitted blinds may also be an issue. If these blinds are closed at night for privacy or security purposes then the airflow into the building will be reduced which will result in the removal of less of the heat that has built up during the day and less cooling of the thermal mass ready for the next day.

Pulse ventilation

Pulse ventilation is another method that can be used to provide ventilation in a building. The principle of pulse ventilation is that windows are opened fully for a short period of time in order to purge the building of stale, warm air and provide cooler, fresh air. The frequency of opening will primarily depend upon the heat loads within the building and the external conditions.

Noise may be a significant issue with pulse ventilation; both the external noise, through the wide open window, and the noise of the actuator. Although the windows are only open for a short period of time this may still be very distracting to the occupants. It is important to time the opening of any windows to avoid peak external noise, such as during busy rush hour periods. The disturbance of the actuators may be minimised by operating the windows as infrequently as possible.

The draughts created whilst windows are open may annoy the building occupants. This disturbance may be reduced by placing the openings used for the pulse ventilation away from desks and again, by operating them only when necessary.

Background ventilation

Background ventilation is intended to provide continuous finely controlled low-level ventilation (such as trickle ventilation) to the room. The ventilation openings should be reasonably secure, adjustable and typically at least 1.75 metres above the floor level to avoid discomfort to the occupants from cold draughts.

Trickle ventilators are the principle means of providing ventilation within windows, with many different types and configurations available.

It should be borne in mind when specifying ventilators that BS 6375: Part 1 1989 *Classification of weathertightness* states that there is no requirement to record the flow of air through a controlled ventilator when closed, however some manufacturers have carried out air permeability tests. It is therefore incumbent upon the designer to ensure that the specified product performs satisfactorily when closed.

A common alternative to using trickle ventilators is to use the windows themselves to provide the background ventilation. For this to be possible the window needs to have very fine control so that it can be opened by very precise amounts (1 or 2 mm) to limit the flow of air. This level of control is possible with automated windows with sophisticated controls.

Acoustic trickle ventilators are available that attenuate the external noise but they tend to be larger than standard ventilators so may not be suitable for all applications.

There will be times when it is not suitable to open windows for ventilation and cooling, for example when it is very noisy outside, or when it is raining heavily. Under these circumstances the conditions within the building have to remain suitable. Buildings that have a high thermal mass tend to perform better as they react more slowly to the changes in air temperature that will occur. In many cases the limit to operating in this state is the air quality, as opposed to the internal temperature, however the use of background ventilation may be sufficient to remedy this.

Cooling ventilation

The requirements and operation if the ventilation is for cooling are quite different from those when ventilation is for air quality. If ventilation is required for air quality opening the vents has an immediate effect, and the necessity can be determined simply by use of a CO₂ sensor. Ventilation for cooling is considerably more difficult. Natural ventilation relies on the occupants or the automated system acting sufficiently early to prevent overheating and therefore the control must be more sophisticated. This requires both the internal and external temperatures to be known in order that the windows operate only when the outside temperature is cooler than the inside.

Once the internal environment has overheated it is too late to act. The response of the building to any change will be slow and therefore it is vital that measures are taken to counter any overheating at the appropriate time and under the appropriate conditions. Ideally windows should be shut when the external temperature is greater than the internal temperature which is something that building occupants tend not to do. Automating this process takes the decision away from the ineffective occupant. However, this means that the building must then be able to cope with the situation and not subsequently overheat during this period. This requires the building to have significant thermal mass in order that this is met.

Ventilation 'scenes'

The performance of naturally ventilated buildings may be further increased if the ventilation and control strategy can be changed according to the external conditions. Whilst not guaranteeing the performance, these different 'scenes' will ensure the best opportunity of providing an adequate internal environment within the building. The principal determinant of appropriate ventilation and cooling strategies is wind direction.

In order to establish the optimum control strategies for the different external conditions CFD (computational fluid dynamics) analyses need to be run for the building. The building is modelled with the wind incident from different directions to see the affect it has on the pressures and wind speeds around the building. This data can then be used to determine the most appropriate strategy (which windows are open and which are closed) in order best to control the ventilation and therefore the internal environment.

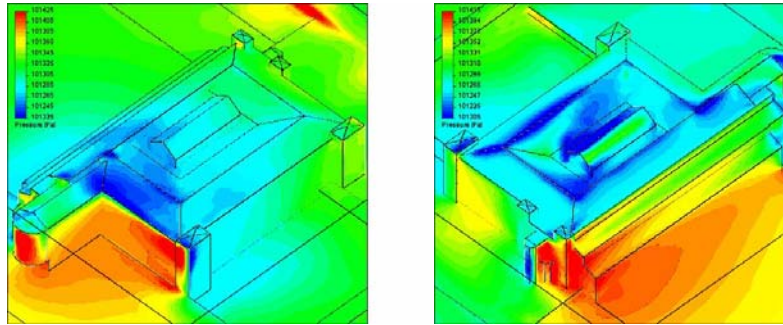


Figure 6.1 CFD analysis of a building with the wind coming from different directions

In order to simplify the control algorithms the wind direction will usually be divided into a number of sectors, with every wind direction within that sector having the same control strategy. In order to implement this the window control system needs to be linked to an external weather station or wind direction sensor so that the wind direction data is available for the system to adjust the openings appropriately.

6.2.4 Occupant control of ventilation

Manual control of certain windows in a building with an automated façade is very important as occupants need to feel that they are in control of their environment. It has been shown that they accept greater variation and deviation from their comfort levels when they know they have override facilities.

This manual control can take several forms. It will usually be provided by having a manually opening window or an automated window that is operated by a switch or TV-style remote control. In the event of an occupant opening a manually-controlled window the control system may close others in the room to compensate for the increase in the ventilation or decrease in temperature.

It is better for this manual control to be in the form of an occupant-controlled automated window linked to the control system or BMS. In this way it can still be closed automatically if it rains or if it is left open at the end of the day, and could also be used for night cooling if required.

A further advantage of having a manually-controlled automated window is the ability of the control system to override the manual operation after a certain period of time and allow the building to revert to the state which it thinks is most appropriate.

The position and style of any manual control is also important. There needs to be an obvious link between a person pressing a button and something happening, ie the operator needs to see or hear something happening to be sure that the controller actually does operate. With this in mind controls should be near the windows they open and should be clearly marked. There are two speed motors available that help with this. Under automatic control they move very slowly and almost silently, whereas under manual control they move more quickly and slightly more loudly, again ensuring that the person operating them feels they are affecting their environment.

The design and layout of the controls are very important if they are to be used properly. If the controls are overly complicated or their operation not clear the occupants will not know what they do and are more likely to be uncomfortable and complain. In one project the designers came up with a novel way of explaining how the manual controllers worked. Each occupant had a mouse mat that had a picture of the controller with clear instructions on how they should be used.

7 STRATEGIES FOR SHADING CONTROL

Shading may be provided to reduce or redirect daylight, to reduce solar gain, to control glare or a combination of these. In the case of daylight control the principle aim is to reduce discomfort or inconvenience from glare. Blinds for control of glare may also be used to prevent views in, particular at night when the room is illuminated.

Solar shading devices are best placed on the outside of the façade so that any heat gained by the shading device is lost by convection and radiation to the outside air. Traditionally in the UK daylight has been controlled by blinds on the inner surface of a window and no solar shading devices have been used. However, in sunnier climates such as Southern Europe it is traditional to use external shutters that limit both solar gain and light transmission.

7.1 Shading against solar gain

Shading devices to limit solar gain may be passive or active. Passive devices include external horizontal shelves (*brise soleil*), similar devices placed in the vertical plane outside of the glazing, and reveals and overhangs that are part of the geometry of the façade.

It is not always necessary to provide shading against solar gain and seldom necessary to provide complete shading of the glazing. The property describing the extent of solar shading is the *g*-value defined as the ratio of total solar energy entering a glazed opening with the shading device and total solar energy entering with no shading device present.

Even for a passive (static) shading device the area of shadow on the window and hence the *g*-value varies throughout the day. For the purposes of specification and design an effective *g*-value is often used. This is the mean *g*-value between the hours for which it is stated.

For an active shading device the geometry of the device may be varied throughout the day and from season to season. This allows the *g*-value to be maximised for each sun position throughout the day and so a higher effective *g*-value may be obtained.

A shading device designed to reduce solar gain will also shade a window against transmission of daylight. A more important feature of active shading is that its geometry can be set to maximise the ratio of light transmission (LT) to *g*-value. This reduces the penalty of reduced light transmission that is usually paid for reduction of total solar energy transmission (*g*-value).

7.2 Shading against glare

Glare is caused by light of intensity great enough to prevent clear vision of objects or cause discomfort when viewing objects.

The first of these may take one of two forms:

- An object when viewed against strong backlighting may be difficult to observe as the eye accommodates to the intense level of the backlighting. This may lead to some loss of definition when viewing the object and in the extreme objects appear only as silhouettes.
- Light incident on a computer screen or other illuminated object may make it difficult or impossible to discern detail on the object.

Discomfort occurs when the lighting is not of sufficient intensity to prevent clear viewing of the object but is sufficiently strong that eye strain results. This is most commonly experienced when reading a book out of doors in bright sunlight.

Glare is most commonly associated with the high levels of intensity of direct sunlight. However, glare may also occur as a result of diffuse light, particularly where daylight is backlighting a viewed object or sunlight is diffused by a shading device.

Problems of glare may be overcome by:

- Changing the viewing position
- Changing the position of the viewed object
- Increasing the illumination of the viewed object
- Reducing the intensity of sunlight or daylight

Unlike shading to reduce solar gain which may be partial shade glare generally requires total shade over some part of the window. For instance, the use of a slatted blind that allows some sunlight to pass may create a shade pattern on a computer screen that includes bright areas of sunlit areas as well as the areas shaded by the slats.

Traditionally glare has been controlled by the use of blinds, shutters or curtains (drapes). These have been under the manual control of the occupants and are adjusted throughout the day to match the angle and intensity of direct sunlight and the activity being undertaken.

Roller blinds comprise a fabric that may be pulled across the glazed area to create a shaded area on the glass. Blinds otherwise comprise vertical or horizontal slats that may be controlled for orientation and shaded area. Most blinds allow for almost total coverage of the glazed area to prevent entry both direct and diffuse light. However variation of the pitch of the slats allows the admission of diffuse light whilst preventing the entry of direct light. Note that some sunlight will enter by double reflection off the slats of the blind. Note that blinds are not totally opaque. Fabric blinds will admit diffuse light unless they are of heavy material and construction such as is used for blackout curtains. Metal blinds contain perforations for operating cords and the like through which light may pass.

Vertical slatted blinds will exclude direct light from a range of azimuths depending on the horizontal angle and spacing of the slats. In general these blinds require adjustment throughout the day as the sun's azimuth changes.

With horizontal slatted blinds the vertical angle of the slats is normally set once and it will then exclude light throughout the day.

In a dwelling blinds may be automated for ease of use or use by the disabled or the idle and simply be controlled individually from a hand held controller or remote switch.

7.3 Control of glare

Problems of glare arise mainly from differences in light intensity radiated from different sources. It is thus difficult to use a single measure of light intensity to predict glare. It also varies throughout a room and depends largely on the direction of view and the position of the viewed object.

One strategy for preventing direct glare could be the provision of partitions or corralling of work stations to prevent direct light however this reduces the availability of daylight all day to prevent a glare problem that is transient and probably of short period. This would increase the need for artificial lighting and reduce the quality of the workspace in terms of views out.

Control of glare is perhaps then best controlled by blinds under the control of the occupants. There are three possible improvements to this arrangement.

Firstly, when the sun is low in the sky in the early morning it may penetrate deeply into a room and cause a glare problem for many of the occupants. At these times it may be better to close the blinds rather than have individuals closing them one at a time.

Secondly, it would be possible to retract the blinds after some period to remind occupants that the blinds were down. Occupants could then close the blinds again if they were still required. A period of an hour would allow the sun to change azimuth through 15° by which time the glare problem may no longer exist. Certainly glare is unlikely to be a problem for more than three hours during the day.

A further extension of this thinking is that of adaptive control. If blinds were retracted after an hour and the occupants closed them again then the algorithm could be adapted to open the blinds later the next day. In practice the algorithm could adapt to a number of scenarios representing say different months of the year.

