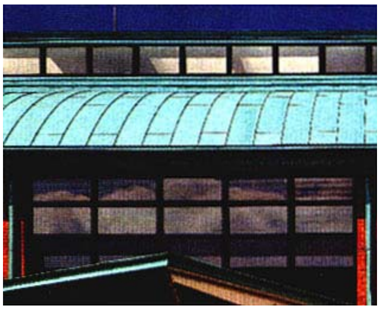
Specification of Automatic Vent Opening Devices for

NATURAL VENTILATION



FINAL DRAFT

Based on a study under the DETR Partners in Technology Scheme

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Foreword

Interest is growing in making use of natural ventilation and cooling in larger and more complex buildings [1]. Natural ventilation can be used by itself; or combined with mechanical ventilation and cooling in "mixed mode" hybrids [2, 3]. It is often increasingly automated - at least to some extent - for example to make effective use of thermal mass and night cooling to help stabilise internal temperatures.

This guide results from a DETR-funded "Partners in Technology" investigation, which:

- visited buildings with automated and motorised natural ventilation components and undertook case studies of how they had performed in practice; and
- reviewed how to improve things by building on the successes and overcoming the problems which had been identified.

The document aims to improve the architectural and engineering knowledge of:

- how the components (opening elements, actuators, linkages and controls) in a controlled natural ventilation system work together;
- what distinguishing features make a system well-engineered and integrated; and
- the importance of defining responsibilities at an early stage.

Acknowledgements

This guidance document is derived from the work of all the partners involved in the study, Bill Gething of Feilden Clegg, Paul Langford and Nick Holden-Brown of Colt International, Andy Ford and Saud Musinovitch of Fulcrum Consulting, Steve Irving of Oscar Faber, Mark Hesketh of Willan Group, Brian Ford, Camilo Diaz and Rosa Schiano of Brian Ford Associates. In addition, we would like to thank the designers and building managers of all the case study buildings, for their time and assistance, particularly Fitzroy Robinson, Jestico & Whiles, ECD Architects, Feilden Clegg, RH Partnership, Sir Colin Standsfield-Smith, Short Ford & Associates, JJ Brown, Ian Wilson, Paul Buxey, Toni Panebianco, John Sloman, Sandy Slattery, James Fisher, Jack Williams, Ian Frame, Gary Stickland, Kevin McCartney, Leeson Medhurst and Martin Hodgson. The findings of the field studies were reviewed periodically by a panel of experts: Bill Bordass, Rob Cohen and Earle Perera.

Contents

1 Introduction: lessons from the case studies

1.1 Getting it right

The case studies showed that achieving successful automated natural ventilation - whether working by itself or together with manual and mechanical systems - depended critically on detailed design, specification, installation, commissioning, operation and usability of the systems and of the ventilators, actuators and controls. The key areas requiring careful attention to detail were:

- **The principles** upon which the system was designed and developed.
- **The products** which were specified.
- **The process** of design, specification, installation, commissioning, and operation.

1.2 The Principles

The purposes of the ventilation and control strategy needed to be effectively thought through: how it would be controlled and managed; and how individual occupants would be affected by and interact with the system and its various components. (See Table 1.1)

1.3 The Products

The case studies revealed difficulties in seamlessly combining components and subsystems which were typically used in different contexts. An automated system will often bring together on site:

- Windows, ventilators and rooflights initially designed for manual controls.
- Actuators sometimes intended for occasional use - as in smoke ventilation; or developed for other purposes: e.g. mechanical ventilation systems, greenhouses, and industrial ventilators.
- Dampers normally used in mechanical ventilation systems. Although tried and tested there; when used for natural ventilation, they could fall short in appearance, building-in details and workmanship, poor insulation, and most frequently insufficient airtightness when closed.
- Control and Building Management Systems normally used in more highly-serviced buildings, and to operate mechanical systems with power to spare. When used with natural ventilation, performance is more critically dependent on precise and effective operation. However, suppliers could be unfamiliar with the design intentions, and inappropriate software was sometimes loaded.

For example, a wide range of issues can arise when fitting an actuator alone:

- Is it properly connected to the opening element and to the frame or building fabric?
- Are its connection points and fixings strong enough and any linkages properly aligned?
- Will the element it opens close and seal as effectively as with manual devices?
- How does it connect to the control system and to supplies of pneumatic or electric power? In one building, the cables had been forgotten and proved too difficult and expensive to retrofit.
- Will it stand up to the duty cycles required? Sometimes the control system was constantly exercising the actuator, leading to a very short service life.
- Can it be maintained safely and conveniently?

There were fewer such problems when the opening, actuator and controls had been procured as a fully-integrated system, so that installation could be largely “specify, fit and forget”. Even then it can be important to check whether products have been adequately developed: manufacturers sometimes “bolt on” actuators to their standard natural ventilation products without enough thought. (See Table 1.2)

1.4 The Process

The case studies also revealed problems in the supply chain, for instance:

- Who specifies what? An architect will often specify the window and a services consultant the actuator and control. Will they be compatible? How will they be put together? What about structural engineering issues?
- What are the implications for construction programming and commissioning? Should the actuator be fitted at the factory or on site? Site fitting had often given rise to problems with mechanical integrity, alignment, and fine adjustment - for example of end limit switches.
- What about trade responsibilities? Ventilation openings which are usually seen as part of the building fabric now also become part of the building services. This may bring trades together at stages and in sequences in which they are not normally used to collaborating. Do specification documents and management of subcontract packages take proper account of this?
- Have effective preparations been made for effective operation, management and fine-tuning? Occupiers often seemed to have assumed that natural ventilation would look after itself; and so were not well-prepared to operate the controls. In addition, neither they - nor the designers or installers - had made provision for the fine-tuning which is often needed during the first year or so of operation. While the desirability of such activities is not unique to natural ventilation systems, they tend to be more critical to its success. Innovation needs more care! (See Table 1.3)

TABLE 1.1: PRINCIPLES

- *Develop a clear overall ventilation strategy as early as possible. Keep it under review.* NOTE: this report is primarily concerned with the specification of automated devices. Guidance on natural ventilation and mixed mode strategies can be found in references [1 to 5].
- *How will manual and automatic controls be integrated? The need for local over-ride by occupants must be carefully considered.*
- *What control and feedback devices will be provided for occupants and management?*
- *How many different types of ventilation device will be required to cope with all seasonal and occupational requirements?*
- *What restrictions are there in terms of noise, security and vandalism?*
- *Will protection will be needed against high winds and rain penetration? If so, how will these be detected and how fast will the ventilators need to close?*
- *Is screening required against insects, birds and small animals?*
- *Will there be safe and convenient access for maintenance?*

TABLE 1.2: PRODUCTS

VENTILATORS

- *What types of ventilator are most appropriately used? How will their geometry affect the available free area and airflow rates?*
- *Can they be well integrated into the building fabric, structurally and aesthetically.*
- *What structural loadings will they have to cope with, in normal and extreme conditions?*
- *Do they have good levels of thermal integrity?*
- *Will they and their building-in details be airtight?*
- *Will they seal well when closed, even after years of use?*
- *Do they protect against any external noise, particularly from traffic and aircraft.*
- *Do they control excessive internal noise breakout, where significant.*
- *Will they clash with other devices, e.g. fixed or movable blinds?*
- *Do they provide the required protection against intruders and vandals?*
- *Do they protect against insects, birds and small animals, where relevant?*
- *Do they provide the required protection against rain penetration?*
- *Are they vulnerable to high winds? Anemometers are often used to close (or limit the travel of) openings when windspeeds are high.*

ACTUATORS AND LINKAGES

- *What actuators and linkages will be used, and how will they be integrated and fixed?*
- *Is protection against dust, moisture and explosion required? If so, how much?*
- *Can they operate reliably with little maintenance, often for many cycles per day.*
- *Will they be quiet enough in operation?*

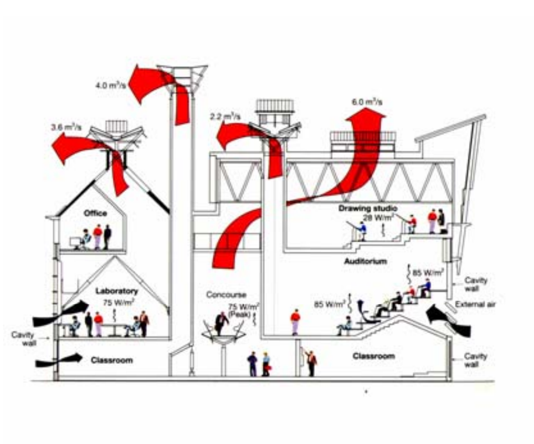
CONTROLS

- *Can the actuators communicate simply with local and/or centralised BMS controls.*
- *Has appropriate provision been made for all control devices, cabling and tubing?*
- *Have the user interfaces been properly considered and effectively designed?*
- *How will feedback of operational status be provided, both to individuals and to the central control system?*

TABLE 1.3: PROCESS

- *Establish a clear division of responsibilities for all aspects of the ventilation and control scheme:*
- *Agree the ventilation strategy with the client and keep it under review.*
- *Take early advice from specialist suppliers.*
- *Design responsibility: strategies, components and integration.*
- *Specification. Include design intent and make responsibilities clear.*
- *Performance specifications. If these are used for any elements involved, note that a change of component may affect other elements outside the scope of the specification.*
- *Construction responsibility: subcontract package boundaries, coordination and programming. Recording progress and build quality. Rectifying faults.*
- *Commissioning responsibility: static completion, mechanical testing, control systems.*
- *Plan for handover, operation, and maintenance.*
- *Occupant awareness: system descriptions, staff training, leaflets for individuals.*
- *Plan for fine tuning during the first year of occupancy. Clearly define the roles of occupier, designer, contractor, controls and commissioning specialists.*

FIGURE 1.1 QUEENS BUILDING, DE MONTFORT UNIVERSITY, LEICESTER
BEDALES THEATRE , HAMPSHIRE



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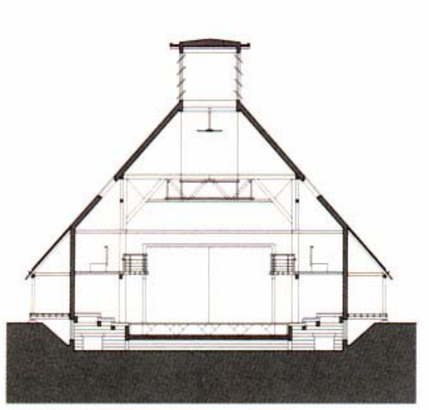

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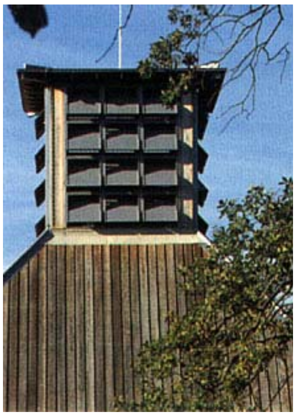


6.

