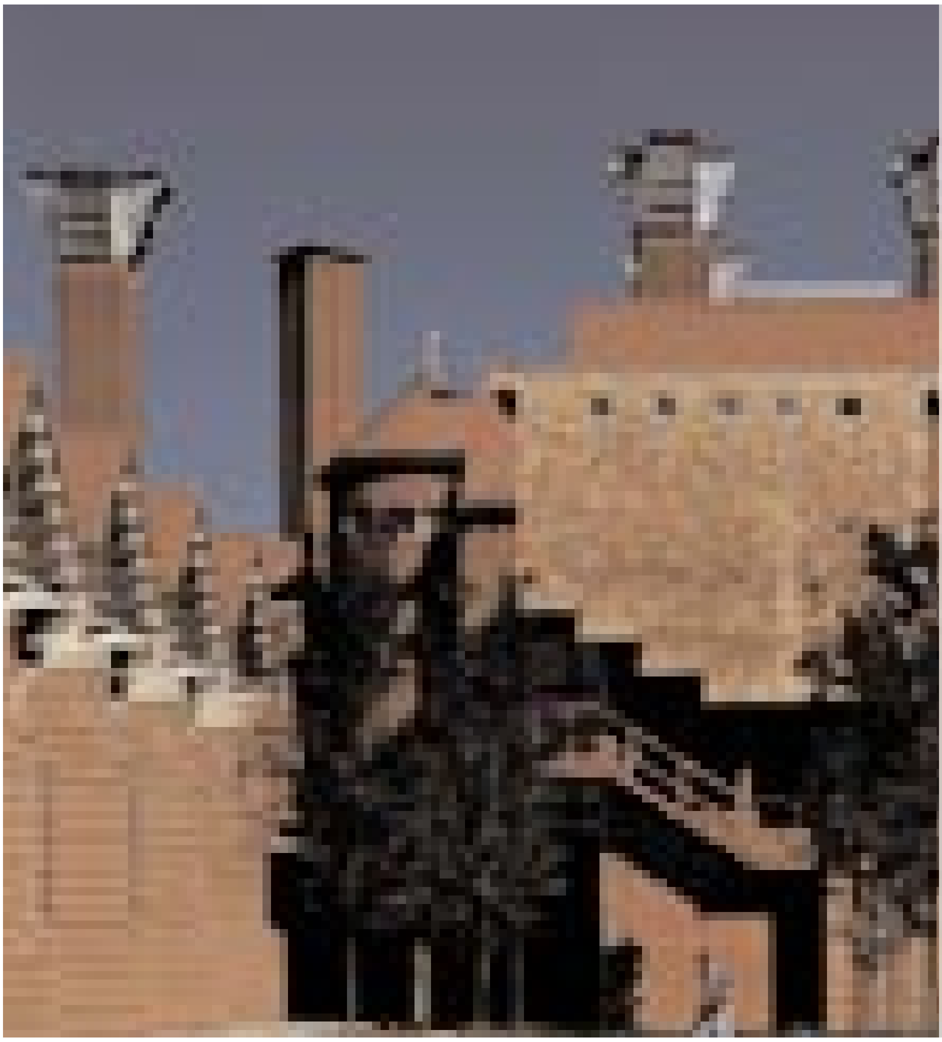
The Queens Building De Montfort University

– feedback for designers and clients



- Energy costs halved at no extra capital cost
- Natural ventilation used for urban site: air-conditioning avoided
- Effective daylighting reduces the need for electric light
- Winner of the 1995 HVCA Green Building of the Year award

BEST PRACTICE PROGRAMME

ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

OVERVIEW

This is the first in a series of reports on innovative buildings to be published under the Energy Efficiency Best Practice programme

The need to rebuild the School of Engineering and Manufacture at De Montfort University afforded the opportunity for a radical approach to the design of a new building, which would be a showpiece for the new university.