Thirdly, it would be possible to open the blinds if the sky was overcast. It is difficult to predict passing clouds and it would be unacceptable for the blinds to respond to a solitary cloud. However, sustained periods of low light intensity could be used as a signal to open the blinds.

The presumption of opening the blinds if possible and using the occupants as sensors to close the blinds has the draw back that the façade would be perceived to be 'in control' or 'have a mind of its own'. This can be minimised by having a long period between automatic openings of the blinds and ultimately to use adaptive algorithms.

Some automated blind suppliers prefer to offer a stand-alone system to control the blinds as opposed to providing the component parts and having the BMS dictate the position. This is because of the level of complexity that is needed for adequate glare control. Some integration between the two systems is still required however, and the stand-alone blind system needs to be linked to the BMS so that it knows what the blinds are doing and can act accordingly (for example, close a window if blinds are lowered).

Experience has shown that if the responsibility for the control algorithms is given to the BMS contractor to write they tend to be crude and not sufficiently sensitive. The number of different zones that large buildings might have to be divided order to provide the best conditions adds to the overall complexity of the control system. There can be upwards of 50 zones in some buildings that would all need to be individually modelled and programmed. This level of complexity makes the writing of control algorithms difficult, even for specialist companies. It is therefore unrealistic to expect a BMS contractor to be able to offer this level of detail.

7.4 Glare – additional functionality

There are numerous approaches to the control of glare. The method used will depend on a number of factors including the building geometry, orientation, and the location amongst others.

Internal and external light sensors are commonly used in order to control any devices incorporated for the control of glare within a space. The number and position of any sensors is important. A simple approach would be to have a single external and a single internal light sensor. This would provide a fairly limited solution as the whole of the internal environment is describing using one sensor. A more sophisticated method would be to use multiple internal sensors, for example one by the perimeter and one deeper in the room. This would allow closer control of the blinds and could result in the blinds being raised for a higher proportion of the time, thus reducing the use of artificial lighting. The zones at the corner of rooms would have light from two facades influencing the visual environment and therefore would require two external, and two perimeter light sensors in order to best control the conditions at those points. These extra sensors would require

more complicated algorithms in order to make best use of the additional information they give on the internal light levels.

Algorithms for the control of glare need to be complex if they are going to provide the occupants of a building with suitable visual conditions. One way in which they could be developed is to combine light sensors with time as a way of controlling blinds. Depending on the geometry of the building, its location and the use of external shading devices (for example brise soleil, or simply the window reveal), direct sunlight might only be incident on the façade for a limited time of the day (in the morning on east facing and the afternoon on west facing buildings for example). This means that glare due to direct sun will not be an issue during these times and therefore the blinds can be raised in order to maximise the use of natural daylight. If this does not happen the occupants may simply leave the blinds lowered, even when not required, which should be avoided.

As well as from the direct sun, light can also be incident on a façade due to reflections from adjacent buildings. Similarly this will only be for certain times of the day so it is important for algorithms to have more than one set point to allow for this additional period of time when there could be a potential glare issue.

The above discussion once again leads to the possibility of adaptive algorithms. These will change their operation depending on how the occupants of the building react to the external conditions. There are two different approaches to adaptive algorithms. The first is to manually adapt them, while the second involves a more sophisticated system that adjusts automatically.

The first method essentially involves an extended commissioning process. Initially the automated blinds are programmed to retract at certain times when it is calculated that the direct sun is not incident on the façade. Manual lowering and raising is also allowed and this is monitored to see how the occupants respond to the automatic control. This can then be adjusted if clear patterns of manual operation emerge. The alternative is to have an algorithm that is self-learning, ie it automatically changes depending on the occupants overrides. This is a more complex approach and it must be ensured that the system learns the correct adjustments so as not to annoy the building users.

With all the algorithms used for glare control the effect of any external shading can have a very large impact on the amount of direct sunlight hitting the façade, and therefore this must be taken into account when determining the position of any blind. As discussed in previous sections the type of shading device used (for example vertical or horizontal) will primarily depend on the orientation of the façade. A good example of this is the shading used on the BRE Environmental Building. Due to the stacks and the external walkways the windows are completely shaded from direct sunlight from April to August and so the external louvres could be fully open during this time. 'Standard' algorithms would not take factors such as these into account so it is important that they are written on a project by project basis.

In addition to simply blocking direct sunlight, external shading devices can also be used to redirect it. Louvre blades may be reflective and angled in such a way that, when not required to block direct light, act as a light shelf. This gives diffuse light reflected from the ceiling deep into the room, which as well as enhancing the overall light level will reduce the glare from the façade.

As well as shading at a façade level, localised shading can also be used. For example cowlings are often used above display screens in transport facilities. Brighter computer screens that have low reflectance surfaces will also reduce glare.

Automated control of blinds for localised glare (on a computer screen for example) is very difficult due to factors such as the subjective nature of glare, its dependence on task and the fact that the level of glare is dependant on the viewing angle, not just position. Therefore in order to accurately assess the specific light conditions a large number of sensors would be required which would not be practical. Therefore occupant control of

blinds for localised glare control is seen as the best approach. In order to keep some control over the blinds, they can still be automated and linked to the BMS so that the system knows the position of each one. This means that after a certain period of time (say one hour), the blinds can be automatically raised. This will help to eliminate the situation whereby the blinds remain deployed and supplementary lighting is used after the glare problem has passed.

7.5 Blinds

The control of any blind depends on its own characteristics, such as its transmission and other properties. Blinds whose light transmission is high could become sources of glare themselves as they will be very bright if direct sunlight is incident on them.

Different blind configurations could be used to control glare whilst still allowing good use of natural light. Rather than having a single blind that when fully deployed completely blocks the window, an upper and lower blind may be used. These would have the advantage that they could be controlled separately (according to the light sensors at the perimeter and deep in the room, as well as solar altitude (time)) allowing for the best compromise between glare control, view and daylight.

7.6 Solar gain

The role of an external shading device is to block direct sunlight, and the heat gains that go with it, from entering the building. This alone is simple, however there is also a necessity to allow in as much daylight as possible in order to reduce the use of artificial lights, and to allow a view out. Therefore there usually has to be a compromise made between these conflicting requirements. However this only needs to happen when there are people in the room. When the room is unoccupied the view out does not matter so the external shading could be fully closed/lowered in order to reduce the maximum amount of solar energy, thus making for more comfortable conditions when the room is later used. Therefore the controller for the shading devices could be linked to an occupancy sensor to allow this to happen.

7.7 Methodologies for blind operation for glare control

Different methodologies can be used for the control of glare, as discussed above. Two potential strategies are described below.

7.7.1 Threshold control

This is the simplest form of blind control. Its operation relies on the utilisation of solar illuminance or irradiance readings, to lower or raise the blinds after a pre-set threshold value is passed. Once the blinds are lowered the slats are rotated to a default position (typically 45°) to maximise the solar protection, whilst still providing some daylight and view out.

It is important to include a time delay so that the blind does not react too quickly to varying light levels. Typically a short delay of maybe 30 seconds is used when the sensor reading rises above the threshold level. This is accounts for any short burst of sunshine (sun coming out from behind a cloud for example) while still offering a quick enough response to the threat of glare. A longer delay is required when the sensor reads below the threshold. A delay of 10 minutes will provide stability on days with mixed conditions.

The number and type of sensors will vary between different systems. Some will rely on a single sensor to control all the blinds in the building, while others may have many in order that the control may be more effective. Diffuse light sensors may be used which, together with sensors on the façade, will give a better representation of the direct and sky component of natural light.

7.7.2 Sun blocking

The principle of a sun blocking controller is similar to the threshold type but they also adjust their slat angle in relation to the position of the sun. This can be carried out either by the use of sensors or by control algorithms. By knowing the exact position of the sun, the angle it makes on the vertical façade can be calculated and the slat angle can be adjusted accordingly.

The simplest type of sun blocking involves using an algorithm, either software based in the BMS or window controller, or hardware based on a chip in the blind actuator. The position of the sun may be calculated for any time of year, by knowing the latitude and longitude of the site. With this information, together with readings from internal and external light sensors, decisions can be made on whether or not the blinds should be deployed, and the angle of the slats.

The second approach to sun blocking is to use sensors to provide real-time information on the sky conditions. Global sky sensors provide information on the overall sky conditions. Diffuse solar sky sensors are placed on the roof of a building away from any obstructions and are used to measure the daylight contribution of the sky. This is done by having an adjustable band that shades the sensor from the direct solar component. When used in conjunction with a global sensing element the difference between the total power and the diffuse power measured is the direct component, which can be used to determine when the sun is shining (as opposed to being behind a cloud), and therefore when direct glare may be a concern.

Alternatively sky scanners are the most sophisticated external light sensors and provide information about the luminous distribution of the sky. They do this by either including a fish eye lens and detector array, an array of sensors positioned at different orientations or a single sensor turning around a single or double axis to measure different parts of the sky. These sensors can be used to calculate the position of the sun by interpolating data from all the sensors about the relative brightness of different parts of the sky. This method provides a reasonable level of accuracy for occasions when glare might occur.

7.8 Shading for privacy

The exact control of shading for privacy will depend on the building type and precisely why privacy is required. The requirements for a bedroom and an office will be very different. In both cases however the occupant must decide the need for privacy, which will usually involve the lowering of internal blinds.

In order to provide the optimum conditions within the building the manual operation of any blind needs to be linked back to the window control system so that clashes between the two are avoided. For example, if the blinds are lowered this should send a signal to the window controller or BMS so that the windows are not opened as well as the two may interfere with the blinds.

There may need to be a time limit on the manual operation of internal blinds for privacy. For example many naturally ventilated office buildings make use of night cooling in order to help control the internal temperatures during the following day. If the blinds remain lowered at night, the resulting air flow into the building will be significantly lower and therefore will not cool the building to the required level leading to potential overheating. The BMS should therefore raise the blinds after a certain period of time so that this does not occur.

8 INTELLIGENT FACADES

The term 'intelligent façade' has been in use for some time but it is a catch all term and both the level of intelligence and the functionality of façades cover a large range of performance. At the simplest level a window may be 'dumb' and simply respond to a manually operated open/close switch. At the other extreme a window may be linked to an IT system with greater computer power than was used in the first moon landing.

Control is a process of using an electrical signal to operate a window, vent, blind or other device. Window and actuator suppliers commonly refer to the interface between the window or façade and a BMS as a control box. However, the control box in this context may not be intelligent. It may simply pass on a signal, albeit that the voltage is changed or that a digital signal is converted to an analogue voltage.

8.1 Simple windows

A simple window is one in which a signal is used to operate the window in response to a manual control. The window requires an actuator and has to be wired to provide a power supply. The window is simple as it responds only to the input signal and gives the same response under all conditions.

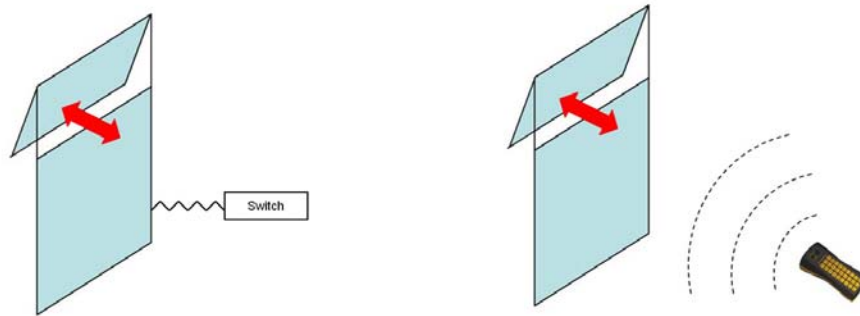


Figure 8.1 Most basic form of control - a simple' window

8.2 Advanced windows

A self-contained advanced window would have sensors and a processor. The control signal output from the processor to the window actuator would depend on the algorithm programmed in the processor and the inputs received from the sensors.