2 Responsibilities in design and specification

2.1 Responsibilities for effective integration

Clear division, definition and ownership of responsibility is vital for a successful outcome. If the boundaries of responsibility are not clearly defined, some problems may not be "owned" by anyone. Important elements may even be left out of the specification entirely. For example, a factor often overlooked is that ventilators (usually specified by the architect) and actuators (often specified by an engineer) are joined by linkages. In many installations visited, linkages and fixings had been major points of weakness and had sometimes failed entirely.

For window-type ventilators, the architect will normally specify the ventilator and the engineer the actuators and control system. Contractually, we would recommend that the actuators form part of the window package, so the window manufacturer becomes responsible for procuring and fixing the actuators, and for testing the performance of the integrated assembly. This will allow many problems to be ironed our before the assembly arrives on site. Even if some site assembly (e.g. installation of projecting actuators) is required, it will have been more carefully planned.
To prepare a complete specification for an integrated window-type assembly, the architect will need to get specification information on actuators, controls, linkages and fixings from the engineer. In order to be able to judge the appropriateness and completeness of this specification, the architect will need to be aware of all the criteria that need to be covered.

Sourcing from a single manufacturer is not essential. However, successful integration of ventilator, control, actuator and linkage components from different manufacturers requires:

- a knowledge of the technical issues; and
- clear lines of responsibility.

Window and actuator suppliers all recommend early dialogue, during which issues can be raised, for example providing suitable fixings for the actuator, suitable linkages, and the need for any reinforcement of the frames. We also recommend that the window/ ventilator supplier is asked to supply shop drawings showing the actuator type, linkage and fixings.

For damper-type ventilators, the engineer is more likely to specify the assembly complete with its actuators and controls, while the architect will be concerned with its appearance, finish, weathertightness and building-in details. Ideally, a detail will be developed which allows the damper assembly to be simply and effectively inserted as an engineering item into a prepared opening in the building which has been specified by the architect.

2.2 The Responsibility Table

Table 2.1 sets out the major items which need to be considered. For each it identifies who normally will have primary responsibility, who will have secondary responsibility, and who needs to be kept informed. It includes cross-references to the sections in this guide where more details can be found.

Table 2.1 can also act as a project checklist, although all projects are different and merely ticking boxes may not adequately cover the necessary activities and interrelationships at a detailed level. At a minimum, one will need to add notes and comments on what needs to be done and by whom.

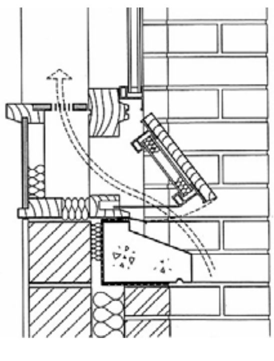
FIGURE 2.1 OFFICES FOR HOUSING 21, BEACONSFIELD

The windows on the south side are from the Velfac range which includes fixed, manually-operable and motorised elements with concealed provision for actuators, controls and wiring. The actuator's chain drive attaches to the window at the same point as the manual latch, making secure fixing easier and helping the windows to close tightly. With tried-and-tested, factory-assembled components from the manufacturer's range, integration was assured and the installation has been virtually trouble-free.

1.

The initial outcome was less fortunate on the north side, which used purpose-made motorised flaps and concealed dampers in site-built enclosures beneath louvres in the window cills. Here integration was less easily achieved: with air leakage both through and around the dampers; and unclear indication of control status caused problems, particularly with heat loss and discomfort in winter.

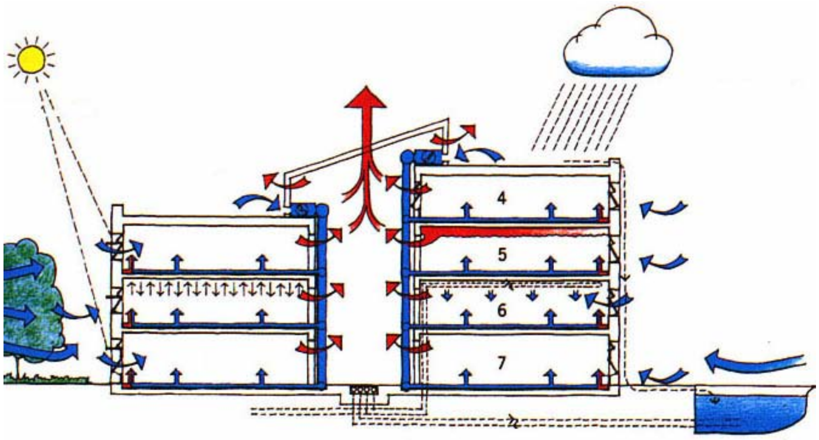
2.



3.

FIGURE 3.1 NATURAL VENTILATION AT BARCLAYCARD, NORTHAMPTON

1.



3.

2.

This office building in Northampton used fixed trickle ventilators and natural ventilation to maintain IAQ, plus a mechanical system (supplemented by chilled beams) for summer cooling. In practice the amount of trickle ventilation has proved excessive, and sometimes draughty; and many of these ventilators have now been blocked-up. However, in other respects natural ventilation via the atrium is working well. High level atrium vents are operated by paired pneumatic actuators. See Reference [9.]

3 Principles: what will the ventilation be for?

This guide assumes that a ventilation strategy has been determined (see references [1 to 5]); and that the free areas and general locations of the inlets and outlets necessary to achieve the required air flow rates have been calculated. The following section is a brief outline only, to help set the scene for the later sections on ventilation products and control strategies.

Ventilation has four principal purposes - as outlined below - of which most or all are combined in an overall strategy. Not all of these will necessarily require ANV: some may be more conveniently done passively (e.g. background trickle ventilation), manually (e.g. window operation by users during the day), or mechanically (e.g. local extraction of heat, moisture and fumes from a kitchen; or using mixed-mode hybrids). Fire and smoke ventilation also needs to be carefully considered.

Because the driving forces for natural ventilation are always changing (particularly wind speed, wind direction and inside-outside temperature difference), it is not practical or even necessary to maintain a constant ventilation rate. The key requirements are acceptable temperatures, good Indoor Air Quality (IAQ), and if possible good occupant perceptions of control. Short-term fluctuations in flow rate are also damped as far as IAQ and temperature are concerned by the reservoir capacity of the air in the space.

3.1 Purpose 1. To control localised sources of pollution at source

A systematic approach to IAQ should start by:

- seeking to eliminate pollution sources, for example outgassing from inappropriate building materials, paints, finishes and furnishings;
- containing any unavoidable localised sources of heat or air pollution and providing local natural and/or mechanical extraction for them where necessary; and
- adopting dilution ventilation only as a last resort.

Where these pollution control measures have been adopted, the ventilation rate required for IAQ control in offices with typical occupation densities is in the region of one air-change per hour (ac/h).

3.2 Purpose 2. To provide acceptable IAQ year-round

Once localised pollution sources have been minimised, good IAQ needs to be maintained without incurring unnecessarily high loads for heating, cooling or humidity control. Key issues are:

- providing adequate winter ventilation when people may well not open windows;
- avoiding excessive winter ventilation, with associated heat loss and discomfort; and
- diffusing incoming air well enough to avoid localised draughts and cold spots - this can be difficult in well-insulated buildings with no perimeter heating; when a mixed mode strategy with low levels of background mechanical ventilation can be appropriate.

3.3 Purpose 3. To remove unwanted heat in the daytime

Required ventilation rates for summer cooling are typically between 3 and 10 ac/h, which if insufficiently well-controlled can be draughty (particularly near the inlets), and may even blow papers off desks. Key issues include:

- the large openings required for summer cooling providing too much ventilation in winter;
- excessive wintertime air infiltration, particularly through damper-type devices;
- during the heating season, telling whether overheating needs to be reduced by more ventilation or by turning down the heating system;
- in hot weather determining whether more ventilation will necessarily cool the building; and
- an absence of natural buoyancy when it is on average cooler inside the building than out: solar or wind effects can sometimes then be used for assistance.

Remember that control of ventilation is inextricably linked with control of the thermal environment. The order-of-magnitude difference between summer and winter ventilation rates can make it difficult to achieve both satisfactorily with the same opening device.

3.4 Purpose 4. To remove surplus heat at

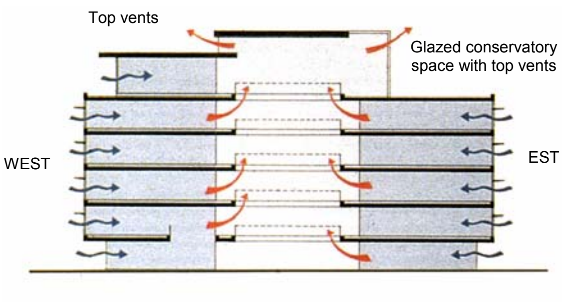
FIGURE 3.2 HIGH LEVEL VENTS AT QUEENS BUILDING, LEICESTER

1.

Ridge vents exhaust warm stale air from the top floor and concourse in the Queens Building. Rack and pinion gear operate top hung vents in series. The status of the vents is not visible from inside which can lead to excessive heat loss in winter when operating under manual override. (See Section 6.7)

2.

FIGURE 3.3 MIXED MODE OFFICES FOR PEARSON EDUCATION



1.

2.

In winter, tempered air at some 1.2 ac/h is supplied mechanically through the floor and extracted via the atrium.
In warm conditions, the windows at the top of the atrium are automated and create a negative pressure which helps to draw air in through the offices - which have exposed concrete ceilings. During the day, occupants operate the office windows manually and close them when they go home. Night cooling was intended but has not proved necessary. For smoke ventilation, the inlets at the bottom of the atrium are opened automatically and exhaust fans at the top and inlets at the bottom of the atrium are both opened automatically.

3.

FIGURE 3.3 AUTOMATED FANLIGHTS AT BRE BUILDING 16

1.

2.

3.