The architects were given the difficult brief to design a complex of laboratories, lecture theatres, classrooms, studios and offices for an L-shaped compact inner city site, closely surrounded by non-university buildings and private houses. In addition, the budget for the building was constrained by the criteria of the Polytechnic and Colleges Funding Council. Normally such a brief would result in the use of mechanical ventilation and air-conditioning in parts of the building. However, the architects were determined to challenge this assumption, and to produce an entirely naturally ventilated solution.

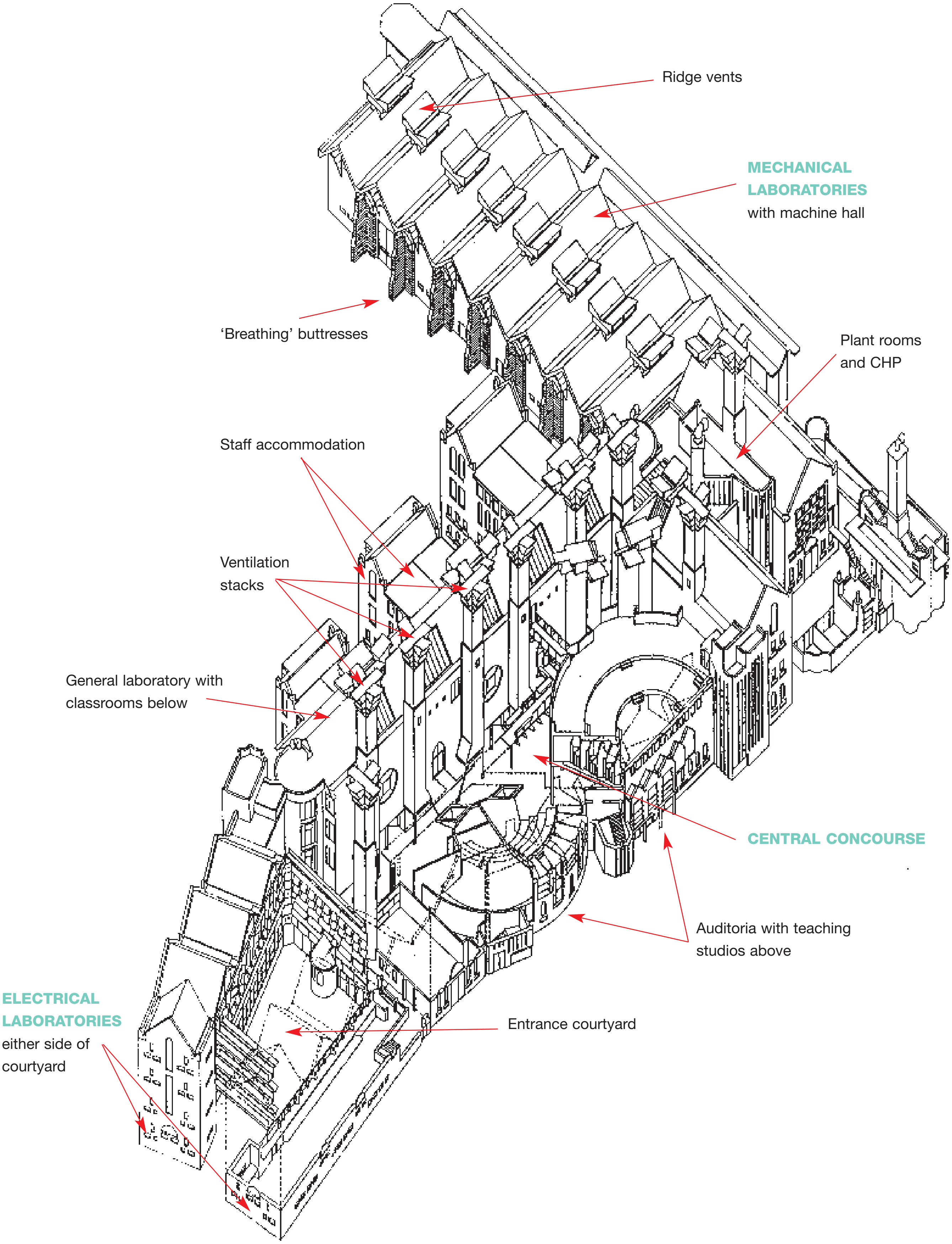
The result is a landmark building that is naturally ventilated and daylit, thereby eliminating the need for air-conditioning, and substantially reducing the need for electric lighting. Consequently, the building consumes approximately half the energy required by a conventional university building of this type, as given in the Department of the Environment's (DOE's) energy yardsticks.