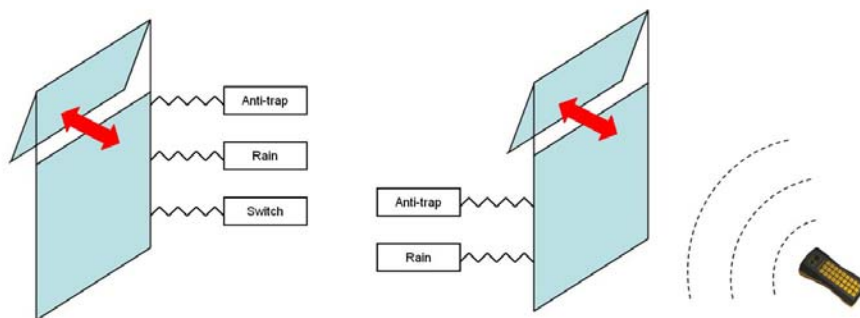


Figure 8.2 Self-contained advanced window'

The most basic sensors incorporated into a window may be an anti-trap sensor or a position sensor or both. In practice all actuators have a position sensor to prevent them continuing to pull or push a vent and burning out, when it is at the extreme range of operation (open or closed). The inclusion of a rain sensor would give additional functionality and a simple algorithm would ensure that the window closed (or did not open) when rain was driving onto the window.

An intelligent control box will receive multiple input signals and process them to give an appropriate control signal. The level of functionality/complexity that can be achieved will depend on the quantity of information that is available and the use of available algorithms. Typically a control box will be used to control a bank of windows in which case only a single rain sensor would be needed with an input to the control box. Most systems currently in use place the intelligence within a control box so that:

- Position signals from the window are passed to the control box to:
 - Prevent overrunning of actuators
 - Prevent entrapment
- A signal from a rain sensor is passed to the control box to limit opening in wet conditions.
- An external signal is passed to the control box indicating the required opening of the window. This may come from:
 - A manual switch
 - A BMS

The control loop for entrapment and position control could be retained in the window. However this would require a micro chip within the window. These are not expensive and the cost may be offset by the cabling saved, particularly if the control signals to the window are carried on a single power supply.

8.3 Intelligent buildings

This raises the question of where the intelligence should be within a control system. Clearly intelligence, data processing, can be sited anywhere in the building, or indeed remotely.

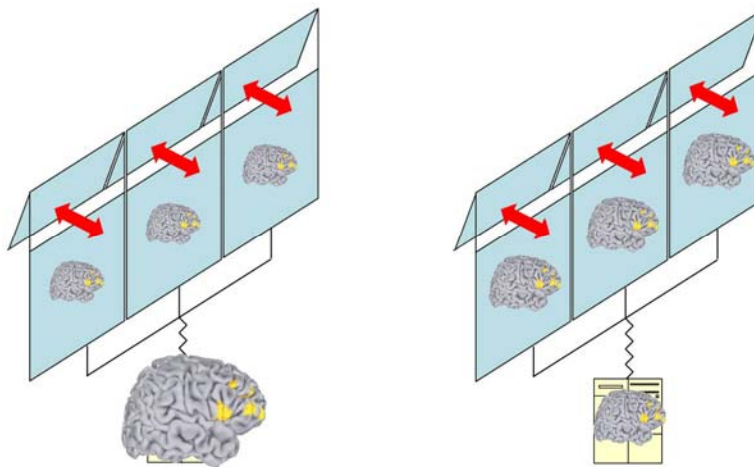


Figure 8.3 Where should the 'intelligence' be?

In general placing the 'intelligence' closer to the window reduces the functionality. For instance, stand-alone windows with separate control will not give adequate control of

cross ventilation and their operation may lead to unacceptable air movement in a room. However, this approach is simple to design, procure and operate.

Placing the intelligence remote from the window will allow the processor to co-ordinate the behaviour of windows, for instance opening windows on only the leeward side of a building. It will also mean that more input signals are available for control of the windows. This approach is complex to design, procure and operate but the added functionality may make this worthwhile.

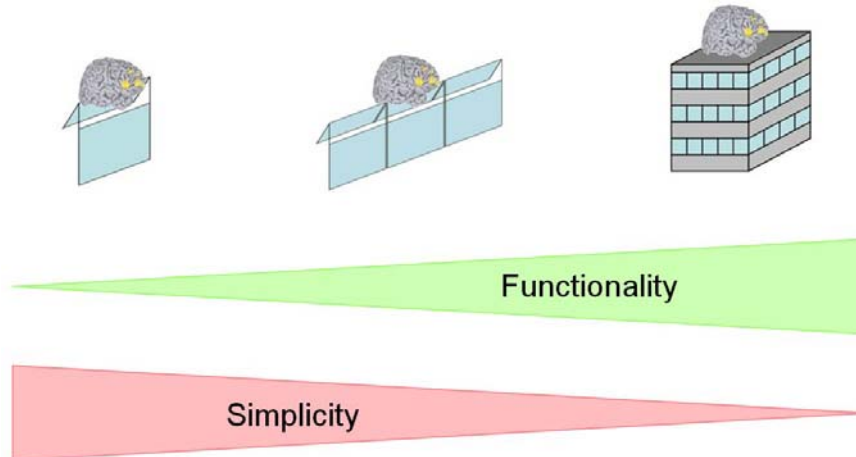


Figure 8.4 Functionality or simplicity

8.4 The need for a control box

It is tempting to think that all of the intelligence can reside within the BMS and that no local control boxes are required, simply cabling and junction boxes.

Even the most basic control of windows is complex. The actuator is commanded to move to a new position but required to stop at the end of its travel or when its movement is impeded, say, by somebody's fingers. This level of control often involves an algorithm that takes account of both position and current drawn by the actuator. Some windows are designed to pull in to a predetermined force and then back off by a very small amount so that gaskets are not over compressed.

This level of control is very specific to each different type and make of component and is best handled within a control box supplied by the actuator supplier. Attempting to include this level of control within a BMS will require early and extensive discussions between the actuator supplier and the BMS contractor. Even then it may not be possible to interface an actuator directly to the BMS.

8.5 Functionality

Functionality can be considered at two levels. The basic functionality is at a component level where functionality may be defined as the ability to give a sufficiently large ventilation opening or to close a blind partially rather than fully closing it.

At the higher level functionality allows useful secondary features such as the ability to close windows when it begins to rain, or not open them if it is already raining. This is clearly a useful secondary function; others may be considered more of a gimmick than a real benefit.

This second tier functionality comes from linking input signals to actuators. Automated façades and BMS systems have to be designed to achieve the required functionality and the intelligence has to be located appropriately within the system so that it has access to the requisite inputs from sensors and outputs to control the necessary actuators.

Functionality	Level of control for ventilation		
	Window	Control box	BMS
Anti-trap	Places the control with the sensor and actuator	Requires more cabling but is the most common practice	Over complicates the BMS and is not necessary
Rain sensor	Requires many sensors and is better input at a higher level	Requires fewer sensors and is simpler than using BMS	Uses even fewer sensors
Internal temperature	Requires many sensors and better to have uniform openings across a zone	Requires fewer sensors and can be used to condition a room	Requires fewer sensors and may be coordinated to heating and cooling systems
External temperature	Requires many sensors and better to have uniform openings across a zone	Requires fewer sensors and can be used to condition a room	Requires fewer sensors and may be coordinated to heating and cooling systems
CO ₂ sensor	Requires many sensors and better to have uniform openings across a zone	Requires fewer sensors and can be used to condition a room	Requires fewer sensors and can be used to condition rooms
Wind speed	Requires many sensors. Allows control of window to limit draughts.	Requires fewer sensors. Allows control of window to limit draughts	Requires even fewer sensors. May be combined with wind direction to control ventilation patterns
Wind direction	Requires many sensors. Will limit opening of window and may deny necessary ventilation.	Requires fewer sensors. Will limit opening of window and may deny necessary ventilation.	Allows the use of alternative ventilation patterns and ventilation scenes. Requires even fewer sensors.
Blind position	Only possible if blind and vent control is integrated within the window which adds complexity of procurement	Only possible if the blind and vent systems use a common control box	Prevents clash of ventilation through blinds that are down
Sun position	No benefit	No benefit	Allows ventilation from the shaded elevation and may be coordinated with blinds

Table 8.1 Appropriate locations for control of a façade

As an example consider linking the operation of a vent to the position of a blind. This has the functional benefit that the window can be kept closed when the blind is down to prevent the wind from causing the blind to rattle. Clearly this level of control can only be located on the window if the blind and vent are wired together at the window, or if a signal from the blind is received remote from the window and sent back to the window. In the first case it is currently unlikely that the blind, vent and their respective actuators will be supplied by the same company or even procured as a single package. In the second case it is simpler to place the intelligence in a control box than transmit the signal from the blind to the window. In practice it is unlikely that a single control box will be used control both the blind and the vent and so the communication between the two will have to reside within the BMS.

Table 8.1 shows the most appropriate locations for control using various sensors. Boxes shaded green are preferred locations, boxes shaded yellow are not preferred and boxes shaded grey give no benefit or are completely inappropriate.

8.6 Simplicity or complexity

The KISS principle, 'Keep It Simple Stupid', is very apt in the design of automated facades. Simplicity is achieved by restricting the intelligence to the window or control box and the result is a less clever building with limited functionality.

The converse of having a wall with a lot of functionality embedded in it will require a more complex solution. This complexity will take several forms:

- Design complexity
- Complex procurement
- Complex commissioning
- Need to train users

All of these may be overcome by planning the process of design, procurement, construction and handover from the outset. A clear statement of the desired functionality should be made early in the design process and this should be used to plan what components are required (vents, blinds, shades and sensors), where signals are routed and where control algorithms reside, responsibilities for specification, supply, installation and commissioning.

Many projects begin with an aspiration of automating the façade but fail to achieve anything other than the simplest of responses (open and closing a bank of windows in response to an internal temperature signal). This arises because budgets are insufficient and early consultation is piecemeal with separate suppliers of components resulting in the selection of components that cannot be integrated or a BMS system that cannot handle the complex algorithms required to give the desired functionality.

At the stage of developing the Client brief, a list of desirable functionality should be drawn up. The desired functionality will be derived from the Client's wishes to have direct control of the building, functionality to ensure comfort, security in response to environmental factors and finally the functionality determined by the façade contractor that is essential to operate the façade. These may be categorised as primary, secondary and necessary functionality. Figure 8.4 a).

These aspects of control can be sensibly re-ordered to recognise where the software has to be located to have access to input the signals necessary to give the required functionality, Figure 8.4 b). Once this has been done strategic decisions can be taken about the overall level of complexity required, integration of the façade with the BMS or IT system and implications for costs, the design process and the procurement process.

Control	Category	Control	Location
Manager commands	Primary	Entrapment	Local Façade Building
Occupant commands		Occupant commands	
Rain	Secondary	Position	
Internal temperature		CO ₂	
Wind (draught)		Rain	
Wind (cross flow)		Internal temperature	
CO ₂		Wind (draught)	
Entrapment	Necessary	Manager commands	
Position		Wind (cross flow)	

a) Functionality desired

b) Processing location

Figure 8.4 Desired functionality and location of processing

8.7 Network based control

A network based control system, as opposed to the traditional centralised control system offers the advantage that the amount of wiring needed is reduced and that the future flexibility of the system is increased.

With centralised control each actuator and sensor is hardwired back to the central controller which can lead to large amounts of cabling being used. This cable will typically be twin core although more complicated multicore controlled actuators exist, with the exact specification dependant on the level of feedback and the number of signals between the two components. Ensuring this cabling is specified, installed and connected properly can be complex.

The method of installing systems has changed with the advent of inexpensive network devices. In contrast to centralised control, a fieldbus system uses local processing at each device. Each device communicates with others on the network, and takes decisions based on the information it receives. With this approach the actuator controllers are soft-wired using the building's IT system. All that is required is a power cable from the controller to the actuator with a digital signal imposed on it.

Once the controllers have been connected to the network they are assigned an IP address and they can then be accessed from the central BMS. This allows a plug and play type arrangement where new controllers can easily be added to the system and immediately communicate with the existing components. Controllers linked in this way are able to make use of components such as room thermostats and weather stations that are already installed as part of the BMS package. This method offers great scope for façade designers to integrate their automated devices with each other and within a building's existing building services. This sharing of information and components makes the automation of buildings cheaper and more efficient.

It is difficult to ensure compatibility between the different components as there is not a standard communications protocol in use. There are a number of fieldbus systems (computer networks) available and each has their own communications protocol. The use of open protocols simplifies matters in this area. This could be a particular issue in

refurbishment projects where new systems have to 'talk' to older systems that are already in place.

The integration of different systems will depend on the individual components being used. Common network protocols include Ethernet, BACnet (Buildings Automation and Control network, developed by ASHRAE), OPC (Open Process Control), EIB (European Installation Bus) and LON (Local Operating Network, developed by Echelon). Depending on the configuration of components different interfaces/connections/integrators would have to be used.