The BRE environmental offices enhance contact between incoming air and the building structure by having a wavy ceiling slab and allowing night air to pass under and over it. The automated fanlights at the perimeter are of the same type as at Housing 21 (Figure 2.1) and use chain drive actuators. (See also Fig. 6.3)

night and pre-cool the building

Many natural ventilation strategies now rely on thermally massive structures which absorb heat during the day and allow it to be removed at night, either by general natural dilution ventilation or more effectively by allowing incoming cold air to flow over the structure, for example using inward-opening fanlights to project air over ceiling soffits. Key control problems include:

- Judging at what stage the building needs night cooling. Sometimes, addition to air temperature measurement, temperature sensors are also embedded in the structure.
- Avoiding excessive cooling overnight. People who come in dressed for a hot summer day will not like a starting temperature of 18°C: 23°C may be the minimum acceptable.
- Not initiating an uncomfortable night cooling regime while some people are still in.

3.5 Purpose 5. To use air as a carrier medium

A fifth purpose is to use the air as a carrier medium for other aspects of environmental control, and in particular filtration, humidification, dehumidification and mechanical cooling. Natural ventilation is not very well suited to this: although recently there have been innovative exceptions, none of the case study buildings included such systems. They are therefore not covered in this guide.

4 Choosing a Ventilator

4.1 Ventilation opening types

Natural ventilation openings are of three broad types:

1 ***Windows and doors, glazed or opaque***
(SeeTable 4.1)

Their major advantages are that they are familiar to occupants and that hinged versions can be made to shut tight relatively easily. In comparison with louvres and dampers:

- they have a shorter crack length;
- effective seals are easier to provide; and
- closing forces can be higher and better distributed about the perimeter.

However, most patterns of window and door were originally designed for manual operation. They may often require some adaptation to accept motorised actuators, and strengthening to accommodate forces applied at different places and frequently also not parallel to the direction in which the window opens.

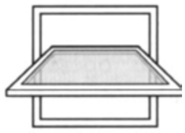
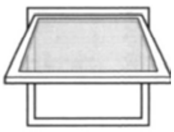
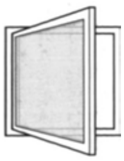
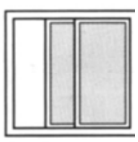
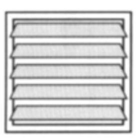
FIGURE 4.1 FARSONS BREWERY, MALTA

1.

The naturally ventilated Farsons Brewery in Malta includes centre pivot as well as top and bottom hung glazed ventilator openings. All are operated via rack and pinion gear which has the advantage of enabling large travel distances and can operate a number of openings in series. (See also section 5.1 and Fig. 5.8)

2.

TABLE 4.1 WINDOW TYPES AND CHARACTERISTICS

Window Type		Actuator Type Options	Comments
HORIZONTAL PIVOT		• Linear • Chain	*These windows have a high ventilation capacity and the geometry promotes good distribution of supply air. Internal blinds are not practical but interpane blinds may be useful alternative. For an opening of 22° then the effective area is 34% of the area of the structural opening.*
VERTICAL PIVOT		• Linear • Chain	*This type provide a smaller effective area than horizontal pivot and are possibly more intrusive with the space. Also more vulnerable to driving rain.*
TOP/BOTTOM HUNG		• Linear • Chain • Rack and pinion • Lead screw • Lever arm • Cable driven (drawbridge)	*These are substantially more effective than horizontal pivot types, although bottom hung inward opening is a useful geometry located adjacent to the ceiling for night vent cooling. Top hung is a better geometry at low level to direct flow towards occupants for daytime ventilation.*
SIDE HUNG (CASEMENT)		• Rack and pinion • Chain	*These windows are not easy to link to automatic opening gear (lever arm must rotate as it extends). Also ventilation characteristics are strongly influenced by wind speed and direction.*
TILT AND TURN		• Cannot be linked to actuator	*The ventilation characteristics have been studied in several buildings, where it was reported that the 'tilt' setting provides too much ventilation in winter and insufficient cooling for occupants in summer.*
SASH (SLIDING)		• Linear sleeved cable or rod • Linear	*These windows have ventilation characteristics similar to the vertical and horizontal pivot window. The effective area is maximum 50% of structural opening.*
GLAZED/ALUMINIUM LOUVRES		• Rotary • Linear	*Advantages are that they can be made secure and still function satisfactorily, therefore have potential application for night ventilation. However when closed, these ones generally have a very poor seal. This is the case with most louvre or damper installations.*

2 ***Dampers or louvres, glazed or opaque***
-Table 4.2

Motorised dampers are widely used in mechanical ventilation systems, where they are usually effective and reliable. However, when used for natural ventilation they have one major disadvantage - they do not shut as tight as most windows, owing to:

- longer crack lengths;
- difficulties with rotating seals; and
- problems with mechanical strength and closing forces

Additionally, they are often characterised by:

- poor insulation
- condensation

In many of the buildings visited, excessive air infiltration caused problems with heat loss and discomfort in winter. Some available products - including some glass louvres - do have good seals; but they need to be carefully selected and checked for construction and performance.

For most dampers, the shaft for the actuator motor projects out of the frame, from the end of one of the damper shafts. This is ideal for ductwork and air handling units, as the motor can be installed, checked and maintained externally. However, for natural ventilation the projecting shaft stops the dampers being installed in the plane of a wall, so either the dampers need to be fitted within a duct spigot, or lever operation may be necessary.

3 ***Trickle ventilators***

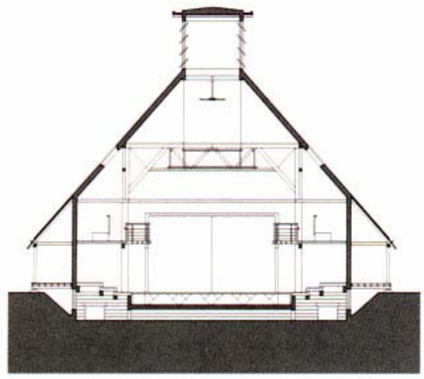
These are not covered in this guide: they have been well-researched recently in the Natvent project [4].

FIGURE 4.2 BEDALES SCHOOL THEATRE, HAMPSHIRE

1.

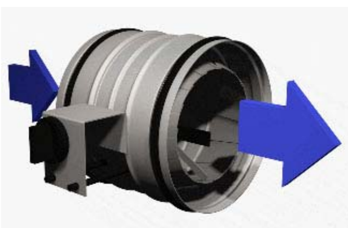
Five bays of vent openings on the north and south sides of the auditorium, located below raised perimeter walkways, supply air below perimeter seating via a plenum. These vents have fixed timber louvres to the outside with a double bank of fully modulating motorised vents behind. Performance is generally satisfactory. Early problems of draughts on north side have been solved, but at high level, poor adjustment of lever arms results in large gaps when in the 'closed' position. Infiltration losses due to large crack length of motorised dampers at low level, and poor sealing to high level window vents cause heating energy consumption to be higher than predicted.

2.



3.

TABLE 4.2 DAMPER TYPES AND CHARACTERISTICS

Damper Type			Construction	Comments
STANDARD BLADE DAMPERS	*This is a damper mainly used for ventilation systems and can be installed in either rectangular or circular ductwork. This damper is also provided with a motor platform. The type of damper is used to control ductwork volume flow rates in connection with ductwork balancing.*		*Standard dimensions: height in sections of 100 - 2400mm, 100mm, width in sections of 100 - 2400mm, 100mm. Special dimensions are available. All dampers have a position indicator and manual adjustment device.*	*The maximum operation temperature of a standard damper is +100°C (with the special model +200°C). In the Closed position the leakage air flow of a closed damper is low. In the Open position the blades are turned in the direction of flow and do not cause a significant pressure loss.*
SEALED BLADE DAMPERS	*This type of damper is often used to close a ductwork branch, as in the closed position the leakage air flow of a damper is low. In the open position the blades are turned in the direction of flow and do not cause significant pressure loss. The damper can also used for the control of volume flow rates.*		*This type of damper is also available as a heat-tight damper for rectangular and circular ducts which can also tolerate mechanical stress and corrosion. Damper is normally supplied with a motor platform. These dampers are available in sizes from 100Ø to 1000Ø in circular ducts or rectangular in sections of 100-2000mm, 100mm width and height. The drive shaft socket is usually made of stainless steel.*	*Such dampers can operate within a system where the system pressure is up to 5000 Pa and the operating temperature range is normally between -40°C - +200 °C, although temporarily +300 °C can be used. It consists of a casing and blades usually made of painted hot-galvanised or acid-proof steel. There are gaskets built into the edges of the blades and between the end of the blades and outer frame.*
CIRCULAR BLADE DAMPERS	*PTS is a motor-operated shut-off damper for circular ducts. The damper has a casing and a circular blade manufactured from hot-galvanized or acid-proof steel. The device can be installed in circular spiral ducts.*		*Standard dimensions: 100Ø - 315Ømm in sections of 50mm. The damper casing can be thermally insulated. The damper is also available with manual adjustment.*	*A ductwork branch can be opened and closed with the device. In the Closed position, there is low air leakage through the damper. In the Open position, the blade is horizontal to the direction of the air flow and does not cause significant pressure loss.*
IRIS DAMPERS	*This is an air volume flow rate adjustment and measurement device for circular ducts 80Ø - 1000Ømm. The volume flow rate adjustment is performed with the iris type blades. The device throttles air flow opening area, when the volume flow rate decreases compared with the open position, and the total pressure loss caused by the device increases.*		*The device has a cone-shaped casing made of hot-galvanised or stainless steel, device blades also made of hot-galvanised or stainless steel and the moving mechanism of the blades partly made of plastic. The casing has duct gaskets.*	

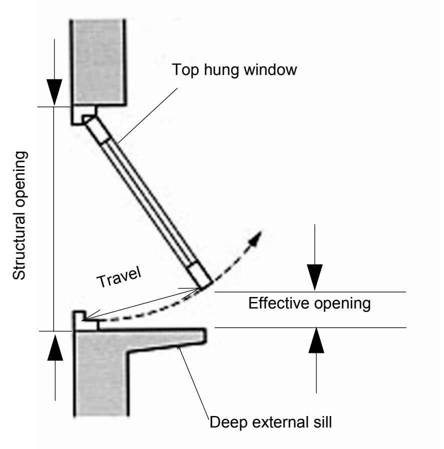
4.2 Ventilator design decisions

Designers will need to consider the following:
(Photocopy and tick the boxes as a preliminary checklist; see also checklist in Table 1.2)

- The types of ventilators to be used. ☐
- The sizes of the individual openings for winter and summer use. ☐
- Loadings in normal service and in extreme situations such as high winds. ☐
- The influence of ventilator geometry on free area and airflow rate, see Table 4.2. ☐
- The actuators and linkages to be used, and their integration and fixing. See Section 5. ☐
- The control strategy required, including appropriate integration of manual and automated controls, and the scope for user over-rides. See Section 6. ☐
- The need for feedback on operational status, both to individuals and to the control system. ☐
- Provision for control equipment and the associated transformers, compressors, switches, indicators, wiring and tubing; together with the associated safety and protection requirements. ☐
- Avoiding adverse effects, such as ingress of noise, rain, fumes, insects and intruders. ☐
- Avoiding clashes: physically with internal curtains and blinds, external shutters and sunscreens, and insect screens; and operationally with building services systems. ☐
- Health and safety issues in installation, operation and maintenance; in particular safe access for maintenance and cleaning. ☐
- Avoiding hazards from unexpected operation, for example trapping fingers or even knocking people over. ☐
- Avoiding grey areas of responsibility for design, installation, testing and commissioning. See sections 2 and 7. ☐

FIGURE 4.3 VENTILATOR DESIGN

Section of window showing distinction between structural opening, effective opening area and travel distance. As a design develops, with restrictions by widow sills, reveals, internal and external blinds have a major impact on the final effective area which is achieved. Ensure that the strategy is carried through into detail design by providing continuity in the design team .