In spite of the absence of a mechanical cooling system, students and staff find the building provides a comfortable working environment. The few hot days when the internal temperature exceeds 27°C coincide with the long summer holidays, when the building is sparsely occupied. These higher temperatures are acceptable under current design guidelines shown on page 8.

De Montfort University has acquired in the Queens Building a notable facility which, while being architecturally striking, does not clash with its surroundings because it is constructed from traditional materials, using traditional techniques, in keeping with the neighbourhood.

The Queens Building won the HVCA Green Building of the Year award in 1995.

AXONOMETRIC OF THE QUEENS BUILDING



INTRODUCTION

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INTRODUCTION

'Inoperable and unsafe' was the judgement passed on the building stock of De Montfort University's city campus (formerly Leicester Polytechnic) in 1989. It was therefore decided to construct a new building for the School of Engineering and Manufacture, with the intention that it should also be a catalyst for the regeneration of the run-down inner city area.

The resulting design brief called for an innovative design, naturally ventilated and daylit, reflecting and inspiring the creative nature of the School, while being sensitive to the environment and using traditional construction techniques in keeping with the neighbourhood.

This Report looks at the design and construction of a multi-purpose building which imposed considerable demands on the designers and resulted in a landmark, user-friendly, environmentally sensitive and energy-efficient building. An axonometric plan of the building is provided for reference when reading this Report (page 3).

Concept

The architects, Short Ford Associates, had used passive techniques in a Mediterranean climate, and were confident that such techniques could be applied to a building in the UK with high casual heat gains. The Queens Building concept was therefore to have a highly insulated, thermally massive envelope with a shallow plan and generous ceiling heights to promote natural ventilation and daylighting. Warm air would accumulate above the occupied zone and be exhausted through vertical shafts and ridge vents. A central lightwell would act as a thermal and acoustic buffer zone while permitting daylight to penetrate deep into the main building. Windows and rooflights would be shaded to reduce glare and solar heat gain.