For example BACnet controllers from the BMS and other contractors simply sit on the Ethernet network. Depending on the type used, a gateway may be required in order to provide horizontal integration between the BMS controllers and other BACnet systems.

Integration of LON devices can be more difficult. There is the belief that communication would be straightforward if all systems used LON, however this is not necessarily the case. Whereas BACnet is simply a language protocol, LON is also a hardware standard (ie it has its own drivers). At the specification/tender stage the assumption may be made that because two systems used are both LON, they will straightaway be compatible and nothing else is needed. This is not necessarily the case; a device called a LONC (LON Object Node Controller) may be necessary which essentially takes the readings from the controllers and converts them to a form that the BMS can understand.

The ultimate goal is to have an integrated, 'plug and play' approach such as that of the IT industry. If a common communications language/protocol was used then any automated component could simply be connected to the network whereby it would be automatically recognised and integrated with others in the building.

8.8 Algorithms

An algorithm is a set of rules for the control of a component or group of components. Outputs controlling the components are determined by combinations of inputs received from the sensors.

There are two approaches to where this algorithm may be placed. The first is to have the algorithm placed in the hardware in the form of an embedded microchip. This allows for a simpler control system as the intelligence is placed in the window, shading device or local control box. This is suitable for simple local control in response to local signals. It is also suitable for components connected to a system in a plug and play approach – additional actuators can be added to the building at a later date without having to modify the central control system. The flexibility of such systems raises concerns however as there may not be scope for changing the algorithm of an installed component if required.

The second approach is software, as opposed to hardware-based. Here the algorithm is coded in the controller or BMS. This method requires a window controller or BMS with a greater processing capacity, however this can be simplified by using localised controllers as opposed to a single central control system. The advantage of this way of controlling automated components is the ability to re-programme the algorithm if the control of the internal conditions is not adequate or if the requirements of the building change.

9 DESIGN, PROCUREMENT, CONSTRUCTION AND COMMISSIONING

When designing, procuring and constructing automated facades it is necessary to recognise the need for:

- Involvement of knowledgeable people in all roles
- Appropriate early decision making
- Designing with a knowledge of what is possible
- Planning the procurement process concurrently with designing the building
- A supply chain that recognises the need for components to be compatible with:
 - Each other
 - The system as a whole
 - The anticipated performance of the façade and the building

This section looks at the different approaches to design, procurement and construction and describes the prerequisites to achieving a façade that meets the project requirements.

The successful design of a building with automated facades requires concurrent decision making by a wide range of parties. It is essential at the outset to plane the decision making process, to assign responsibilities for different activities and show all of the parties to be involved at each stage.

Schedules are included in this Section showing the activities and participants at each stage of the process. The matrix given is not exhaustive and a project specific matrix should be prepared. The responsibilities assigned to different parties will depend on the form of contract adopted (traditional, design build and so on). The parties involved in a project will vary depending on whether independent consultants are employed or a specialist contractor is appointed early enough to make a consultancy input. This is particularly the case for façade and BMS contractors. The sequence and timing of decision making may be varied from that shown but it should be recognised that deferring decision making or involving fewer parties at any stage will increase the risk of: cost over runs, programme over runs and failure to deliver the required functionality.

9.1 Pre design decision making

It is essential to establish the Client's brief prior to concept design. Increasingly the Client will employ M&E consultants and façade consultants as Client advisers.

The Client brief should describe the intention for servicing of the building in terms of ventilation and cooling technologies to be adopted. This requires definition of activities and occupancy densities, or requirements for flexibility of use. The Client brief will also contain requirements for BMS and IT provision within the building.

At this stage the Client and their advisers have to develop a functionality wish list for the performance of the building and interactivity between the different components. Depending on the level of functionality requested decisions will be made on the degree of interactivity required between the many systems within the building and the best strategy for either providing stand-alone control or some degree of integration of the façade control with the BMS and IT systems. Table 9.1 shows the early decision making activities and the participants' roles.

At this stage the Client advisers should be discussing with the Client what is possible, who may be the suppliers and implications for the procurement process. Table 9.1 shows the parties that should be involved at this stage and the decisions that have to be made.

	Client	Client M&E adviser	Client façade adviser	Architect	M&E consultant	Façade consultant	Façade contractor	Shading contractor (external)	Shading contractor (internal)	BMS contractor	Electrical contractor	Main contractor
Pre-design stage												
Agree ventilation technology	X	X	X									
Agree shading technology	X	X	X									
Discuss required functionality	X	X	X									
Check feasibility		X	X									
Discuss costs	X	X	X									
Agree revised functionality	X	X	X									
Develop Client's brief	X	X	X	X								
Appoint Architect	X			X								
Appoint façade consultant	X			X		X						
Appoint M&E consultant	X			X	X							
<i>Appoint façade contractor</i>	X	X	X				X					
<i>Appoint electrical contractor</i>	X	X	X								X	

Table 9.1 Pre-design activities and participants

	Client	Client M&E adviser	Client façade adviser	Architect	M&E consultant	Façade consultant	Façade contractor	Shading contractor (external)	Shading contractor (internal)	BMS contractor	Electrical contractor	Main contractor
Concept design stage												
Agree Client brief	X											
Agree building geometry	X			X	X	X						
Agree façade geometry	X			X	X	X						
Agree ventilation strategy				X	X	X						
Agree shading requirements				X	X	X		X	X			
Develop BMS strategy				X	X	X		X	X	X		
CFD analysis for ventilation settings				X	X							
Shading studies				X	X							
Confirm feasibility				X	X	X		X	X			
Develop performance specification for vents				X	X	X	X					
Develop performance specification for shading				X	X	X	X	X	X			
Develop performance specification for BMS				X	X	X				X		

Table 9.2 Concept design activities and participants

The client and design team should not be tempted to do things simply because they can be done. Conversely the architect and building physicist should establish the minimum functionality required to condition the internal space. Automated facades are more expensive than manually controlled facades. Costs comprise the cost of the components, design and integration costs, costs of cabling and installation. It has to be recognised that the added functionality and complexity comes at a cost.

9.2 Design

9.2.1 Concept design

The required functionality should have been defined in the Client's brief. The greater the complexity required of the façade and the more deeply the control of the façade is embedded in the BMS the more important it is for the design to be integrated from an early stage. Table 9.2 shows the scope of activities at the concept design stage and the likely participants.

The use of automated facades is principally associated with the control of ventilation and shading. These are fundamental aspects of building design and have to be considered from the outset of the building design process. Naturally ventilated buildings have geometries developed with floor plates and elevations that allow cross ventilation and stack effects. The position of windows, rooflights, overhangs and external shading devices are the primary determinant of solar gain, shading and light levels.

It is crucial that building services engineers, preferably building physicists, are involved in the early concept design of a building. General guidance on natural ventilated buildings is available in CIBSE (2005). Guidance on shading is available in Littlefair (1996, 1999).

Similarly the façade contractor or a façade engineer should be involved at an early stage. A simple example of this might be that the consulting engineer has modelled the building based on an assumption about the size and configuration of the windows. A design would be established, and that design could rely on a window opening of say 300 mm in order to provide the required free area for cooling; however when it comes to finding a suitable window the maximum achievable opening distance might be only 100 mm. This would mean that the design and all the calculations that go with it would have to be redone with huge cost implications, both in terms of time and money. In fact it may not be possible to achieve the required ventilation with the proposed façade layout and windows may have to be placed differently within the façade, for instance at greater height.

It is often necessary to adopt a flatter hierarchy than normal when seeking advice at the concept design stage. Traditionally the architect will involve a façade contractor or consultant and an M&E consultant early in the design process, although normally not early enough, Figure 9.1. They will in turn seek advice from the actuator supplier and BMS contractor but the actuator supplier and BMS contractor are unlikely to talk to each other under this arrangement.

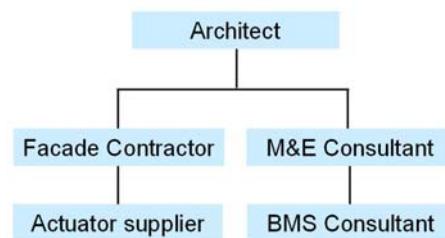


Figure 9.1 Traditional approach to concept design

A better approach is the flatter structure shown in Figure 9.2 where the actuator supplier and BMS contractor are involved simultaneously in early discussions about what is achievable and how both the technical aspects and procurement of the system should be planned. This approach allows concurrent design of the different components and systems, a practice adopted in many other industries.

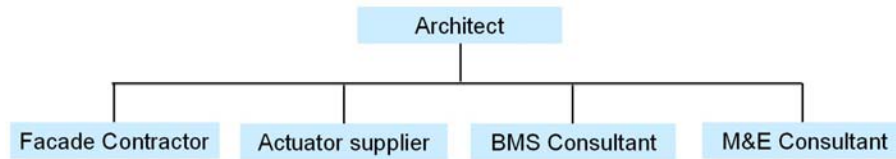


Figure 9.2 Improved approach to concept design

When there is to be a BMS, it is important that BMS contractors are involved in projects early on in a consultancy role. This is the only way to bring to the project the specific knowledge required to put together a suitable specification. M&E consultants do not always fully understand everything involved with the specification of the BMS and these close relationships are vital at the time the building services concept design is undertaken.

Many of the potential pitfalls in the packaging of the different automated façade components can be avoided or their impact minimised if main contractors, specifiers, consultants and design teams are more aware of them at this early stage in the project. A lot of information is required at an early stage in the design, and getting this information to the right people at the right time is the key to a successful project. By addressing the issues at this stage not only are the risks of problem occurring during construction minimised (compatibility and communication amongst others) but also those during operation when the building is occupied. The difference between best practice and typical practice in this respect is very large with some architectural practices well experienced in the design of automated facades and others still learning.

9.3 Procurement

Appropriate procurement of components, construction packages and their associated design is essential for the realisation of a successful automated façade. The activities required within the procurement process, and the participants in each activity, are shown in Table 9.3

A feature of procuring automated façades is that the different component parts of the system are often chosen and supplied by different contractors. It is important that the technical and functional design of the system is not carried out in isolation of the procurement process. The procurement process should be planned concurrently with the functional design. This should mean that the procurement process is capable of supplying the level of complexity required with an adequate assurance that the system will work as intended once assembled. The converse of this is that if the procurement process is considered separately from the design the use of multiple suppliers and late appointment of contractors may limit the functionality that can be achieved with reasonable confidence.

Procurement is based on packages of work that are supplied by a single specialist contractor or a specialist contractor and sub-contractors. Appropriate packaging of work is essential if different elements of the automated façade are to be compatible and work as a system.

The most common practice is that the actuators are placed in the façade package and the controls are placed in the M&E package. If there is a BMS in the building this will usually be part of the M&E package.

Automated façade control

	Client	Client M&E adviser	Client façade adviser	Architect	M&E consultant	Façade consultant	Façade contractor	Shading contractor (external)	Shading contractor (internal)	BMS contractor	Electrical contractor	Main contractor
Procurement												
Short list contractors	X			X	X	X	X	X	X	X	X	X
Agree extent of façade work				X	X	X	X					X
Agree façade system				X	X	X	X					
Agree BMS protocols and software				X	X	X	X	X	X	X		
Agree interfaces with IT system				X	X	X	X	X	X	X		
Agree vent actuator supplier				X	X	X	X					
Agree shading system				X	X	X		X	X			
Agree shade actuator supplier				X	X	X		X	X			
Agree design responsibility				X	X	X	X	X	X	X	X	X
Appoint contractors	X			X	X	X	X	X	X	X	X	X

Table 9.3 Procurement activities and participants

An unfortunate consequence of packaging work in this way is that the need for control boxes may be overlooked altogether. There is a misconception within the industry that window actuators are straightforward to control and can therefore be left to the BMS contractor to operate. Whilst this is possible it is common for BMS companies to underestimate exactly what is required in order to properly control an automated façade.

A further feature of packaging work in this way is that the co-ordination required between the actuator supplier and the BMS contractor is easily lost. There is no contractual link between the two suppliers and it is for the main contractor to ensure that a co-ordinated approach is taken. Most main contractors, even those with experience of procuring automated windows do not realise the importance of co-ordinating these two packages. Ultimately if there is little or no co-ordination the project will only be completed by fire fighting problems as they occur and may never fully deliver the anticipated performance. The best approach is for the actuators and controllers both to be packaged with the main contractor, rather than being unconnected items in separate packages; however, whilst this does happen, it is far from common practice.