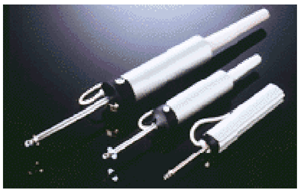
5 The actuator and linkage

5.1 Actuator types and characteristics

The types of actuator commonly used for natural ventilation, together with their linkage options, typical applications, and comments on their suitability, are listed below. See also Table 4.1.

1 ***Linear push-pull piston actuators***, *where a motor propels a push rod forward. These are most commonly pneumatic but electro-hydraulic versions are also available. Advantages include mechanical simplicity, robustness, fire resistance of pneumatic units, and generation of large forces. Disadvantages include large projecting cylinders and mechanical damage to windows, linkages and fixings which are not robust enough. Travel is typically 200-500 mm, but longer distances are possible with large cylinders. They are most widely used for rooflights and high-level windows. (see Fig. 5.1 - source: 1. SEControls, 2. BFA)*

FIGURE 5.1 LINEAR ACTUATOR

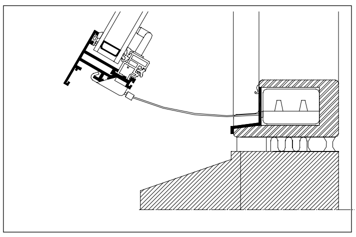


1.

2.

2 ***Projecting chain drive push-pull actuators.*** *An electric motor drives a chain over a sprocket wheel, providing linear motion to push out a window. They are generally modest in size and mechanical strength; and with limited travel of typically 150-200 mm. A useful feature is that the motion tends to be at right angles to the axis of the actuator body, which can therefore be tucked away in the plane of a window frame; or even recessed concealed into it (see Fig. 5.2 - source: 1. BFA, 2. Velfac). Their compact size and unobtrusive appearance makes them best suited to smaller windows such as inward- and outward-opening fanlights.*

FIGURE 5.2 CHAIN ACTUATOR



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3 ***Rack and pinion actuators.*** *A rotary electric motor drives a geared shaft which engages with one or more racks, providing linear motion with less bulky projections than linear actuators. Typical travel distances are 500 mm but they can go up to 1000 mm or more. They are particularly useful for windows which require paired actuators (on each side): with a common pinion the two racks move together and the window is not twisted (as happens, for example, if one of a pair of linear actuators fails; sometimes breaking the window). They are most commonly used for rooflights with relatively light frames. (see Fig. 5.3 - source: Feilden Clegg)*

FIGURE 5.3 RACK & PINION ACTUATOR

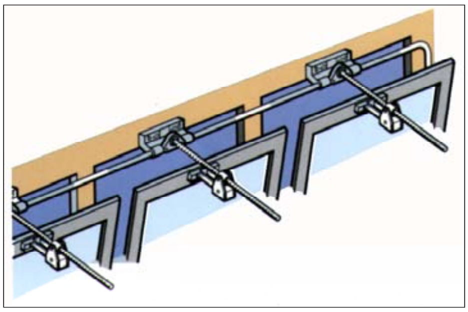
4 ***Linear sleeved cable or rod actuators.*** *These are driven by a rack-and-pinion, worm gear or chain drive electric motor and allow linear motion to be transferred, for example to sliding sashes.*

5 ***Rotary actuators.*** *These are most commonly applied with dampers and louvres, often rotating one of the shafts directly, with mechanical linkages to the other louvres. Sometimes they also operate shafts connected to cranks and lever arms to provide linear motion. There are two main types: one with a bi-directional motor used for opening and closing, and one which motors in one direction only and uses a spring to return, which can be useful for fail-safe operations. (Fig. 5.4 - s.: Belimo)*

FIGURE 5.4 ROTARY ACTUATOR

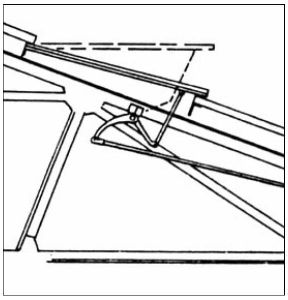
6 ***Lead Screw actuators.*** *These actuators form the majority of linear actuators and are sub-divisible into high and low power applications. For general applications a low friction nut is driven along the lead screw to provide motive force. (See Fig. 5.5 - source: Morse Controls)*

FIGURE 5.5 LEAD SREW ACTUATOR



7 ***Lever arm actuators.*** *Lever arm gear is often found in Victorian schools and hospitals. Continued use is testament to the robustness of this gear. It is often regarded as visually intrusive and unnecessarily cumbersome today (but it is still being manufactured). (See Fig. 5.6 - source: Ventilation Gear)*

FIGURE 5.6 LEVER ARM ACTUATOR



8 ***Gas struts with cables.*** *A linear variant on the spring return motor is where an automatic catch releases the window and a gas-filled strut opens it, or holds it open. Closure is then affected by pulling on a cord, either manually or by means of small electric winch. (See Fig. 5.7 - source: Colt International)*

FIGURE 5.7 GAS STRUT ACTUATOR

5.2 Factors in choosing an actuator

5.2.1 Location of vent and manner of opening

There are three common variants: a hinged flap, a set of centre-pivoted louvres, and a panel sliding on runners. Linear actuators are most commonly used for rooflights and chain drives for low level windows, where it is more important for actuators to be unobtrusive and for them not to obstruct the interior.

5.2.2 Weight and size of vent

The motor should be sized to support the appropriate level of forces, including wind, snow and ice loads. See Section 5.3.

5.2.3 Angle of attack

Owing to geometrical restrictions, the actuator force cannot always be applied exactly in the direction of motion; and can sometimes be nearly at right angles to it. This can lead to large shear forces and moments on fixings (Fig. 5.8).

5.2.4 Travel and free area to be achieved

Chain actuators are usually limited to 150-200 mm, though some concealed units can reach up to 500 mm. The chains have limited buckling strength, so they are most commonly used to open top or bottom-hung windows by a small angle. Linear piston actuators typically have travels up to 600 mm, while rack and pinion drives can go up to 1000 mm and more.

FIGURE 5.8 RACK AND PINION GEAR AT FARSONS BREWERY IN MALTA

1.

2.

3.

Rack and pinion gear can achieve very large openings as can be seen in this photograph of a bottom hung vent in a south tower at Farsons Brewery in Malta (image 1). However the racks can intrude a long way into the adjacent space (see image 2). To minimise this problem curved racks can also be used (image 3).

5.2.5 Available space

Actuators tend to swing as a window opens, so articulated linkages are required. Actuator and linkage components must clearly not clash with each other - or with the surrounding structure - during their full range of travel (fig. 5.9).

5.2.6 Travel speed

Low travel speed is desirable to reduce loadings on the actuator. However, where occupant control is used, visible response is also important, so people can see that their control actions have had a result. If the actuator moves too slowly or is not visible from the point of operation, then some visual feedback such as an indicator light or display should be provided.

5.2.7 Smoke ventilation

Sometimes the ventilator may have to open or close within a specified time. For example smoke control often requires any ventilation device to be fully open within 60 seconds. For rooflights, rapid closure is desirable; or a lot of rain can get in.

5.2.8 Linkages and fixings

Linkages and fixings must be carefully considered for appropriateness, mechanical strength, durability and ease of installation and maintenance. The supplier of the ventilator should be made responsible for the fixing and mechanical commissioning of the actuator and linkage. This should include adjustment of any end stops and limit switches; which if not carefully done can easily lead to mechanical damage to the actuator, linkages, fixings or ventilator.

5.2.9 Electrical safety/level of protection

Electrical actuators tend to be either 240 volt or 24 volt. The former is cheaper (but needs more relays) and the latter is safer (but needs transformers and fatter cables). Although normally indoors, some actuators may be exposed to high humidity, drips, or even driving rain, and occasionally they may need to be flame or explosion proof (when pneumatic operation would be preferable). For electrical equipment, the level of protection is defined by the IP rating (from IP 00 to IP 68).

- The first digit refers to ingress of objects (from 0 = unprotected to 6 = dust-tight),
- The second to ingress of water (from 0 = unprotected to 8 = submersible).

Linear actuators in exposed positions might be IP 65 (dust-tight and protected against water jets from any direction) while chain drive actuators sheltered by an opening window might be IP 33 (resistant to objects above 2.5 mm, water drips, and water spray at an angle of up to 60° from the vertical). IP 54 is a reasonable cost compromise to aim for (particularly important for motor housing, but this may be difficult to achieve for chain drives). For products with lower rating then perhaps a secondary housing is required for the motor.

FIGURE 5.9 TRAVEL SPEED OF ATRIUM VENTS

The slow travel speed actuation of the rooflight vents in this atrium has led to serious problems of rain penetration particularly in heavy rain conditions. It has been said that pneumatic motors would have been quicker but also more expensive. This also raises the issue of vent type selection. Perhaps vertical glazed openable vents would have been more suitable.

1.

2.

FIGURE 5.10 LINKAGE AND FIXING

1. *2.*

Problems have been found with these high level centre pivot vents which are operated by lever arm gear. These problems include poor fixing of lever arms and brackets and difficulty in attaining good alignment. The long linkages are often unable to drive the array of openings from one end. The resulting poor sealing may have a significant impact on background infiltration in winter.
Fixings must be detailed if future problems are to be avoided.

5.3 Forces imposed on an actuator

These are determined by the weight of the ventilator; and external and uncontrollable forces especially wind, snow and ice; and sometimes maintenance loads. How these forces are transferred to the actuator depend on the angle of the ventilator, the location of the fixing points, the geometry of the linkage (which will often change with the extent of opening), the geometry of the actuator, the speed of opening, and any frictional and adhesive forces.