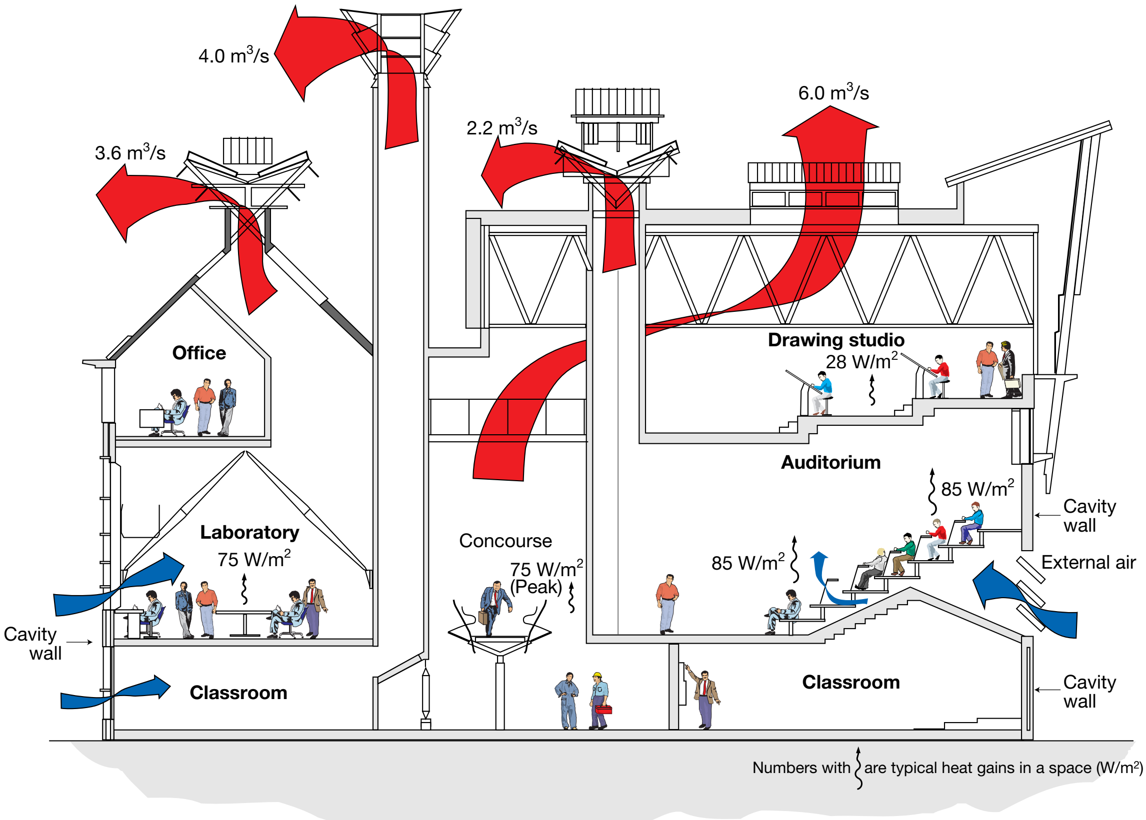

Figure 1 Natural ventilation strategy in the central building

BUILDING DESCRIPTION

GENERAL

The Queens Building provides academic facilities for 1500 full-time students in the School of Engineering and Manufacture. At present, during the hottest summer months, the building is occupied only by researchers and university staff, but the design allows for the possible introduction of a four-semester year, which would entail full occupancy during the summer.

The building is characterised by the exposure of its thermally massive structure which includes fair-faced brick and blockwork internal walls and exposed soffits to the concrete floor slabs. The construction of the building makes visible the structural, acoustic and ventilation techniques employed. The 10 000 m^2 structure has three distinct elements, as follows.

Central building

A full-height central concourse (figure 2) acts as a lightwell and thermal buffer zone for adjoining spaces. The ground floor classrooms and the auditoria are ventilated by the distinctive chimneys which act as ventilation stacks, while laboratories and staff areas on the upper floors are served by rooftop ventilators. Air from the concourse passes up through the drawing studios to ridge ventilators, which are glazed and have a northerly orientation to optimise daylighting without solar gain penalties.

Mechanical laboratories

To reduce noise levels at a nearby terrace of private houses, the naturally ventilated machine hall is flanked on the western façade by a two-storey block of specialist laboratories. This also provides a secondary function of resisting the lateral forces of the travelling gantry crane. These forces are opposed on the east elevation by a series of buttresses. Each buttress is hollow, providing an attenuated fresh air inlet duct, with similarly lined voids over and between ground floor offices supplying air from the west façade (figure 3).

Acoustically baffled ridge vents and inlet louvres on the west façade are operated automatically, while internal timber doors to the breathing buttresses can be opened manually. The glazed ridge vents, and the west-facing gable windows, which are triple glazed to reduce noise penetration to the outside, ensure that the machine hall is well daylit, with roof overhangs and reveals shading machinery from direct sunlight.

Electrical laboratories

The electrical laboratories are housed in two shallow-plan, four-storey wings, on either side of the entrance courtyard, and so benefit from simple cross ventilation and well distributed daylighting. Low-level and high-level opening windows are large enough to provide sufficient ventilation to dissipate the high internal gains from computers and equipment, while the cantilevered façade reduces direct solar gain and glare (figures 4 and 5).