There are several procurement models that have been used with varying degrees of success:

- 1 The window supplier may receive actuators from the actuator supplier and pass completed automated windows to the façade contractor, in which case the window supplier has to communicate with the BMS contractor to ensure compatibility of the actuators and the BMS, Figure 9.4.

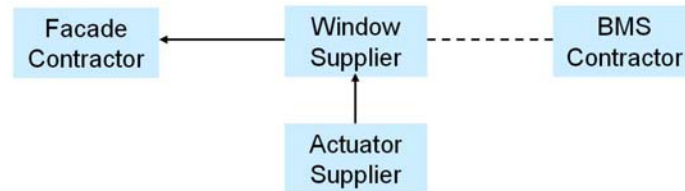


Figure 9.4 Window supplier as integrator

- 2 The actuator supplier may supply actuators directly to the façade contractor, in which case the actuator supplier has to communicate with the window supplier to ensure compatibility with the window frame and operation, and with the BMS contractor to ensure compatibility with the BMS, Figure 9.5.

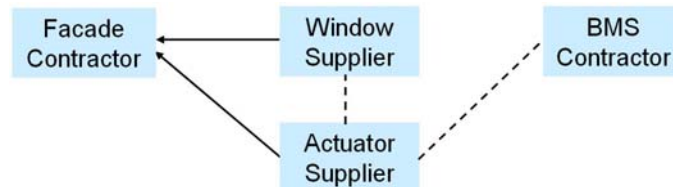


Figure 9.5 Façade contractor as integrator

- 3 The actuator supplier may be contracted by the main contractor to fit the actuators at site, in which case the actuator supplier has to communicate with the window supplier to ensure compatibility with the window frame and operation, and with the BMS contractor to ensure compatibility with the BMS, Figure 9.6.

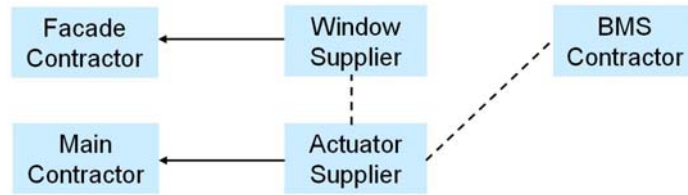


Figure 9.6 Main contractor as integrator

The benefits and disadvantages of these different approaches to procurement are described below:

If the components are in different packages then the specification becomes crucial. If the specification for the automated system is sufficiently detailed then co-ordination will follow; however the specification of such products is another area of weakness. Good specification ties in the controls to the actuators and therefore will ensure that suitable, compatible products are used, even if they are provided by more than one contractor. A more detailed specification would for instance say 'the window should open 300 mm and only draw a current of 1A'. This would require the actuator supplier to think more about their choice of product and improve the system as a whole. However, it requires better communication at the concept design stage to ensure that a specification appropriate to the design aim is achieved.

The best approach is for the actuator supplier to fit the actuator to the window. There are many different ways to fit actuators to windows depending on the type, the opening requirements, switching arrangement and requirements for multipoint locking amongst others, which the actuator supplier will understand better. For this to occur there obviously has to be co-ordination between the façade/window contractor and the actuator contractor.

The compatibility between actuators and controls may be ensured by including them in a single package but this may create further problems. If the actuators are included in the M&E package there are no direct contractual relationships between the actuator suppliers and window suppliers involved, making this procedure potentially more complicated. Due to their mounting on the windows, the actuators have to be part of the façade package but if they are in the façade package the façade contractor is also responsible for the controls, which is not an area where they have a great deal of knowledge or experience.

The general outcome is that because of packaging the different components inappropriately, and the vagueness of many specifications, it is difficult for the façade contractor to make properly informed decisions regarding which components to use. Typically the façade contractor will then put forward a proposal listing some products that could be used and leave responsibility for actually selecting the actuator to somebody else.

Some window system suppliers have developed automated suites of windows that include the actuator as part of the window package. This has obvious advantages in terms of compatibility and single product sourcing and so has the potential to make the job of the façade contractor simpler when it comes to selecting products. However, these are specific products and may not meet the requirements of a good specification or be too costly when compared with product permitted by an inadequate specification. Early involvement of the façade contractor can help in specifying suited systems of windows and actuators; however, the client and architect have to be aware of the advantage of these products if the premium price is to be paid. Main contractors will often try and remove these more expensive branded components unless they are clearly specified.

There are other considerations when procuring the components within different contract packages. For example the overall sophistication of a system will depend upon both the

motors and the controls used, but due to the different procurement routes these decisions might not be made at the same time. Similarly the system may have been designed with a particular control supplier in mind but the contract may be awarded to a different contractor and because of this the system, once installed, may not perform to its full potential. In one case the compatibility between the controls and the actuators had been considered during the initial design of the automated system, however there were still problems as the choice of controls was changed late on (after the actuators had been ordered and fitted), as a result when everything was connected together the motors would not communicate with the control system.

With these issues in mind maybe a better procurement route would be to specify the whole automated façade package together instead of the windows and motors being in the façade contract and the power supplies and controls systems being in the M&E package. In theory this might offer a more complete and co-ordinated product, but the reality is not as straightforward as that. The knowledge and expertise required for each element are very different as are the supply chains, the regulations, the installation and co-ordination of other trades, so trying to provide the two systems as a complete package can be very difficult.

There are certain steps that the different contractors can take in order to try and ensure compatibility of products. For example, if the actuators and controls are being sourced separately the façade/window contractor could issue an operation specification so that the company responsible for the controls knows exactly what has been fitted and how they should be powered and operated. As there are no contractual links between the two suppliers this information would be passed to the main contractor and it would be their responsibility to pass it on to the appropriate company. This step may occur before the actuators have been procured, so that approval can be gained thereby absolving the façade contractor of responsibility if there are subsequent compatibility issues. However even if this does happen there is no guarantee that the information will be passed to the correct person and so problems may still occur.

9.3.1 Cabling

One of the most difficult responsibilities to establish is who carries out the cabling from the window to the control box. Cabling for local controllers is generally quite easy as short cable lengths are required and it would often just be a case of running the cable down/within the window frame or within the wall to the control panel under the floor or in a ceiling void.

It is however more difficult if the controller is not local, for example if it is in a plant room, as the distance between the window and control box will affect the specification of the cable. This is because typically the actuators used to open and close the windows are low voltage, 24V components. It is critical that these components receive the correct voltage, and with the lower values involved there is less margin for error than there would be with 230V actuators. The further the control panel is from the actuator the larger the voltage drop will be. The linear distance from the control panel to the window is required, as this will take into account the positions of the controller and window and the route that the cable has to take, so that the appropriate voltage drop calculation can be carried out.

There are two approaches to who selects the appropriate cable. The first approach is to say that because there is the need to provide certain voltages to components it is the responsibility of the actuator supplier to specify this cable. They will know the input voltage required by their actuator and the output voltage supplied from the control box and given the linear distance between the two, can size the cable accordingly. This method relies on knowing where the control boxes are going to be in the building, which might not have been decided when the information is required by the actuator supplier. This approach gives the main contractor the advantage that there is a single point responsibility for correctly cabling to the actuators.

There is a counter argument saying that the actuator supplier would not have the detailed knowledge of the building that the M&E contractor has. For example they would need the

full plans and ducting routes from the control box to the window. This would not be available at the tender stage, making it impossible to give an accurate quote for the job and the actuator supplier would not know what other cabling has to run in the duct route (230V power, network cables etc) that might cause interferences (actuators generally run on 24V).

The alternative approach is to leave the selection of the cabling to the electrical contractor. This method can be appropriate because at the time the actuator supplier requires all the information on which to base their selection, decisions on where the controls are to be placed might not have been made. Therefore the actuator supplier would give the current required by the actuator and the electric contractor would specify the cabling. The electrical contractor would then be responsible for calculating the distances of cables and voltage drops so that the correct type of cable is installed.

9.4 Detailed design

Detail design involves:

- Detailing the façade
- Selecting actuators
- Developing the BMS
 - Selection of sensors
 - Positioning of sensors
 - Writing algorithms
 -
 -
- Detailing cabling

The scope of work required at the detailed design stage is shown in Table 9.4 along with the participation required in each activity.

Façade detailing and M&E detailing will be undertaken by separate specialist contractors but both will need to exchange information with the actuator supplier.

It is only at this stage that what is actually possible is finally established. It is to be hoped that design up to this stage has been undertaken in the knowledge of what is possible and in consultation with contractors and suppliers.

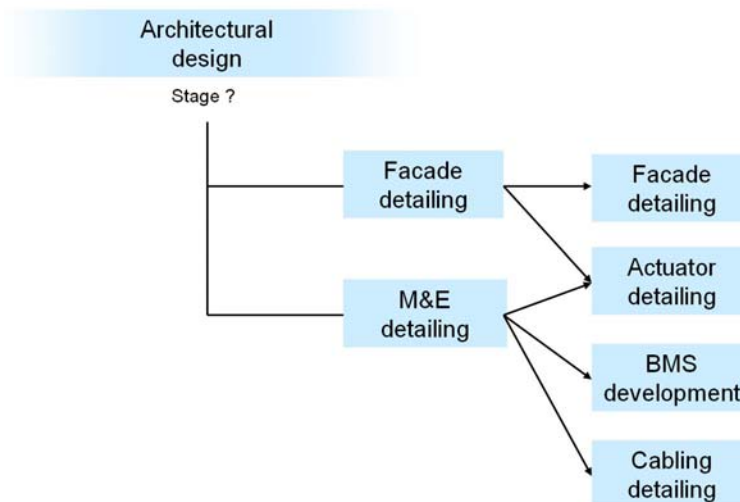


Figure 9.7 Approach to detailed design

It is at this stage that the type and size of the actuators is finally reconciled with the size of the windows and the required aperture. Concealing actuators is generally more difficult and more costly (through increased labour and potentially having to use a larger frame than necessary in order to fit the actuator inside). Current narrow frames (50 to 60mm) make this very difficult, especially if the opening distances are large. If the opening distance is small the actuator can be smaller so there is greater possibility that it can be concealed.

Cable routing and sizing, and the location of control boxes is finally decided at this stage. It is now that the implications of frame selection and the ability to conceal cabling become apparent.

'Value engineering' at this stage may reduce the number of sensors and require rewriting of algorithms

9.4.1 Costs

However, the cost should not be greater than necessary. Early collaboration and holistic design will prevent unnecessary expense which might arise from: the need to make bespoke brackets to attach actuators to windows, the need for larger power supplies to drive inappropriately specified actuators and the need to make bespoke interface boxes that condition or interpret incompatible signals.

For example, the choice of controllers is usually the responsibility of the M&E contractor who will have a responsibility to drive the window via the BMS. Economical actuators that draw a high current may require controllers with higher power output which are more expensive.

9.5 Construction

9.5.1 Installation of automated components

The installation of automated opening lights is generally no more complicated or different from installing manually opening windows. The nature and degree of any complication will depend on the particular project and the parties involved.

The main contractor will be co-ordinating the work of the façade contractor, M&E contractor and BMS contractor, Figure 9.7. The BMS contractor may work directly for the main contractor or be a sub-contractor to the M&E contractor.

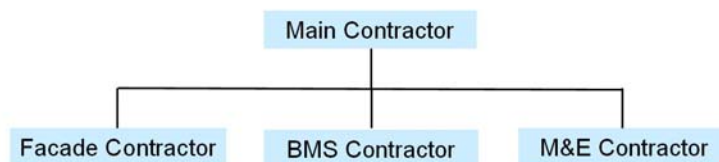


Figure 9.8 Responsibility for installation

The work of the specialist sub-contractors has to be co-ordinated and this may be achieved by the main contractor acting as co-ordinator and passing information between the specialist contractors. Rather than simply acting as postmen the main contractor should be proactive in the role of co-ordinator. A better model is that of the main contractor as facilitator promoting the exchange of information between the specialist contractors, Figure 9.8. If this arrangement is to work well it is necessary to specify that the specialist contractors will exchange information in this way.