5.3.1 Self-weight

The effect of self-weight depends on geometry. A rooflight will need a considerable force to open - and to keep open - but only requires the actuator to resist the weight during closing. A top-hung window will require much less force to open and to be resisted during closure; and a centre-pivot window even less. A bottom-hinged window will need very little effort to open, but may need a significant force to close, depending on the opening angle. If a fanlight is to open no more than 10 to 15° , then the forces required can be often met by a small chain drive actuator producing 500 N, with a maximum static load of twice the dynamic load, or 1000 N.
CONSIDER: Weight to be supported when shut and when fully open. Moments on pivot points when shut and when fully open.

5.3.2 External forces

Wind, snow and ice loads may often be far higher than the weight of the ventilator itself, particularly for rooflights. High suction loads may also require latches to ensure that the unit remains closed under extreme conditions. Rooflights used for smoke ventilation are required to operate under any conditions, including a 1 in 50 year occurrence (wind loading of 2400N/m2 and or approximately 160 mm of fresh snow). If the system is for natural ventilation only, then there may be no requirement to open under snow load - but this may still affect the design of actuators, linkages and safety measures to avoid actuator failure when attempting to operate under excessive loadings. *CONSIDER: Snow, ice and wind loads in all positions. Will catches be required to keep the ventilator secure in the closed position?*

5.3.3 Actuator position

The positioning of actuators and linkages will often be affected by the size and shape of the ventilator, the availability of fixing points, the presence of obstructions, and aesthetic considerations. Angular and leverage effects can then multiply forces. The less the distance from the pivot point to the actuator, the greater the force required but the shorter the stroke. *CONSIDER: Multiplication of forces owing to actuator positioning and angle. Strength of ventilator. Effect on specification of actuator, fixings, linkages.*

5.3.4 Other forces on the actuator

Where possible, actuators should operate slowly. High speed operation will cause greater stresses on the unit and large shock loadings at each end of its travel. Where the actuator acts as a strut holding the ventilator open, buckling loads will also need to be considered. *CONSIDER: Dynamic and buckling stresses.* The complexity of predicting the performance of these different integrated elements suggest that testing of the final assembled package is vital before final production is agreed.

"Engineering advice should be sought"

FIGURE 5.11 DIAGRAM OF WIND FORCES ON AN OPEN WINDOW

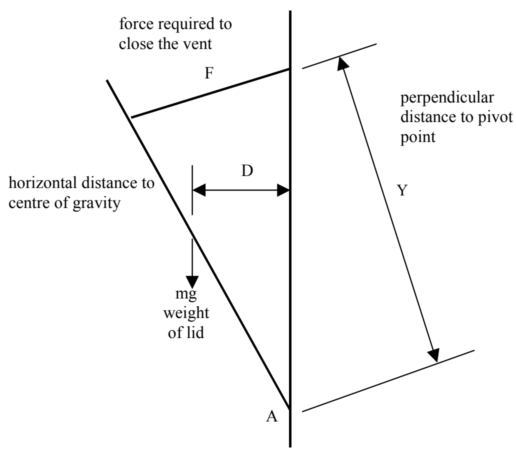
A wind speed of V m/s can be converted into wind pressure in N/ m2 using the following formula:

Dynamic pressure = 0.5 rV2,

where r is the air density of approximately 1.2 kg/m2.
For a window area of 2 m2, and assuming the load is shared equally between the actuator and the hinges, the 1000 N static load for a chain drive actuator would be exceeded by wind loading alone at a wind speed of 29 m/s or 65 mph. It is not unusual to find windows of 3 m2 and more: these would clearly need much stronger actuators; or alternatively effective windspeed over-ride, together with mechanical latches to withstand uplift loads. Note also that air turbulence can increase local wind pressures in some parts of a building, particularly near edges and corners, causing lower wind velocity settings to be selected.
Regard the forces as static and take moments in the open and closed positions. For example, taking moments about pivot point A:

mg x D = F x Y

In this example, the linkage will always be in tension under static loading. To this wind loads need to be added or subtracted, to give the range of forces operating. The force on the fixing points then needs to be converted to those on the linkage or linkages (which may be an angle to the perpendicular) and then into a force on the actuator, taking account of the linkages involved and the frictional effects.



5.4 How many actuators?

The case studies revealed that a good general rule was to have one actuator per ventilator: if one actuator powered several ventilators, then difficulties in obtaining good initial alignment - together with accumulating backlash in the linkages - nearly always meant that not all the ventilators closed tightly, leading to problems with airtightness and security. This could be aggravated by twisting of the ventilator frames; by distortions from poor fixing; by flexing of the linkages, lever arms and brackets; or from shock loads from wind or at the ends of travel.

If the end stops were not correctly set or drifted as backlash accumulated, the more powerful motors necessary to operate multiple ventilators could easily run on beyond the end of the linkage's available free travel and severely damage themselves, linkages or fixings. To deal with this a current limit on the motors can be applied.

If one window was powered by two actuators - typically on the left and right hand sides - it could easily be damaged if one actuator failed; or even if they operated at a different speeds. If two fixing points are needed - typically on windows more than 1200 mm wide (and much less if lightly-framed) then it will often be preferable to use a single actuator with a linkage, for example a rack-and-pinion or a cable drive (eg. at Portland Building), or an anti-skew control system.

5.5 How many cycles should an actuator be designed for?

A typical mean time before failure is 30,000 operations under normal conditions. This represents about five complete operations per day for 250 days per year for a 25-year product life. While at first sight this seems a lot, on several sites we found that the controls operated the actuators very frequently, leading to failures after a year or two; or even more rapidly if the motors overheated. It is therefore important that the control system is designed not to move the actuators about too often. It is important that a hysterisis loop is integrated into the control (but don't be too clever!).

5.6 Linkages and fixings

Linkages and fixings are just as important as any other part of the system. However, they are often taken for granted, making them a common source of failure. Fundamentally, it must be clear:

- how the linkage transmits the motion of the actuator to the ventilator without distortion; and
- how the actuator and linkages are fixed to the ventilator and the support structure so that the entire assembly is secure and can function satisfactorily through tens of thousands of cycles.

Although the one-actuator-per-vent rule is ideal, it will not always be possible to avoid using multiple linked vents. When these are required, particular care should be taken in specifying the linkage and how it is fixed. Where several windows are driven by a long set of linkages on one shaft or push rod, it proved particularly difficult to get good alignment when they were all driven from one end: it is better to place actuators in the centre if at all possible.

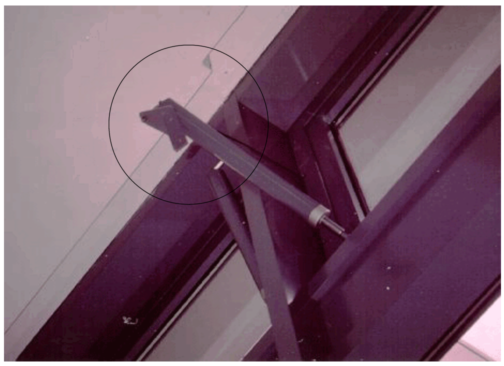
Having established the loads on the fixings, the method of fixing must be given careful consideration, together with the need for reinforcement to the ventilator and its frame. The fixings, brackets and attachment points should always have a significant safety margin to cope with added shock loads from wind buffeting and actuator operation; and with any rotational and shear forces. As a general rule, fixings with self-tapping screws and rivets will not be adequate: thread-locked screws or bolts are normally

FIGURE 5.12 FUNCTION AND AESTHETIC ISSUES

A pair of pneumatic linear actuators attached to an aluminium-framed window system for atrium ventilation. These minimal brackets, bolted onto threaded holes in the aluminium window section proved to be insufficiently robust and started to fail after two years' operation.

The occupier has had to add new brackets and fixing plates. The same actuators fixed to the lower mullion would reduce the forces acting on each actuator and simplify the fixing, but would be more visually intrusive.

FIGURE 5.13 LINKAGE PROBLEMS



The pneumatic linear actuators operating these motorised fanlights at the top of an atrium are virtually in the plane of the window when closed, leading to large turning moments and shear forces, also applied eccentrically to projecting studs from the brackets. After four years, this had proved too much for the self-tapping screws fixing the brackets to the mullions. The occupier has had to upgrade the fixings with bolted connections.

6 Control system

6.1 Background

The amount of ventilation a building needs - from IAQ control only in winter to maximum cooling in summer - can easily vary by an order of magnitude. During unoccupied periods even less ventilation may be desirable. The amount of air flowing through a given opening in a given position can also vary widely, as the driving forces (wind, natural buoyancy) change with indoor and outdoor conditions. In addition, the internal resistance to cross-ventilation will vary as doors, etc are opened and closed.

With these wide variations in the amounts of air needed and the associated driving forces, it can be difficult to achieve the full range of requirements using the same ventilation device. For example:

- The large openings required for summer ventilation will need to be shut tight in winter - when much less air is required but natural buoyancy pressures are higher.
- Winter ventilation will require much smaller openings.
- In summer, people may welcome air movement for its additional cooling effect (provided they can personally decide whether or not to sit in a draught).
- In winter people will complain of draughts unless the incoming air is either well-diffused or preheated.

Designers need to work out their control strategies very carefully and to present them clearly and diagrammatically in a step-by-step manner. If you expect the providers of controls and BMSs to second-guess the design intentions and to work things out for you, prepare to be disappointed.

6.2 Flowrates through ventilators

The flow rate through a ventilator is a function of the open area, but often this is not directly proportional to the actuator movement. In particular, the thickness of the ventilator and the way it fits into the building fabric can greatly affect the relationship. With a centre pivot or hinged window, the lower opening can be much restricted by the frame, the window sill and the reveal, particularly for the first 100 mm or so of travel, see Fig. 6.2. This can provide useful fine control, but it may restrict the required opening area for summer ventilation, particularly if safety considerations also restrict the permissible amount of window opening. For centre pivot or bottom-hung hopper windows, the upper opening may also be restricted by the reveal and by any internal blinds. External shading may also restrict flowrates and openings (it may also preheat the outside air, particularly if it is dark in colour and of a metallic finish).