Figure 2 Central building concourse

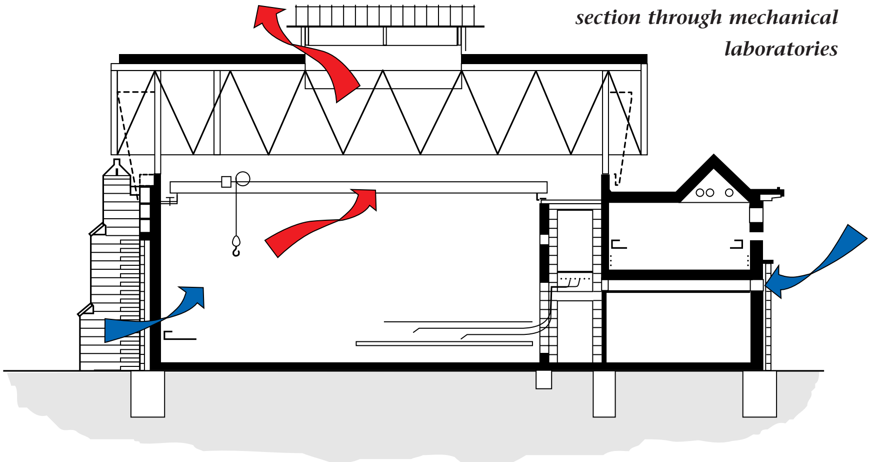

Figure 3 Diagrammatic section through mechanical laboratories

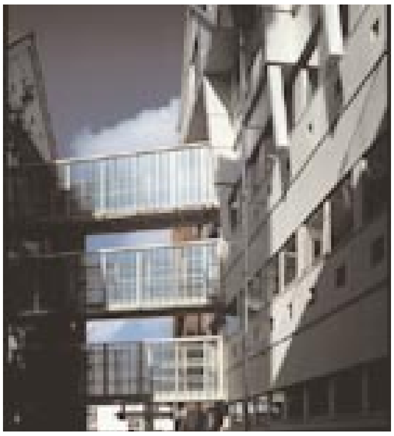

Figure 4 Stepped white façades and opening windows on courtyard elevations of electrical laboratories

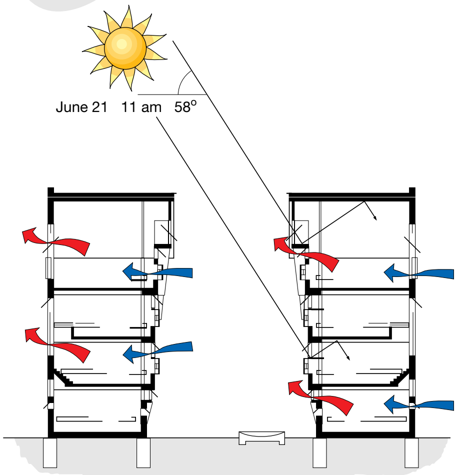

Figure 5 Diagrammatic section through electrical laboratories

SERVICING STRATEGIES

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Ventilation

Natural ventilation has been exploited throughout the building. The natural ventilation strategy for the two auditoria is particularly innovative. Fresh air enters these areas via plena below the raked wooden floor (figure 6) and also directly through the external façade in Auditorium 2, and is exhausted by two 13.3 m high chimneys. In the winter, the intake air is heated by finned tubes positioned behind the vertical supply grilles. A simple punkah fan has been installed in one stack in each auditorium to aid ventilation when necessary. Motorised dampers at the top of the ventilation stacks are adjusted by a building energy management system (BEMS) to maintain room temperatures in the greater part of the building. The auditoria required more sensitive controls with the addition of modulating dampers on the air inlet.

The basic requirement when the auditoria are occupied is for a minimal supply of fresh air, as determined by carbon dioxide (CO_2) sensors, with an increasing air volume to meet the cooling load, provided that the internal temperature exceeds the external temperature. To avoid draughts, the fresh air is heated to a minimum temperature, and stack dampers will close if the temperature in the middle of the stack is sensed to be less than 12°C. Sensors also prevent dampers from opening to more than 50% if there is a risk of entry of wind-driven rain.