Figure 9.9 Required communications

Actuators may either be fitted in the factory or on site, with factory-fitting the preferred method due to the tighter control of workmanship. Actuators can either be concealed within the frame or surface-mounted and there are advantages and disadvantages associated with each. Concealed actuators will be fitted in the factory. Then they have to be transported to site so have to be adequately protected to avoid damage in transit and when on site. They take up more space when fitted at the factory (eg the windows can no longer be stacked). They will usually have to be checked and tested again once the windows have been installed. Surface mounted actuators can be fitted on site; however the window frames may be pre-drilled, etc. during the fabrication process. If site fixing, it is important not to do this too early as damage could easily occur from water and other trades. Warranties may also be invalidated.

Some companies supply complete automated windows. In most such cases installers approved by the fabricator will carry out the installation. The list of approved installers might depend on the size and complexity of the façade. Suppliers of such systems will usually provide training to installers who have an interest, or who are required to know about these products.

	Client	Client M&E adviser	Client façade adviser	Architect	M&E consultant	Façade consultant	Façade contractor	Shading contractor (external)	Shading contractor (internal)	BMS contractor	Electrical contractor	Main contractor
Detailed design stage												
Agree communication protocols					X		X	X	X	X	X	X
Select façade system				X		X	X					
Select actuators				X		X	X	X	X	X	X	
Select external shading system				X		X	X	X				
Select internal shading devices				X		X	X		X			
Detail physical interfaces							X	X	X			X
Detail communication interfaces							X	X	X	X	X	
Write algorithms				X	X							
Write BMS software					X		X	X	X	X		
Write IT software					X		X	X	X	X		
Develop procedures for commissioning							X	X	X	X	X	X
Confirm design	X			X	X	X	X	X	X	X	X	X

Table 9.4 Detailed design activities and participants

	Client	Client M&E adviser	Client façade adviser	Architect	M&E consultant	Façade consultant	Façade contractor	Shading contractor (external)	Shading contractor (internal)	BMS contractor	Electrical contractor	Main contractor
Construction												
Define responsibilities and scope of work packages					X	X	X	X	X	X	X	X
Agree programme of work							X	X	X	X	X	X
Develop method statements							X	X	X	X	X	X
Develop system commissioning procedures					X		X	X	X	X	X	X
Agree method statements							X	X	X	X	X	X
Agree QA procedures							X	X	X	X	X	X
Agree procedures for handover of components and assemblies							X	X	X	X	X	X

Table 9.4 Detailed design activities and participants

The skills required to install automated windows are greater than those required simply to install window. Window installers are not trained and certified electricians. When installing windows it is possible for the window installer to fix the window in place and leave the factory fitted cable available to the electricians who follow. With more complex construction such as curtain walling it may be necessary to arrange for curtain wall installers and electricians to work alongside each other.

9.5.2 Cable installation

It is particularly important that cables running into the control box should be clearly labelled because of the number and diversity of companies involved in installation. If this does not take place serious delays can ensue. Examples are known where this has not happened and the window supplier has had to spend a number of weeks establishing exactly which cable is linked to which actuator. Similarly if cables are labelled incorrectly then there is little choice but to test each individual cable to determine what it operates.

Cabling may be damaged after installation. There are reports that during the attachment of skirting boards and plasterboard screws and nails have pierced the cables behind. The fact that there are electrical components and cables within the window frames and cables running through the adjacent walls should be made known to all the trades who will subsequently work on the building.

There are reports that concealed actuators have been damaged by fixings that have been screwed directly into window frames. It should be made clear to other contractors that there are actuators present within the frames, may be by the use of stickers or labels attached to the windows in question.

It is a good practice for whoever installs the actuators to test each motor during installation because of the possibility of subsequent damage. If there is a problem at a later date, the installer has a record showing that the installation was satisfactory.

9.6 Commissioning

The commissioning process should start with the design of the BMS and other automated systems. At the outset the design itself should be commissioned as it is important to show that the design is commissionable and operational. A large part of the success of an automated façade may be attributed to how easy it is to actually commission and operate it.

The time required for the separate sub-contractors to commission their systems should be established during the pre-contract stage of the project. Failure to do this and hold to the proposed schedule is a major cause of frustration on projects. It is easy to underestimate the time required to commission an automated façade and BMS and insufficient time and resources are allowed for this important stage of the work.

There is much to be gained from working together during the commissioning process, although the extent of any collaboration will depend on what is written in the specification and the actual construction programme.

BMS contractors are still learning to work with window companies. They are more experienced at working with boiler and chiller manufacturers and are establishing similar relationships with window suppliers. The extent to which the BMS and window contractors have to work together will depend on the level of integration there is between the two systems.

The commissioning process will run more smoothly if it is already proven that the different components of the system and the cabling will work together. It may be that a similar system has been installed elsewhere. It is possible to show that components are compatible by constructing a very simple system on a work bench prior to installation.

The initial commissioning process is conducted with the building unoccupied at a particular time of year. Estimates will have been made for the heat gains that will occur and the efficiency of the ventilation, however these might not be accurate, and it is subsequently necessary to optimise the settings of control systems, and sometimes the algorithms that drive them. Commissioning is therefore a multi-stage process that continues after handover. There should be money available in the project for this to happen all the time.

9.6.1 Integration

An important factor for the BMS contractor is where their system is going to reside in the building and what it is going to control. If the BMS is part of a fully integrated IT system often there will be an IT contractor at the top of the chain managing the commissioning of all the different packages (security, fire, CCTV, BMS, automated windows etc) as ultimately they are connecting to the same network. For a stand-alone BMS the BMS contractor will take the lead role in the commissioning process. Each contractor will then be responsible for cooperating with the lead commissioning contractor and make information available as necessary.

The compatibility of components may be overlooked because of build programmes and time constraints, and only come to light during the commissioning process. It takes experienced engineers, who fully understand the integration between different systems to identify problems and deal with them before the commissioning stage. Problems of compatibility discovered at the commissioning stage are not easy to rectify.

9.6.2 Scheduling

There will often have been delays and problems with other aspects of the project and therefore the time left between completion of all the building works and the handover of the building will be reduced. The commissioning then has to be squeezed into the remaining time, which is not ideal, especially if difficulties arise.

The first stage of the commissioning process should start during the installation of the window actuators. The installer should check the operation of the motor during the installation. By doing this the installer and actuator supplier are protecting themselves against any problems that may occur later when the actuator is connected to the controller and to the BMS. For the case of a window company supplying an automated window, this might be all they have to do in order to commission their part of the system.

If a stand-alone window control system is being provided then the contractor responsible will carry out the final termination of all the relevant wiring commission the system itself. This would involve testing every window to ensure they function as they should, by inputting different signals into the system.

With the limited time usually allowed for commissioning the fact that the controls contractor may have to make an additional visit to site to commission and make final checks can also be problematic. These companies do not have unlimited resources and have to plan their time carefully. If it is not possible to commission a project at the scheduled time there is no guarantee that the contractor will be able return at a particular time in order to carry this out.

There are usually at least three different sub-contractors that have a part to play in the commissioning of automated/BMS controlled windows. Best practice is for the process to be co-ordinated so that all are on site at the same time which can facilitate the immediate resolution of many problems without the need for further visits. Usually it is the individual sub-contractors who drive the commissioning process and co-ordinate it between themselves although there are no contractual links between them. It is better for the main contractor to co-ordinate the commissioning process and require all of the sub-contractors to be present during the commissioning.

Problems in commissioning certain areas of the building will not necessarily prevent the handover of the building. If any of the inoperable components are smoke vents then the building cannot be completed as they are a legal requirement. If the inoperable windows are solely for natural ventilation then the building could be handed over as there will usually be manually openable windows in the rooms as well as automated ones.

Commissioning often has to take place whilst the building is still under a temporary power supply. When the power is being switched on and off it is difficult for commissioning, especially if any programming is being carried out on site. If the commissioning is carried out under temporary power, the window controls contractor will usually have to go back to site and check the installation again once permanent power has been established.

9.6.3 The main contractor's role

The main contractor should be responsible for co-ordinating all the testing and commissioning as ultimately it is their responsibility to ensure that all the systems in the building work correctly when handed over.

The actual commissioning of each system is the responsibility of the individual specialist contractors. Sometimes the client will employ a commissioning engineer to oversee what is happening, although they would have no direct role in any of the testing.

Main contractors are now realising the complexity of the commissioning process and the way in which the building can be commissioned is considered at the outset. The commissioning may now be a separate package, specialists may be employed, and commissioning managers may be used to ensure the process runs smoothly.

9.6.4 The roles of the specialist contractors

The roles of the controls and actuator contractors will depend on exactly how the system has been packaged and exactly what they have provided. It may range from simply showing that the actuators work in isolation to proving that the whole automated system works as it should. The division of the different packages can lead to problems in the commissioning process as responsibilities and demarcations are not always clear.

To ensure that everything has been completed, the controls contractor will sometimes issue a checklist to the main contractor detailing everything that is required in order for the windows to be commissioned. For example the fire and BMS systems must be completed, all other trades must be clear of the windows and the building must be under permanent power.

9.7 Specification

Ensuring that the specification for any automated system is correct and sufficiently detailed is a key step to successful procurement. There are many different elements involved in these systems and it is vital that they all work together in order to fulfil the design brief.

A performance specification will be derived from the Client's brief and the design stages. However, far more detailed specification is required to procure the components and cabling of an automated façade. The specification passed to each supplier or specialist contractor has to be sufficiently detailed to ensure the compatibility of components and their operability within a system. Issues arising from the preparation of detailed specifications are described below.

There is currently no single agreed approach to the specification of automated systems, and projects may get into difficulty through misunderstanding of what is required or making the wrong assumptions about what is required. There is a misconception within the industry that window actuators are simple and straightforward to control, however this

is not the case and unless the actuators and their operation is specified there will always be the opportunity for mistakes to be made and problems to occur.

A typical procedure for the specification of a window actuator might be as follows: The architect or consultant might input the variables of the building into a CFD package and from that they may determine the free opening area required to provide the necessary cooling. The specification to the window/façade contractor might then simply read automate the window via the BMS and open it 300 mm. Given the choice of potential actuators and controls, this is not an adequate specification and it will probably lead to problems with the design, more attention to detail at this stage will lead to a smoother design, procurement, construction and commissioning of the building.

The reasons a simple specification such as this may cause problems are:

- It takes no account of appearance
- Components have different fineness of control
- Some actuators are noisier than others
- The interface with the BMS is not defined.

There are many different configurations of products that could be used to open a window 300 mm and from the window contractor's point of view, they will usually only be concerned with the supply of the window actuator. Their primary concern will be compatibility of the window frame and actuator and the cost of the actuator. They may have no interest or concern with the automated system as a whole.

Cheaper actuators generally perform less well than more expensive ones. They are likely to make more noise, have only open and closed settings, be less reliable and draw a larger current. Cheaper actuators may cost only half the price of better actuators but there are very large differences in performance.

Generally projects that run smoothly are those on which the consultant has spoken to BMS and natural ventilation specialists at an early stage and subsequently produced an effective and achievable specification. It is beneficial for BMS contractors to develop relationships with M&E consultants to enable constructive discussions on projects. The smaller systems houses often ignore these relationships as they tend to work more closely with the M&E contractors. M&E consultants should establish relationships with BMS consultants and seek help and advice with specification when it is required.

9.7.1 System specification

Best practise is to specify that the control box and the actuators together and this may have both commercial and practical benefits. As well as the commercial benefit from providing a better value of contract, there are many practical advantages in splitting the packages in this way. The main advantage is that this will ensure compatibility between components. Having a single contractor to carry out this work also means that there is a single company responsible for dealing with any problems that arise when integrating the components into the system. It is convenient to test the signals for the BMS, fire alarm and power supply at the control box, so once it is established that these are working there is a single contractor responsible for ensuring the windows operate as they should.

A further area where specifications can fall down is by omitting the control boxes. In this instance it is often left to the BMS contractor to control the windows, which can result in the use of non-certified (not CE marked) products that do not have all the features required to control the windows. Poor specification can lead to non-specialist companies under-estimating what is required to operate a window actuator effectively.

When specifying it is important to distinguish whether an opening light has a smoke control requirement. SHEVS (smoke and heat exhaust ventilation systems) must be approved to BS EN 12101-2, which is a system-based solution, ie everything associated with the window (motors, cables etc) is tested as a complete system. These

requirements can be met by having a specialist partner company who is responsible for all the wiring and connections associated with the vent.