6.3 Developing a control strategy

A wide variety of control strategies is possible (see reference [5] for flowcharts); and many will be used in combination. It is necessary to consider how the system will work at all times: not just in normal operation modes but in emergencies including power failures and fire alarms and during construction. The principal purposes were introduced in Section 3:

1. ***Localised heat and pollutant removal*** may be assisted by time, temperature or air quality-controlled ANV, particularly via ventilation stacks over heat sources.
2. ***IAQ and heating,*** this is often principal winter control mode. Key control problems are providing sufficient, but not excessive, background ventilation whilst avoiding draughts.
3. ***Daytime cooling.*** Key control problems during the heating season include telling whether overheating is a result of insufficient ventilation or too much heating; and in hot weather determining whether additional ventilation will necessarily cool the building (but some people may like the air movement even if the air is no cooler).
4. ***Night pre-cooling.*** Strategies are summarised in reference [6]. However, more recent studies such as Natvent [4] suggest that much simpler algorithms are easier to implement and can work better. They include aiming to keep embedded sensors in exposed fabric at a constant temperature; and progressively reducing night-time setpoints if daytime temperatures climb. However, remember not to over-cool the building at night in a quest to achieve lower afternoon temperatures: the occupants may well object to low morning temperatures.

Natural Ventilation may also be part of a ***mixed-mode*** strategy, where mechanical ventilation or cooling assists the natural systems. Integrated controls are particularly important here, see references [2] and [3].

6.4 Operating natural ventilation openings

Ventilators can be controlled in a number of ways. In order of increasing sophistication:

1. **On/off.** The opening has two positions: fully open and fully closed. This coarse method is best suited to buffer spaces and atria in which close control of comfort conditions is not essential. It is also more suitable for outlet positions at high level and remote from individual workstations than to inlet positions near workstations, where it may well cause draughts.
2. **Bank control.** The space has a number of windows or ventilators, in different banks each with on/off control. This allows the ventilation rate to be varied by opening-up banks of ventilators in succession. The banks can be multiple identical ventilators; or ventilators of different capacities which can provide either background or rapid ventilation.
3. **Stepped control,** which each opening having a number of fixed positions. This simplifies the controller/actuator interface, but does not offer such close control as a modulated system.

4 **Fully-modulating operation.** Here the actuator position is infinitely variable in response to a control signal. This type of control will usually be necessary on large openings if any degree of control over flow rate is to be achieved.

Control may be either "closed loop" - in which when the condition of the controlled variable changes the sensor detects the changes and initiates correcting action to the final control element. The effect of this is reflected in the controlled variable and reassessed by the sensor which continuously provides feedback to the controller ; or "open loop" - which does not include feedback of the type described above [12]. Open loop control is widely used because it is cheaper, but the case studies revealed widespread problems with uncertain status and undetected faults. With stepped or modulating operation, positioning errors can also mount up cumulatively in the course of a day.

As a general rule, the further the automated device is from individual occupants, the coarser its control can be, For example, it may be acceptable for opening lights which let heat out at the top of an atrium to be under on/off or banked control, while control of the inlets will need more finesse, see Box 6.1

6.5 Control sensors

The specification, type and location of control sensors can have a major effect on the success of a control strategy. In particular:

- Avoid unrepresentative "hot spots" when measuring inside and outside temperatures. A common problem is where the sun shines on a sensor, or warm exhaust air passes over it.
- Cold spots may also be a problem, for example sensors in the path of incoming outside air, or subject to air infiltration through the cable holes at the back.
- Take care about location when measuring slab temperatures. If sensors are too deeply embedded, the inertia can be too great; if close to a surface they may be too responsive; and avoid local effects such as proximity to fanlights or to heat rising from vending machines.

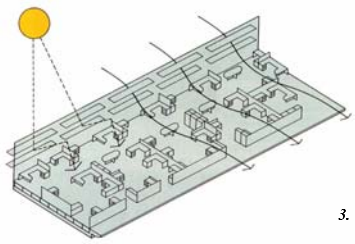
Direct measurement of pollutants (in particular carbon dioxide concentrations) can be effective in controlling air quality, but the sensors can be expensive and/or unreliable. Suitable locations for sensors can also be more difficult to find in naturally-ventilated buildings than in common mechanical ventilation extract ducts. An alternative is to use time schedules or occupancy sensors to activate the ventilation.

FIGURE 6.1 NATURAL VENTILATION CONTROL AT POWERGEN

1.

The automated windows at the top of the atrium at Powergen's mixed-mode headquarters in Coventry are opened under on/off control as necessary to let heat out of the top and to provide a negative pressure to help draw air in through any open perimeter windows. Occupants can open the middle and lower manually-controlled lower windows in the

2.



3.

facade to suit their individual requirements, but are asked to shut them when they go home. If overnight pre-cooling is required (evening office temperature over 23° C) the automatic controls open the atrium windows and the upper motorised fanlights in the façade draw air in over the exposed ceilings. The inlets are banked: if the air temperature in a zone falls below 18° C its bank of windows are closed and re-opened if it rises back above 20° C. All automated windows are closed at an airspeed of 10 m/s in the day and 20 m/s at night.

6.6 Combining user and automated control

Naturally ventilated buildings have frequently suffered from insufficient or inappropriate user control. As one occupant said "The BMS may know about the temperature, but it does not sit in the draught it causes." Automatic controls have sometimes also opened windows to let in noise, fumes, dust, insects and even small animals; or swung into draughty night cooling modes when buildings were still occupied.

Sensible integration of user and automated controls is therefore critical to the success of ANV schemes. The subject is discussed in general terms in references [6] and [7]. Occupants will always know more about what is going on in their part of the building than an automated system ever can, and must be allowed to make sensible choices.

User behaviour is governed by five key rules:

1 If they perceive conditions as "good enough", they will accept them, even if they are not ideal.

2 If local conditions are perceived as not good enough, occupants will wish to take action to improve them, e.g. by pressing a button, opening or closing a window, or telephoning a help desk. They will rarely act in anticipation of becoming uncomfortable. The ensuing action needs to be local too: one person may want their window open; their neighbour may not.

3 When users decide that they need to intervene, the actions they take will tend be those which they find simplest, most convenient and most accessible. The designers' task is therefore to make the actions that would suit the design intentions best to be the simplest, speediest and most intuitively obvious for the user. For example, if the design strategy wants a high-level window to be operated first, then it should be easier to do this than anything else.

4 Rapid response is essential. Occupants who are unable to take action to alleviate their discomfort - or unable to tell whether their actions have had any effect - will become disgruntled.

5 If an automated control action (like window opening) is perceived to be capricious or to make matters worse, occupants will get angry if they find themselves unable to countermand it.

For effective involvement, occupants must be informed about how the building is designed to work, so that the goals of good comfort, air quality and energy efficiency are all achieved. Ideally, the strategy should be clear, straightforward and as far as possible intuitive, so that people need to be told what to do only once. The control requirement will often change with the context for the user. for example, occupants sitting beside a window are most affected by the draughts from the lower casements, while those in the centre of the room are more likely to want to adjust the fanlights.

Suitable combinations of automated and manual control will not only provide backup in the event of BMS malfunctions, but will also empower the

FIGURE 6.2 CONTROL SYSTEM AT THE QUEENS BUILDING, LEICESTER

1.

In the mechanical laboratories at the Queens building in Leicester lack of feedback of vent status to the BMS has resulted in almost all the openings in this part of the building being manually operated through local press button control.

2.

occupants, improving their adaptive opportunities [8], and making variations in conditions more acceptable than when there are no over-ride facilities. The automated system must not usurp control too rapidly after user intervention (in one building studied it did this after just one minute!). As a general rule, manual over-ride settings should be retained until the end of the day; or at least until there is some major change in internal or external conditions. The ideal system will operate in the background, allowing users to undertake over-rides as they wish, and will afterwards quietly and unobtrusively restore systems to their most appropriate safe, comfortable and efficient default states - rather like the fictional butler Jeeves. Simple non technical description of the system is extremely important.

6.7 Ventilator status indication

As part of an effective strategy, it is important to know at the point of local control the status of the ventilator and that control action is being undertaken. Window-type ventilators are often used where they are visible, but even then it is not always easy to tell whether it is tight shut or a little bit open. Then status lamps or other forms of indication are helpful. Dampers or louvres are frequently hidden from view: status feedback then becomes particularly important, but is rarely included because of cost. Status lamps can also be used to advise users of the system's preferred state: for example, if it is hotter outside – or if it is very cold outside – a red light by the window can advise the occupants that the system would

FIGURE 6.3 CONTROL OF AUTOMATIC VENTS AT BRE ENVIRONMENTAL OFFICE

At the BRE Environmental office, hand-held infra-red controllers permit users to over-ride not just the automated windows but also the external louvres and the electric lighting from any point within the space. In spite of this good control, occupants have commented on insufficient feedback owing to the slow response times of windows and louvres; and not being able to see the automated windows which are behind the low points of the wavy ceiling.

1.

2.

3.

7 Installation and Commissioning

7.1 Installation

The objective is to provide a ventilation system which meets the specified requirements and satisfies the users. This requires properly managed resources to be allocated to the process of constructing a commissionable system. The design project team should be responsible for establishing the commissioning strategy. The system installer must study the enquiry and contract documents carefully, so that they understand the strategy and the designers' requirements; identify any unresolved items; and can enable the commissioning process to proceed.

Commissioning specialists - whether employed by the installer or independently - need to become involved as early as possible, so that their experience can be applied to planning and programming commissioning and pre-commissioning tasks. The installer and commissioning specialist should:

- Establish effective lines of communication between them and other parties involved.
- Review the contract documents to determine the requirements for commissioning, taking nothing for granted and seeking clarification where necessary.
- Produce a realistic programme with the commissioning activities phased alongside the installation programme.
- Regularly review the programme during installation, to establish the effect of any modifications and delays on the planned static completion and power-on dates; and to any other dates critical to the commissioning activities.
- Obtain from equipment suppliers and manufacturers their latest information for all items supplied. Standard details which are not modified to suit the particular project should always be treated with caution. Manufacturers' literature should be checked for installation requirements additional to those specified.
- Progressively record "as-installed" information on at least two sets of drawings: one "clean set", to form the basis for the record drawings and operating and maintenance documentation; and one "site set" for use by the commissioning specialist.
- Establish systematic site control procedures to assist the progressive monitoring of the standard of the installation practices maintained on site.
- Establish an equipment and materials procurement procedure which includes an effective means of checking each delivered item against the specified requirements.
- Retain all documents and literature provided with each delivered item of equipment for use by the commissioning engineer (and for inclusion in the operating and maintenance manuals).

If the installation is done carefully, then commissioning can be much quicker, easier and more accurate. Installers must therefore:

- ensure that their operatives and supervisors are adequately trained;
- give appropriate instructions on good housekeeping, workmanship, detailed system arrangements, accessibility and inspection;
- before commissioning ensure that any remedial work has been completed, and that all the works comply with the specified requirements.