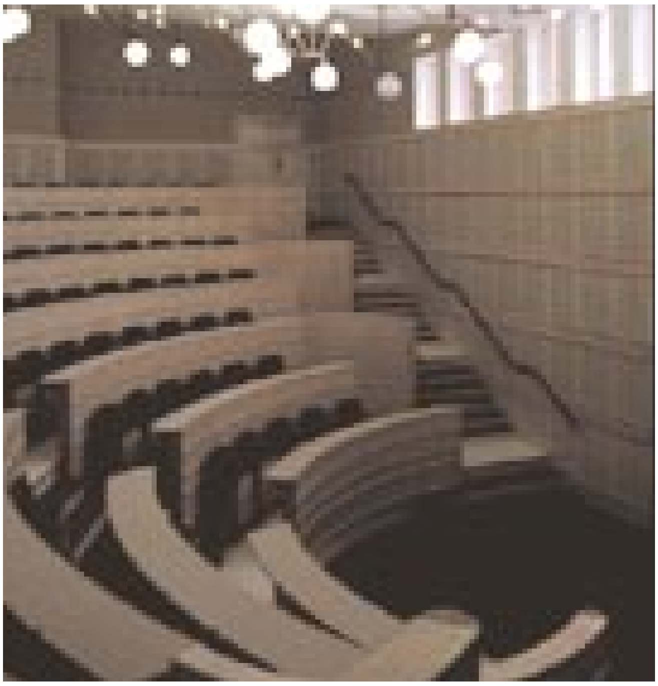


Figure 6 Air enters the auditorium through plena under the raked seating

In the summer, outside air is used to cool the auditoria during the night but this is limited to a minimum building structure temperature of 17°C to avoid discomfort, and the risk of activating the heating plant.

Thermal mass

Thermal mass has been utilised extensively in combination with night cooling, avoiding air-conditioning in spaces that would normally require it.

Daylighting strategies

Spaces are lit primarily from side windows, which are shaded from direct solar heat gain by deep reveals, overhanging eaves or adjacent parts of the building. A number of small windows are used, in preference to large glazed areas, to provide well distributed daylighting without the penalties of high heat transfer. Northlights and rooflights are used extensively to meet the combined needs of stack ventilation and daylighting, while the full height concourse admits daylight into the core of the main building. In the mechanical laboratories, high light levels are achieved by gable glazing and rooflights, which also act as ridge ventilators (figure 7).

In the electrical laboratories, continuous internal light shelves extend over the full depth of the perimeter benches because of the extensive use of computer terminals (see figure 8). A series of small windows below the shelves provides a low level of illumination and minimal glare to each workstation. Larger areas of glazing above the shelves ensure good daylight levels deep into the room. The courtyard façades are all clad with white panels to reflect daylight into the lower floor areas. This compensates for shading by the adjacent wings. The daylighting performance of the building has been extensively monitored over a 12-month period and the results are discussed in ‘Daylighting under the microscope’**[1]**, an article in the CIBSE Journal.

BUILDING SERVICES

Space heating and domestic hot water

The main heating plant consists of a small (38 kWe)* combined heat and power (CHP) unit, a condensing boiler and two high-efficiency boilers, sequenced to fire in that order, provided there is sufficient demand for electricity and heating. The inclusion of the CHP unit was justified on educational grounds for research potential rather than for its economic viability, so its performance has not been assessed here. Heating circuits are compensated, while thermostatic radiator valves (TRVs) and room thermostats provide local trimming. Most rooms have perimeter radiators or natural convectors, except for the mechanical laboratories which have high-level radiant panels in the machine hall and low-temperature hot water heater batteries in air handling units serving specialist laboratories.

Electric lighting

High-efficacy lamps such as compact and T8 linear fluorescents, and high-pressure discharge sources are used to supplement daylighting. During normal working hours, lighting circuit contactors are energised by the BEMS and then controlled locally by manual switches. At other times the BEMS switches off circuits in unoccupied spaces via passive infrared detectors (PIRs). There is an option to relate switching to external daylight levels, although this has not yet been adopted.