9.7.2 Façade specification

A typical specification for the façade contractor might simply read 'automatic control' and nothing else. A vague specification such as this has the potential to create many problems with the overall system. Details regarding the type of controls that are to be used, the power supply (24V DC or 230V AC), the opening distance required and the length of cable needed are all factors that will influence the choices made.

A further complication for the façade contractor is that often they will be asked to tender for a project while the specification is still being developed. It is therefore impossible for them to know exactly what is required and price accordingly. Even if all the information is available it can be hidden away in other parts of the specification, for instance, in the small power requirements.

9.7.3 Specification of controls and actuators

If a single contractor is responsible for providing the complete system of windows, actuators, cabling and control then the specification may be very much a performance specification with the detailed design left to that contractor. Usually the different elements are let as separate sub-contracts without either specifying in detail or checking that the separate contractors are capable of working together and that their components are capable of integration on the building.

From the controls and actuator contractor's point of view, the depth of specification is still poor with regards to actuator selection. There are many factors to be considered when selecting appropriate components. These include power supply voltage and current, cost, size, and load capacity amongst others. However this level of detailed information is not usually included in any specification.

9.7.4 Specification of the BMS

An appropriate specification is important not only in terms of overall performance but also in terms of cost. There may be a number of ways of achieving the same result, but the costs involved in doing that may be very different. A BMS specialist will be able to ensure that the most suitable method is specified.

Some projects are very loosely specified which makes it difficult for BMS and M&E contractors to interpret the real project requirements. Obviously the BMS contractor will want to win the job so will always tender to the minimum plausible requirements if they are quoting to the M&E contractor. If there is any ambiguity in the specification cheaper controls and components are likely to be used which could affect the performance of the building. This ambiguity in specifications may arise because the consultant does not have the necessary knowledge or has not spoken to a BMS specialist. Another possible reason for ambiguous specifications could be that the consultant is worried that if the specification is too tight and the building does not function properly then all the blame will fall on them. This worry could be removed by involving the correct people at each stage of design and specification.

9.7.5 Specification of the cabling

Issues can arise where the purpose of the window has not been identified - is the window being connected is for ventilation purposes or is it a smoke/fire window? This can be especially true if there are many automated opening vents in the building. The choice of cabling changes between standard PVC coated or silicone coated depending on whether it has to be fire-rated, and there is a huge difference in the cost of the cables.

The required information is not always available early enough (often not in tender documents), and therefore it is very important to establish exactly what is required as early as possible. This is particularly important for some windows systems where the

motor is fitted with either standard or fire-rated cable in the factory during fabrication. The information will be required when the window is ordered, and it is vital that the correct part is fitted.

If these distinctions are not properly established before installation and it is found that the incorrect cabling has been fitted, especially if standard cable has been used instead of a fire-rated type, then it will have to be removed and replaced with the correct type. This will be both very costly and time consuming for the contractor responsible for the mistake.

10 EDUCATION, MONITORING AND MAINTENANCE

10.1 Education

There is a need to train the occupants of a building (and the facilities managers who will be running them) so that they appreciate what is happening in the building and therefore get the best out of the system. An example of this could be explaining why the windows might close during a hot day in order to keep the heat out and the building cooler, with the aim of reducing the manual opening of windows when outside conditions are unfavourable.

These education issues for the occupants of a naturally ventilated building are very important and will lead to increased acceptance of the systems. Along with having manual controls, by having an occupant who has an understanding of the building and what it is trying to achieve, they are more tolerant of higher temperatures within the building. With this in mind building specific user guides should be provided so that the best performance can be realised.

Such training should be ongoing, ideally with regular updates to all occupants so that they understand if maintenance issues are ongoing, or if certain zones are operating differently to normal. Also training should include background to the variability of human comfort perception, so that there is an understanding that everyone has different perceptions of what is comfortable, and that there must always be a degree of personal responsibility for personal comfort.

It is not just the occupants of the building that need to be educated. Experience has shown that facilities managers also need proper training in order to be able to run the building in the most efficient way. Building operators generally do not have degrees in building services so it is important to make the systems intuitive so they are used correctly. It is often the case that buildings designed to be low energy do not perform as well as they can when they are first used. It can take a year of occupation before the building is being used and operated correctly so education of the building managers/occupants is vital in order to achieve the designed energy use.

In one example that was discussed, complaints were being made by the facilities manager that their building was overheating. The data received from the building was analysed and the results could not be understood so a visit was made to the site. It was discovered that the building that was initially open plan had been partitioned and blinds had been installed to offer privacy at night. The strategy of the building relied on cross ventilation and night cooling to control the internal temperature, both of which were drastically reduced by the changes made. Therefore it is vital that facilities managers understand the strategies employed so mistakes such as these do not happen.

With these issues in mind, handover management of the building is very important. The BRE have produced a document entitled 'Handover of office buildings operations (HOB0)' that encourages handover to be seen as a process of many activities with emphasis on information exchange, training, demonstration and fine-tuning. 'Soft-landings' is another term synonymous with this concept.

It is also important to temper the aspirations of clients/building owners of naturally ventilated buildings, by stating that the building is unlikely to be as comfortable as one with air conditioning for example. Therefore if natural ventilation is to be used, instead of having a building that will be at a temperature of 22°C all year round, it might go up to 27/28°C in the summer and the occupants should expect to wear a T-shirt, and in the winter it might drop to 19°C and the occupants should expect to wear a jumper. It is important for clients to understand that the close control that is possible with a mechanically ventilated building is not possible with natural ventilation because natural driving forces are being relied upon to cool the building.

Getting people to engage with the building is one way of ensuring the occupants 'do their bit'. This method used will depend on the type of building and occupant. For example, in an office block there could be a meter that shows how much energy is being used and how much it is costing. However this would not be suitable for a primary school, where something more relevant to a child would engage them more.

Several ways of educating and engaging the building occupants were used in one project that was discussed. Firstly the strategy and thinking that went on in the design of the building was explained with the intent that occupants would then be more accepting of the internal conditions. Because the building was naturally ventilated they were encouraged to have a jumper at their desks which they could wear if it was cold in the mornings and a newsletter was circulated each season to explain what was happening with the building. Finally they could access a webpage that showed various parameters within the building so they could see how the systems were operating.

10.2 Monitoring

The monitoring of BMS and automated windows play a vital part in the performance of the systems. One of the reasons why monitoring is so important is because of the number of variables that make up the model of the building as discussed in the CFD section.

Monitoring is important because what the building was designed for and how it has been fitted out and actually used by the client might be two very different things. Therefore by looking at the actual operation of the building it is often possible to tweak the systems so they perform better.

The design of the cooling/ventilation of buildings is not an exact science due to the interaction with the users of the building. Commissioning takes place before any occupants are in place, so from an energy savings point of view it is vital to look at them again when they are being used, to see how they could be optimised. Assumptions for the density of occupants and the hours of occupancy have been made in the initial model that can be quite different in reality. Many people believe that post occupancy evaluation like this is so important in the efficient running of buildings that it should be part of the Building Regulations.

Monitoring such as this is usually an added cost to the client and therefore does not always take place, however this cost is often quickly paid back in terms of energy savings in operating the building. Clients need to be educated in this area so that more monitoring and post occupancy reviews take place.

A further benefit of monitoring after the building has been occupied is that it enables designers and consultants to learn from past buildings and use that information in new projects. Studying how different systems, technologies and strategies work in practise should help design teams develop more effective designs in subsequent buildings.

Monitoring buildings in use also allows realistic energy targets to be set. As already mentioned buildings rarely perform optimally straight away due to differences between the design assumptions and actual usage of the building. Therefore instead of energy targets being based on the results from models, it allows more realistic targets to be set based on the real performance of the building.

Another area in which post occupancy monitoring is useful is finding areas of the design that have been overlooked. For example in one building that was studied the communications room and the kitchen used approximately 50 per cent of the total energy use of the building. This means that whilst the rest of the building performed very well a lot of the hard work that went into the design had been wasted by failing to consider these two vital areas. Lessons such as these are important and the monitoring of buildings is the only real way they can be learnt.

The monitoring itself could be carried out by a number of different contractors, depending on what systems are present. If a stand-alone window control has been installed the monitoring will be carried out by the controls contractor, otherwise it is usually done by the BMS contractor. A good specification will include this. Ideally whoever is responsible should revisit the project once or twice during the first year of operation and make any changes to the system as necessary. For particularly complex projects it has been suggested that the systems should be tweaked for each season to ensure the best performance and energy savings. With this in mind it is essential to have a flexible system that allows this as some of the cheaper controls do not allow the settings to be changed.

Whilst in the past any changes to the BMS or automated window system would have required a visit to site to re-programme the controllers, this is now not always necessary. The latest components allow remote access so changes can be made without expensive site visits.

10.3 Maintenance

Maintenance of automated façade components is essential in ensuring that they operate to their full potential and to guarantee long-term performance. For example motors need to be cleaned of dirt/salt, windows need to be checked to ensure that all the fittings are still tight and the seals are in tact amongst others things, in order to keep the components operating as they should and to keep the reputation of the industry. This maintenance regimen is especially important for life saving systems such as smoke vents.

Most automated façade suppliers have a maintenance division and encourage clients to take out a contract with them to look after the hardware (actuators and controllers) and the software. It is recommended that at least one visit per year is carried out, although two per year tends to work out cheaper in the long run due to the principle of prevention rather than cure – this is backed up by experience of many projects that have demonstrated this principle in practice. An added benefit of such a maintenance inspection is that if any obvious problems with the window or façade are noted by the service engineer, the client can be made aware.

In addition to physical inspection, maintenance and monitoring can take place remotely. Remote access to the control system can be a very favourable option for the client. The window control specialist provides additional hardware that allows access to the control system from the building's intranet so that the facilities manager can view the system status, sensor readings and make adjustment to certain parameters using their own desktop PC or laptops. With such a system in place the window controls specialist can gain access remotely using the internet or wireless technology; in this way they are able to troubleshoot system failures and make changes to system setpoints at the clients request, in far shorter lead times and at much smaller costs than a site visit might entail.

Some clients can have security concerns if control systems are connected to their intranet, as there is potential for them to be hacked into which could compromise operation/security. With a wireless connection protected by high level encryption and a kill switch controlled by the facilities manager, such concerns can be overruled.

11 CASE STUDIES

11.1 BRE Environmental building

The BRE Environmental Building was completed in December 1996 and is situated at the centre of the Building Research Establishment's Garston campus. Max Fordham LLP were the M&E services engineers. The building was designed as a showcase for different technologies and for use as a test bed for further research by BRE on the performance of buildings.



Figure 11.1 The BRE Environmental Building

One of the main drivers for the use of an intelligent façade was the need to create a building that met the energy efficient office of the future specification. The BRE worked with industry partners to produce a specification that would create an office building that provided a comfortable and healthy internal environment, while reducing both energy use and impact on the external environment. The specification included energy consumption, comfort, visual environment and acoustics. As this specification was intended for use on other buildings it had to be easily replicable, be capable of use on as many buildings as possible and realistic in terms of cost. The Environmental Building was used to test this specification. It also allowed the BRE to receive feedback from designers on their experiences.

The building has two main automated components: external louvres and high-level windows.

11.1.1 Ventilation

Windows

Natural ventilation is used to cool the building. The principal method for cooling is cross ventilation which is why the office space was kept to a width of 13.5 metres. There are two types of window in the office space. The main windows are large panes, some fixed and some manually openable. The upper areas of windows are smaller and are automatically controlled. The use of these high level automated windows enables secure night cooling of the building.

There was also a requirement for the ventilation strategy to be flexible, especially to provide sufficient cooling even if the office space is partitioned with a consequent reduction in the cross ventilation capability. The traditional solution to this is to create a false ceiling and allow the air to flow above it; however this method was not considered as it would result a significant part of the thermal mass of the room being lost (the underside of the concrete floor slab).

This problem was overcome by creating air paths across the building within the slab itself so the cross ventilation could bypass any internal partitions whilst keeping the floor slab exposed to cooling air. This solution provided a number of added benefits. The incoming air now passes through the structure and so is exposed to a greater area of concrete whilst the new shape of the slab (wave-shaped) increased the surface area by around twenty per cent resulting in greater air contact and thermal mass. The automated high-level windows provide air to the slab. Air entering through alternate windows enters the building directly whilst air from the intermediate windows or enters the floor slab itself.