During installation, there should be a regular planned system of continuous inspection and monitoring for correctness, quality and good engineering practice. It can benefit from proforma sheets which methodically register compliance and monitor the progress of any remedial action. These will help to:

- establish a consistently high standard of workmanship, and maintain it throughout the contract;
- stop defects accumulating which need to be put right before proper commissioning can start;
- stop defective work being temporarily hidden, only to surface again during commissioning.

TABLE 7.1 POSSIBLE INITIAL VALUES FOR CONTROL SETTINGS [5]

Wind speed to close windows:	*between 8 m/s and 15 m/s*
Wind direction:	*dependent upon site orientation*
Rain detection:	*generally on/off control determined by sensor: typically first drop of rainfall initiates a change in the sensor output.*
CO2:	*600 - 1000 ppm*
Indoor Air Quality:	*sensor-dependent (typically 50%, 5V or 12mA)*
Stack downdraught:	*shut dampers if 12° C or less in stack*
Solar gain:	*part-open windows if external temperature >18° C and solar gain rise is greater than 20 W/m2 (measured at a horizontal position 5m below the atrium glazing) over a period of 10 minutes.*

7.2 Readiness for commissioning: static completion

To be certified as ready for commissioning, an installation must have:

- been installed complete and in accordance with the specification;
- been subject to final inspection, with all outstanding remedial works completed;
- been successfully tested for air leakage in accordance with the specification and/or the relevant HVCA and CIBSE guidance documents;
- been satisfactorily cleaned in accordance with the specification;
- had all spaces in the vicinity of all system equipment and components needing safe access for commissioning cleared of all obstructions;
- be made safe and ready to set to work.

An installation in this state of readiness for commissioning is said to be statically complete.

7.3 Control schedules

Many control strategies currently employ on/off (open/close) control of inlets and particularly outlets. Better control could well be obtained where each of the variables are 'scheduled' over a range to determine the maximum travel of the ventilating device. For example, the wind speed can be scheduled against outside air temperature to obtain the best performance from the ventilation system. Say a wind speed of 13 m/s is the maximum that can be allowed in warm summer weather - 24°C or more - with fully open ventilators: at higher windspeeds papers would be blown around. However at 18°C outside, 8 m/s may be the maximum wind speed permissible, owing to the cooling effect of the draught. At a lower outside air temperature, say 14°C, 3 m/s might be the maximum.

Such scheduling may incorporate outside air temperature, internal space temperature, wind speed and wind direction. Measurements of rain intensity and wind speed can also permit windows to stay open in parts of the building where driving rain is not a problem. Table 7.2 shows typical initial schedules which might be used. Further tuning should be carried out on-site to determine the most appropriate limits for these schedules, based on the dominant factors for the particular site.

7.4 Practical completion

In order to demonstrate successful completion of commissioning, one will need to simulate summer or winter sensor values or to manipulate the setpoints in order to mimic the summer, winter or some intermediate condition. If the requirements of the BMS control system specification can be proved to the consultant in this way 'practical completion' will be possible.

7.5 Fine-tuning after practical completion

It is recommended that the designers' appointments and the contract includes provision for fine tuning in the year following handover. Typically this may require three visits to site in different seasons. How long each visit is will depend on the size of the building and the complexity of the system: a small building might only need a day each time, while a larger one (say up to 10,000 m^2) might need a week.

On the visits, the contractor should check system operation, focus on the any complaints and fine tuning problems reported by the occupants, and implement changes whilst still on site. The contractor must develop a plan for fine tuning beforehand. This should include a log book maintained by both the occupant and the contractor in which any reported problems are recorded; with the system status and the inside and outside conditions at the time also being noted. The history built up, also detailing any changes made to control strategies and setpoints, can be very helpful when considering any control alterations which need to be made.

For fine-tuning to be effective, the controls engineer and the building operator must work together and have confidence in each other, so avoiding situations in which each manipulates the system in a different way. A common direction should be decided, with each party notifying the other of changes made to the system, via the log book.

In innovative buildings - and particularly those which combine active and passive systems - contractors, facilities, and maintenance staff may find it difficult to develop mental models of the behaviour of an unfamiliar system and to identify clearly what interventions need to be made. The added perspective of the designer can often assist discussion and lead to more effective resolution of problems. We therefore recommend that the designers keep in close touch with the fine tuning activities and plan to go to site for at least one day in the middle of each fine tuning visit.

BOX 7.1A TYPICAL FINE TUNING PROGRAMME [5]

First visit:
Before fine tuning can begin, all control points on the system should be checked to ensure that they are working properly. All ventilation devices should be examined to ensure that they close tightly, do not let in rain, and their opening/closing mechanisms are in sound condition and not obstructed. A spot check of the calibration of relevant sensors should be carried out. Trend logging of relevant points should be set up.

NB: It is often easiest to assess the performance of the system and to identify any important problems if the control strategies are simple to start with - even if this means temporarily disabling some of the more advanced features. Similarly, it can help to start looking at only basic monitored data (though it may well be worth collecting extra data for later analysis).

Second visit:
The data from the monitoring set up on the first visit should be analysed. This will give an initial indication of the performance of the system and its controls, and the need for any fine tuning. Setpoints and control algorithms may need adjusting, but take care in making adjustments if there is not enough data to make a firm assessment of the situation.

Third visit:
Tuning of other variables should be concentrated upon. For example, is ventilation system working effectively with the current wind speed and direction setpoint; or is it being limited unnecessarily?

Completion
A report detailing the ventilation system's performance and associated controls should be produced, incorporating information covering the operation of the system, setpoints, example graphs and details of changes made. The O&M manual will also need updating to take account of the changes in strategies, schedules and setpoints which have been undertaken.

8 Operation and maintenance

8.1 O&M Manuals

Good operation and maintenance manuals are essential to communicate how the system works (in technical terms, for the facilities manager, and for individual occupants), control strategies and settings; how to operate the system in different seasons, and how to undertake routine maintenance and basic troubleshooting. They should also include record drawings, commissioning and fine-tuning records, manufacturers' technical and maintenance data on all items of equipment installed, and heath and safety issues.

BOX 8.1 TYPICAL CONTENTS LIST OF AN O&M MANUAL

SECTION 1
INTRODUCTION

SECTION 2
EQUIPMENT SCHEDULE

SECTION 3
SYSTEM DESIGN

SECTION 4
OPERATING INSTRUCTIONS

SECTION 5
HEALTH AND SAFETY
INFORMATION

SECTION 6
MAINTENANCE INSTRUCTIONS

SECTION 7
WITHDRAWAL FROM SERVICE

SECTION 8
DRAWINGS, CERTIFICATES, LEAFLETS

Reference should be made to the new CIBSE Guide to Operation and Maintenance:

- *Guide to ownership, operation and maintenance of building services*, CIBSE, March 2000.

This almost certainly covers most of the issues which are relevant to this section.

8.2 Maintenance Procedures

Frequency and requirements of maintenance for the various system components.

8.3 System optimisation

Procedures for reviewing system performance and adjusting in the light of experience and changing occupant requirements.

8.4 Project feedback

Suggested proforma for recording experience and lessons gained that can be fed back into future designs.

9 References

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10 P Pike & K Pennycook, *Commissioning of BEMS - a code of practice,* BSRIA Applications Handbook 2/92 (1992).

C Parsloe, *The commissioning of air systems in buildings,* BSRIA Applications Guide AG 3/98 (March 1998).

11 CIBSE Commissioning Code, *A: Air Distribution Systems,* CIBSE (1996).

12 CIBSE Application Manual, *Automatic Controls*, 1985.

Legislation

Standards Relevant to Automatic Vent Opening Devices

- **British Standards:**

BS 5925:1991 Code of Practice for ventilation principles and designing for natural ventilation.

BS 7346:

Part 1: 1990	Components for smoke and heat control systems. Specification for natural smoke and heat exhaust ventilators.
Part 2: 1990	Components for smoke and heat control systems. Specification for powered smoke and heat exhaust ventilators.

- **European Standards:**

BS EN 55014:

Part 1: 1997	Electromagnetic compatibility. Requirements for household appliances, electric tools and similar apparatus. Emission. Product family standard
Part 2: 1997	Electromagnetic compatibility. Requirements for household appliances, electric tools and similar apparatus. Immunity. Product family standard.

BS EN 55104:1995 Electromagnetic compatibility. Immunity requirements for household appliances, tools and similar apparatus. Product family standard.

EN 60335

Part 1: 1995	Specification for safety of household and similar electrical appliances. General requirements.

EN 60742: 1996 (BS 3535-1;1996)

Isolating transformers and safety requirements.

- **DIN Deutsches Institut für Normung (German standards institute):**

Regulation for fire security.

E260 N 2/1 (einschließlich UP-variante) ab Serien –Nr. 2000

E260 N 4/1-2 ab Serien – Nr.1000

E260 N 8/1-4 ab Serien – Nr.1000

Manufacturers and suppliers of vent opening gear

AUTOMATED CONTROL SERVICES LTD
Unit 7
Milburn Road
Westbourne
Bournemouth BH4 9HJ
Tel: 01202 768177
Fax: 01202 768277
E-mail: sales@automatedcontrolservices.co.uk
Alex Wiseman

CLIMATE CONTROLS Ltd
Le Bourg
Forest, Guernsey
Channel Islands GY8 0DS
Tel: ` 01481 237691
Fax: 01481 238234
E-mail: info@climate-controls.com
John Page
Pierre Bisson

BETA NACO
Stourbridge Road
Bridgnorth
Shropshire WV15 5BB
Tel: 01746 761921
Fax: 01746 766450

GEZE UK Ltd
Chelmsford Business Park
Colchester Road
Chelmford
Essex CM2 5LA
Tel: 01245 451093
Fax: 01245 451108
Spencer Buck

SE CONTROLS
Crossfield Road
Industrial Estate
Trent Valley
Lichfied
Staffs. WS13 6RJ
Tel: 01543 415750
Fax: 01543 415747
Will Perkins

MORSE CONTROLS Ltd.
Christopher Martin Road,
Basildon
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Tel: 01268 522861
Fax: 01268 282994

TITON HARDWARE Ltd
International House
Peartree Road
Stanway
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Essex CO3 5JX
Tel: 01206 562400
Fax: 01206 543126
E-mail: sales@titon.co.uk
Nicola Rivers

VELFAC Ltd
Window System
Merlin Place
Milton Road
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Tel: 01223 426606
Fax: 01223 426607
E-mail: post@VELFAC.co.uk
Pam Wade

WINDOW MASTER
Kettering Parkway
Wellingborough Road
Kettering
Northants NN15 6XR
Tel: 01536 510900
Fax: 01536 510411
Leeson Medhurst / Martin Hodgson

VENTILATION GEAR Ltd.
9 Morjon Drive
Great Barr
Birmingham B43 6JH
Tel. 0121 3587592
Fax. 0121 3582364

COLT INTERNATIONAL
New Lane
Havant
Hants PO9 2LY
Tel. 01705 451111
Fax. 01705 454220
E-mail info@coltgroup.com
Paul W. Langford

SKF ENGINEERING PRODUCTS Ltd
Sundon Park Road
Luton
Bedfordshire LU3 3BL
Tel. 01582 496758

Manufacturers and suppliers of dampers and louvres

ABB VELODUCT LTD

ACTIONAIR GROUP LTD

ADVANCED AIR (UK) LTD

AIR DIFFUSION LTD

BELIMO AUTOMATION (UK) LTD

BESTDELL INTERNATIONAL LTD

BROKE AIR

CAPPER GPS

GGS KLIMAT

GILBERTS (BLACKPOOL) LTD

KONVEKTA LTD

LINDAB LTD

LORIENT POLYPRODUCTS LTD

POWER UTILITIES LTD

RCM PRODUCTS LTD

REGA METAL PRODUCTS LTD.