Building energy management system

The BEMS controls the heating, lighting and ventilation systems. Averaging thermostats in the ten different control zones are ‘set back’ to allow night-time cooling in summer. Due to the complexity of the natural ventilation procedures, the operating instructions are written in simple English, which should simplify subsequent refinement by the user. Numerous additional sensors have also been included so that the BEMS can be used by the students for educational purposes.

Figure 7 Gable glazing and rooflights help to achieve high light levels in the mechanical laboratories

Figure 8 Lightshelves over VDUs in electrical laboratories

*The unit kWe denotes the electrical output of the CHP unit.

AUDITORIA DESIGN ANALYSIS

AUDITORIA DESIGN ANALYSIS

It was originally thought that the auditoria, with design heat gains of 100 W/m^2, would require mechanical ventilation. However, preliminary calculations by the mechanical and electrical (M&E) consulting engineers, Max Fordham Associates, suggested that the auditoria as well as the laboratories might be naturally ventilated successfully. Further analysis was partly funded through a pilot study by the DTI's Energy Design Advice Scheme.

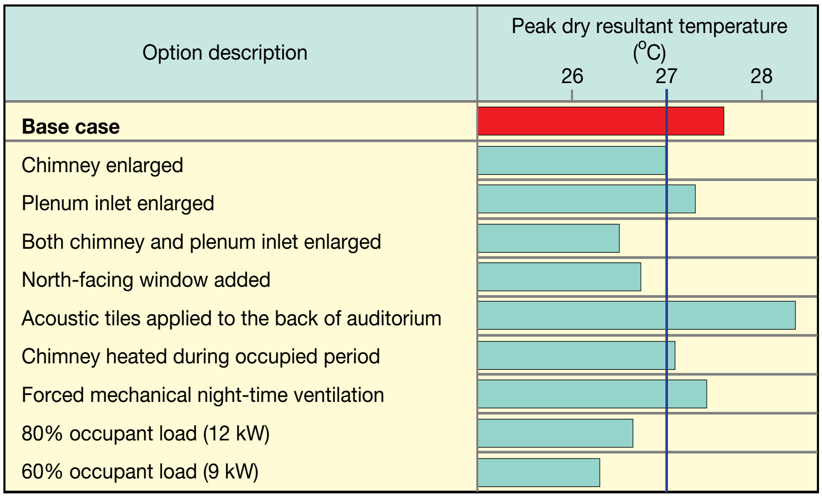
Computer modelling, using dynamic thermal simulation software, was undertaken for the auditoria by one of the University's own departments[2]. Using weather data for a typical hot sunny day, the program predicted ventilation rates of over 6 air changes per hour (ach), with a peak dry resultant temperature of 27.6°C for the base case. The influence of various design options on temperatures and air flow rates was then studied (figure 9).

For a typical year, the program predicted that, even with the inclusion of acoustic tiling, there would only be 9 hours per year when the dry resultant temperature would exceed 27°C, none of which would occur during normal term time. Acoustic treatment was therefore included without further optimisation of the original design.

Laboratory tests were also carried out at Cambridge University on the performance of the ventilation stacks, using a scale model inverted in a salt bath[3]. The falling of the denser salt solution equates to the rising of warm air in the building, and an index of equivalent temperature can be determined. Generally, it was found that all spaces could be adequately ventilated and, if anything, the proposed classrooms would be over ventilated. Specific recommendations were to increase the area of emergency vents in the concourse to prevent the build-up of stale air and smoke in the communal meeting and transit areas, and to use individual rather than shared ventilation stacks for concourse and lecture rooms to avoid the risk of hot air or smoke transfer between spaces.