The thermal mass in the concrete slab means that it can both heat and cool the air entering the building. In wintertime any air admitted through the high level windows would travel through the slab pick up some warmth before it drops into the offices. In summertime night cooling is used to cool the slab down so that during the day air entering through the high level windows and travelling through the slab is also cooled before entering the office space.

Stacks

Stack ventilation has been incorporated to try to provide adequate ventilation when there is insufficient wind for cross ventilation. These connect to the ground and first floors. The stacks are on the south side of the building and are clad in glass blocks so the sun will heat up the air within the stack causing it to rise which will in turn draw air from the office space in the process. There are low power fans at the top of each stack to encourage additional airflow if it is needed.



Figure 11.2 Stacks

The top (second) floor of the building is not connected to the stacks as there is less height available and so they would be as effective. Instead the roof rises from a height of 2.5m

to 5m creating its own stack effect. Warm air in the second floor offices will rise and be expelled via north facing clerestory windows.

11.1.2 Solar shading

The main form of glare control in the Environmental Building is by external louvres on the south façade. Internal and mid-pane blinds were also considered. Internal blinds were dismissed, as the solar energy would already be in the building by the time it reached the blind and as such they would not be as effective in controlling solar gain. Mid-pane blinds were thought to be quite effective, however it was decided that they would either limit the view too much if they were fixed, or they would be difficult to maintain if they were retractable.

It was decided that the external louvres should be motorised. If they were not then they would either not provide shade for a sufficient amount of time, or they would block out all the sun. They would not provide an acceptable view out of the building and would increase the reliance of electric lighting. Due to the geometry of the building the standard louvre algorithms that were provided had to be changed in order to provide the best conditions. The control algorithm that was developed had three set points based on the external light levels and proved to be a challenge to write.

When the external light levels are low the external louvres are rotated past their horizontal position and so act as light shelves, allowing daylight further into the office space.



Figure 11.3 External louvres

11.1.3 Building management system

To achieve the best performance from a naturally ventilated building requires a sophisticated management system. A BMS operating through a LON network was used, with the control algorithms for the ventilation and cooling divided into four modes.

For winter day-time operation the windows allowing air into the ventilation ducts within the slab are open to provide the offices with the minimum requirement for fresh air, which is pre-heated by the slab. Radiators and under floor heating turn on to maintain a minimum temperature with the under floor heating favoured as it is slightly more efficient.

Winter night-time operation provides no ventilation and only sufficient heat to prevent frost within the building.

Summer daytime operation provides the minimum ventilation to the building when the building is below a certain set temperature. Above this point the automatic windows open, unless the outside temperature is hotter than the internal temperature in which case the windows stay in their minimum positions. If it is windy the windows modulate towards the closed position, if it is windy and rainy they are limited to twenty-five per cent open. The stack windows will close if it is raining, as these are hopper type windows that will allow rain to enter. The stack fans will turn on if the building reaches a certain temperature to increase the ventilation.

In summer night-time operation the windows open to remove the excess heat that has built up during the day. This only occurs if it is hotter inside than outside.

The BMS was required to log data every five minutes over an extended period. This data was to be used during the commissioning stage of the building and during the first year of occupation in order to carry out additional checks on the operation of the building.

11.2 Luton Innovation Park – Butterfield Offices

These offices comprise a 70,000 sq ft suite of supported units to accommodate growing businesses funded by the East of England Development Agency (EEDA).

The building has an 'Excellent' BREAAAM rating recognising the incorporation of best environmental design practice.

Part of the design brief was to allow the facilitation of future flexibility in the internal layout with the possibility of moveable walls and partitions to accommodate expansion of companies. This resulted in complexities in the internal climate modelling as the natural ventilation system would need to take due account of changes to the internal zoning.

A typical office building may have up to 50 separate control zones where the internal conditions are monitored and determined by the management system. The control system designed for this project incorporates over 150 zones to provide the future flexibility in the internal space.

Opening windows are linked back to a façade control system which also interfaces with roof mounted windcatchers that capture the prevailing wind from any direction. The air is then directed through a controlled damper arrangement into the rooms below and coordinated with the façade openings. The strategy works in tandem with the heavyweight concrete core, which is used to provide thermal mass and night cooling strategies assist in the provision of structural 'coolth' for the working day.

An external weather station monitors the prevailing conditions including wind direction, wind speed, temperature and rainfall. Along with data resulting from the modelling of pressure coefficients on the façade, these parameters are programmed into the control system where they are analysed with the readings from the internal sensory devices.

The control system continually oversees the façade and roof terminals to maintain the air quality and temperature and also incorporates an integrated entrapment function to negate the possibility of injuries whilst the windows are in operation. Manual opening windows are also provided for user control if desired.



Figure 11.4 Automated windows

Considerable efforts were expended during the design and coordination phases with close collaboration between the consulting engineer, architectural team, façade manufacturer and controls supplier to ensure that the control system would operate sympathetically to the needs of the building whilst being fully integrated with the window system. The subsequent installation and commissioning phases were relatively trouble free although areas of the building suffered flooding early in the operational phase which resulted in the replacement of cabling and controls.

The system has been monitored since opening in June 2008 and some optimisation and adjustment has been made through the remote link back to the control system supplier.

11.3 Charities Aid Foundation

The requirement for this project was to provide a highly sustainable ventilation strategy that would maintain a comfortable internal environment, reduce CO₂ emissions and reduce the need for air conditioning. To achieve this the ventilation specialist worked closely with the heating contractor and the building services consultant in order to ensure all the systems in the building would be compatible and provide the desired internal conditions.

A complete natural ventilation system was used in the building. This consisted of the window control system and the window actuators. In total more than 260 chain actuators were used, controlled by over 60 advanced zone controllers. These zone controllers were able to communicate via a LON network, to a series of central control panels that were responsible for enacting the overall natural ventilation strategy for the whole building. The zone controllers were grouped and placed within the floor voids to minimise the wall space required in the plant room.

The ventilation strategy made use of night cooling when necessary. This allowed cooler night time air to enter the building and cool the structure. This strategy was particularly suited to the Charities Aid Foundation building as it had exposed concrete ceilings. This thermal mass was able to store the 'coolth' from the night air which would then be reradiated to the occupants the next day. Using this strategy the resulting morning temperatures were about 1°C lower than without night time cooling, with this improvement in the internal temperature being maintained throughout the day.



Figure 11.5 – Charities Aid Foundation building

Wind speed and direction sensors were incorporated in reduce draughts from high winds, and rain sensors were used to avoid damage due to rain ingress. The control panels operated at 24 V which meant that a battery backup could be used that would ensure essential operation of the system in the event of mains power failure.

In order that any issues could be dealt with efficiently, or new strategies implemented, GPRS technology was used to securely connect the ventilation engineers to the system.



Figure 11.6 – inside the building

Several measures were taken to help ensure that the occupants of the building accepted the new control system. Before handover was complete, the ventilation specialist delivered a series of seminars to various groups of staff, explaining the background to automatic natural ventilation and how their system works. This training greatly improved the understanding and acceptance of the system. In addition to this all staff were able to monitor the building and the outdoor conditions on their own desktop PC, so they able to see what the ventilation system was doing and why.

12 FURTHER READING

The Building regulations Approved Document L2A, Conservation of fuel and power in new buildings other than dwellings, 2006. NBS. London

The Building regulations Approved Document L2B, Conservation of fuel and power in existing buildings other than dwellings, 2006. NBS. London

The Building Regulations Approved Document F, Means of ventilation, 2000. NBS. London

BREEAM

Anderson J, Shiers, D., E, 2002. The Green Guide to specification. Blackwell Publishing. Oxford

The Building Regulations (Northern Ireland) Technical Booklet F2, Conservation of fuel and power in buildings other than dwellings, 2006. Department of Finance and Personnel.

The Building Regulations (Northern Ireland) Technical Booklet K, Ventilation, 1998. Department of Finance and Personnel.

The Building (Scotland) Regulations, Non-domestic Technical Handbook Section 3, Environment, 2007.

The Building (Scotland) Regulations, Non-domestic Technical Handbook Section 6, Energy, 2007.

Littlefair, P. J, 1991. Site layout planning for daylight and sunlight: a guide to good practice. BRE. Watford

Barry, R, 1982. The construction of buildings, Volume 2; Windows, doors, fires, stairs, finishes. 3rd Edition. Oxford. BSP Professional Books

Martin, A. J, 1996. Technical Note TN11/95. Control of natural ventilation. Bracknell. BSRIA

CIBSE Applications Manual AM10: 2005, Natural ventilation in non-domestic buildings. 2005. CIBSE. London.

CIBSE TM37: 2006, Design for improved solar shading control. 2006. CIBSE. London.

Liddament, M. W, 1996. A guide to energy efficient ventilation. The Air Infiltration and Ventilation Centre. Coventry

Littlefair, P. J, 2005. Summertime performance of windows with shading devices. BRE Trust. Watford

Littlefair, P. J, 1999. *Solar shading of buildings*. Construction Research Communications Ltd. Watford

The Building Regulations, Approved Document B, Fire Safety, Volume 2 – Buildings other than dwellinghouses, 2007. NBS. London

Bordass, B, Leaman, A, Bunn, R, 2007. Controls for End Users: A guide for good design and implementation. BSRIA. Bracknell.

Building Bulletin 101, Ventilation of School Buildings, 2006. DfES. London

Building Bulletin 93, Acoustic design of schools: A design guide, 2003. The Stationery office. London

Jenkins, G, Perry, M, Prior, J, UKCIP08. The climate of the United Kingdom and recent trends, Met Office. Exeter

Martin, A, Fitzsimmons, J, 2000. Guidance Note GN 7/2000, Making natural ventilation work. BSRIA. Bracknell.

Bell, J, Burt, W, 1995. Designing buildings for daylight. Construction Research Communications Ltd. Watford

CIBSE Guide A: Environmental design, 1999. CIBSE. London.

13 TERMINOLOGY

Algorithm	An algorithm is a set of rules for the control of a component or group of components. Outputs controlling the components are determined by combinations of inputs received from the sensors.
AOV – Automatic Opening Vent	This may be for the purpose of either ventilation or smoke control.
Cross-ventilation	Cross-ventilation occurs when there are ventilation openings on both sides of a space. Air flows from one side of the building and exits on the other side, picking up heat and pollutants along the way. An example of this would be an open plan office space with windows on both external walls.
Mixed mode ventilation	Not all parts of the building have to be ventilated in the same way. Different natural ventilation strategies may be applied to different areas of the building as appropriate. Mixed mode ventilation may also describe the use of mechanical ventilation or air conditioning to assist the natural ventilation within a building.
Night cooling	Night cooling takes advantage of lower night time temperatures to promote cooling. Warmth is purged from the building fabric and providing there is sufficient thermal mass this can be cooled in order to help control the internal temperatures the following day.
Single-sided ventilation	Single-sided ventilation relies on openings being on only one side of the ventilated enclosure. An example of this may be a cellular office with opening windows on one side and closed internal doors on the other.
Stack ventilation	This term is used to describe those ventilation strategies where driving forces promote an outflow from the building, thereby drawing fresh cool air via ventilation opening at a low level. Stacks can comprise stairwells, atria or ductwork to take the warm air from within the building to exhaust outlets at high level.
Total solar energy transmittance	The total solar transmittance is the sum of the direct transmittance and the absorbed radiation entering the room by long wave radiation and convection from the glass. It is commonly known as the solar factor, g-value, and:

$$g = \tau_e + q_i$$

Where:

τ_e = Direct solar transmission

q_i = Solar radiation absorbed and re-transmitted inwards

The g-value is often used to specify glazing performance.

14 STANDARDS

BS 6375-2: 1987, Performance of windows – Part 2: Specification for operation and strength characteristics.

BS 8213-1: 2004, Windows, doors and rooflights – Part 1: Design for safety in use and during cleaning of windows, including door-height windows and roof windows – Code of practice.

DD CEN/TS 13126-1: 2004, Building hardware, fittings for windows and door height windows – Requirements and test methods – Part 1: Requirements common to all types of fittings.

BS EN 12101-2: 2003, Smoke and heat control systems. Specification for natural smoke and heat exhaust ventilators

BS EN 13141-1: 2004, Ventilation for buildings – Performance testing of components/products for residential ventilation – Part 1: Externally and internally mounted air transfer devices.