SAME LTD

TROX (UK) LTD

VENT-AXIA LTD

WATERLOO AIR MANAGEMENT

WOODS OF COLCHESTER LTD

TABLE 2.1 PRINCIPAL RESPONSIBILITIES & INTERACTION

KEY:

Stage:				
	A	Brief	G	Bills of quantities
	B	Feasibility	H	Tender action
	C	Outline proposal	J	Project planning
	D	Scheme Design	K	Operation on site
	E	Detailed design	L	Completion
	F	Production information	M	Feedback

PRIMARY RESPONSABILITY (white) — SECONDARY RESPONSABILITY (grey)

Categ.	Section	Client	Architect	Services Engineer	Facilities Manager	Specialist Subcontractor / Product Designer	Contractor	Comments
Briefing (Stage A)	1.1 1.2 1.3	❑ Define site / location ❑ Activities ❑ Occupancy ❑ Performance criteria ❑ Control preferences	Comment on: ❑ Area / Volume requirements ❑ Plan depth / massing ❑ Orientation ❑ Spatial relationships ❑ Performance criteria	Comment on: ❑ Performance criteria	Comment on: ❑ Performance criteria			The structure of this table of responsibilities assumes a conventional contract. Where the contractor is engaged in design then the responsibility chain will change.
Ventilation strategy (Stage B, C)	3.1 3.2 3.3 3.4 3.5	❑ Take ownership of strategy ❑ Question implications for: ❑ Lifecycle cost ❑ Occupant satisfaction ❑ Control options ❑ CDM Issues	Define relationships of supply and Exhaust for different purposes: ❑ Zoning ❑ Airflow paths ❑ Geometry ❑ Application of principles ❑ CDM Issues ❑ Operational instructions	Define flowrates to achieve: ❑ Internal Air Quality ❑ Cooling ❑ Local extraction of pollutants ❑ Control Plus ❑ Pre-commissioning ❑ CDM Issues ❑ Draft simple instructions for Users	Question Implications for: ❑ Occupants satisfaction ❑ Operation ❑ Maintenance ❑ CDM Issues			It is important that all involved take ownership of the agreed strategy. This includes the quantity surveyor. Elements which are fundamental to the working of the building cannot subsequently be regarded as optional extras in cost cutting exercises.
Ventilation openings (Stage C, D)	4.1 4.2	Implications for: ❑ Appearance ❑ Operation ❑ Maintenance ❑ Access ❑ Replacement	❑ Preliminary sizing of vent openings ❑ Opening type ❑ Weathering ❑ Security ❑ Clashes with other elements ❑ Air tightness / thermal performance ❑ Interface with building envelope	❑ Preliminary sizing of ventilation openings for supply and exhaust ❑ Performance prediction in relation to briefing criteria ❑ Pollution and noise control ❑ Access for maintenance	Access for: ❑ Commissioning ❑ Cleaning ❑ Maintenance	Implications of: ❑ Actuator type ❑ Linkages and fixings ❑ Effective area achievable ❑ Frame reinforcement	❑ Subcontract package boundaries, coordination and programming ❑ Advise on maintenance procedures	❑ Generally the vent supplier should be made responsible for integration of vent with actuator linkage and controls.
Actuator (Stage E - J)	5.1 5.2 5.3 5.4 5.5		Implications for: ❑ Appearance ❑ Achieving required free area opening ❑ Achieving required ventilation purpose	Choice of type in relation to: ❑ Weight and size of openings ❑ Type of opening ❑ Location (low or high level) ❑ Operating parameters	Implications for: ❑ Operation ❑ Maintenance ❑ Replacement	Implications for: ❑ Fixings ❑ Frame reinforcement ❑ Noise ❑ Speed of operation	❑ Recommend that actuators form part of the window package where appropriate	❑ Engineer must also allow for power and control requirements and circuiting, as well as maintenance, alteration and replacement.
Linkage (Stage E - J)	5.6		❑ Number of openings operated ❑ Geometry and connections ❑ Maintenance and cleaning	❑ Commissioning requirements ❑ Maintenance and cleaning	Implications for: ❑ Operation and maintenance	Advise on: ❑ Forces acting on fixing points	❑ Check linkages and fixings have been defined by design team	❑ Where vent, actuator and control are not integrated, the architect will become responsible – beware !
Controls (Stage E - J)	6.1 6.2 6.3 6.4 6.5 6.6 6.7	❑ Implications of control strategy for occupant satisfaction.	❑ Control strategy ❑ Operation during construction ❑ Status feedback	Control stategy: ❑ Status feedback ❑ Automatic / normal / fire modes ❑ Occupant override ❑ Wind /rain/snow thresholds	Implications for: ❑ Operation and maintenance	Control logic: ❑ Pre-commissioning demonstration of system		
Installation and Commissioning (Stage K - M)	7.1 7.2 7.3 7.4	❑ Recognise importance ❑ Ensure time in programme	❑ Recognise importance ❑ Ensure time in programme	❑ Commissioning requirements ❑ Access ❑ Witnessing	❑ Access for commissioning ❑ Commissioning requirements	❑ Undertake commissioning according to commissioning plan	❑ Commissioning requirements Ensure time in programme ❑ CDM Issues ❑ Supply O & M Manuals	❑ Allow for modifications during first year of operation
Operation and maintenance	8.1 8.2 8.3 8.4	❑ Allow for training		❑ Fine tuning ❑ Simple user instructions	❑ Fine tuning ❑ CDM Issues ❑ Understand functioning ❑ Explain to occupants	❑ Undertake maintenance		

TABLE 5.1 ACTUATOR TYPES

Actuator Type	Linkage Options	Vent Type Options	Length of travel	Typical Loading range	Comments
LINEAR PUSH-PULL PISTON Linear push-pull piston actuators, where a motor propels a push rod forward. These are most commonly pneumatic but electro-hydraulic versions are also available.	Single opening only	High level windows Sash Windows Rooflights	Pneumatic: 1m – 3m Electric: Up to 1m	Electric: 3kN	*Advantages include mechanical simplicity, robustness, fire resistance of pneumatic units, and generation of large forces.* *Disadvantages include large projecting cylinders and mechanical damage to windows, linkages and fixings which are not robust enough or not well integrated with the ventilator. Travel is typically 200-500 mm, but longer distances are possible with large cylinders.*
CHAIN DRIVE PUSH-PULL Projecting chain drive push-pull actuators. An electric motor drives a chain over a sprocket wheel, providing linear motion to push out a window.	Single opening only	Top and bottom Hung Horizontal Pivot Casement window	300mm – 500mm	250 – 500N	*They are generally modest in size and mechanical strength; and with limited travel of typically 150-200 mm. A useful feature is that the motion tends to be at right angles to the axis of the actuator body, which can therefore be tucked away in the plane of a window frame; or even recessed concealed into it. Their compact size and unobtrusive appearance makes them best suited to smaller windows such inward- and outward-opening fanlights*
RACK AND PINION A rotary electric motor drives a geared shaft which engages with one or more racks, providing linear motion with less bulky projections than linear actuators.	Large single openings Multiple openings in series	Top hung vents Sash Window Rooflights	500 – 1000mm	Max 500N	*Different types are available. They are capable of operating a large number of opening in series. They are also useful for windows which require paired actuators (on each side): with a common pinion the two racks move together and the window is not twisted (as happens, for example, if one of a pair of linear actuators fails; sometimes breaking the window).*
LINEAR SLEEVED CABLE OR ROD These are driven by a rack-and-pinion, worm gear or chain drive electric motor and allow linear motion to be transferred, for example to sliding sashes.	Multiple openings in series	Louvres Rooflights	1000mm but much longer specials	200N	*Individual components and fixings often not as robust as other actuator types. Size and weight of individual vents should therefore be limited.*
ROTARY These are most commonly applied with dampers and louvres, often rotating one of the shafts directly, with mechanical linkages to the other louvres. Sometimes they also operate shafts connected to cranks and lever arms to provide linear motion.	Single or multiple damper or louvre assemblies	Dampers Louvres	90° rotation	15NM – 30NM	*There are two main types: one with a bi-directional motor used for opening and closing, and one which motors in one direction only and uses a spring to return, which can be useful for fail-safe operations.*
LEAD SCREW These actuators form the majority of linear actuators and are sub-divisible into high and low power applications. For general applications a low friction nut is driven along the lead screw to provide motive force.	Multiple openings in series	Louvres Rooflights	Up to 1000mm	200 – 2000N	*The motor can be mounted in line with the lead screw or perpendicular to it. In-line mounted motors use a planetary gearbox to transmit the drive to the lead screw. This keep the profile of the actuator slim but limits the available torque and therefore force of the actuator.*
LEVER ARM GEAR This gear which exploits the mechanical advantage of the lever is suitable for high level vents and multiple openings.	Multiple opening in series	Top Hung vents Centre pivot vents	Bespoke	Bespoke	*Traditional type of vent opening gear often found in older (Victorian) buildings. Robust but visually intrusive.*
GAS STRUTS WITH CABLES A linear variant on the spring return motor is where an automatic catch releases the window and a gas-filled strut opens it, or holds it open. Closure is then affected by pulling on a cord, either manually or by means of small electric winch.	Single openings	High level rooflights	Allows up to 60° of flap movement	2000N	*To make the mechanism more compact gas struts can be used “back to back” (such a system has been patented by one manufacturer).*