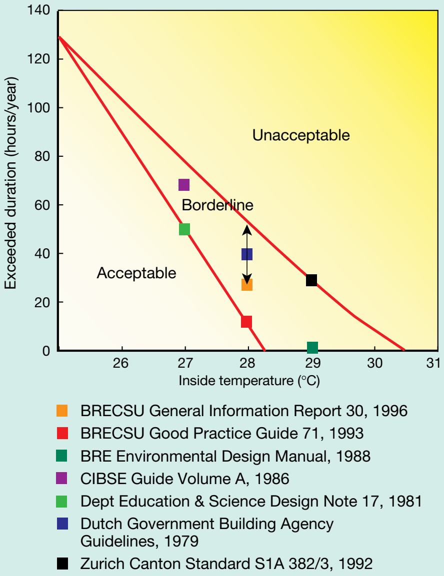
The two methods of analysis – computer and salt bath – are fundamentally different; the computer simulation is a dynamic model, so can account for the effects of thermal mass, while the salt model predicts steady state temperature distribution but is better suited to complex spaces. However, there was sufficient agreement between the two sets of results to give the design team confidence to extend the stack ventilation strategy to the auditoria.

Figure 9 Predicted effect of design options on peak dry resultant temperatures in the auditoria



Overheating design criteria

There is no universally accepted criterion for predicting summertime overheating in passive buildings, but there is a general consensus among European guidelines that 27-28°C is a realistic threshold.



PERFORMANCE IN USE

PERFORMANCE

Internal temperatures

Analysis of the BEMS data indicates that internal temperatures have been maintained within the design criteria (see Design Analysis) throughout the building (figures 10 and 11). The higher temperatures in the third floor staffrooms were largely attributable to the absence of the roof light opening mechanism and a defective three-port valve, preventing proper isolation of the main heating circulation during the summer. Although the temperature in the second floor staff offices and central laboratories can be seen to also rise above 27°C, this occurred for only 22 hours and 7 hours respectively over the whole year.

Auditoria

The auditoria have been subject to the most extensive monitoring. Short-term heat load tests suggested that internal temperature would not rise above 24°C, even with 160 students (16 kW) present for the whole day and the outside temperature reaching 30°C. This does not, however, account for the effect of a series of hot days when the effectiveness of 'night cooling' would be successively reduced.

Monitoring over a longer period[4] has recorded air temperatures remaining stable between 20°C and 22°C, air change rates in general accordance with basic stack effect theory, and air velocities within comfort parameters. Some problems have been identified with uneven air distribution, which may be overcome by baffles on the inlet grilles (this was intended during the fitting out but they have not yet been installed) or independent operation of each inlet and stack damper.

Down-draughts have also been experienced from the stacks even when dampers are closed. As well as adverse wind pressures, this is likely to be caused by circulation within the stack itself which may warrant some form of heat source at its base.

Noise levels are reported not to be intrusive. However, the adjacent road is not heavily used. Cleaning access to the plena is difficult. Filters would improve the situation, but the resulting reduction in air pressure may compromise air flow rates.

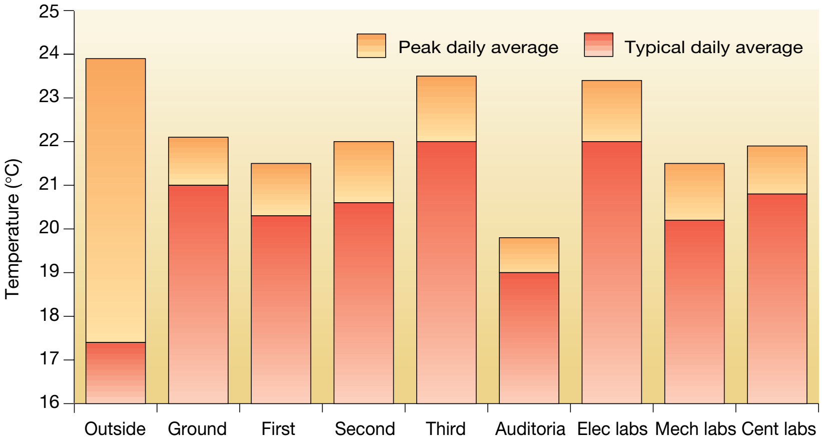


Figure 10 Mean building temperatures (June-August 1994)

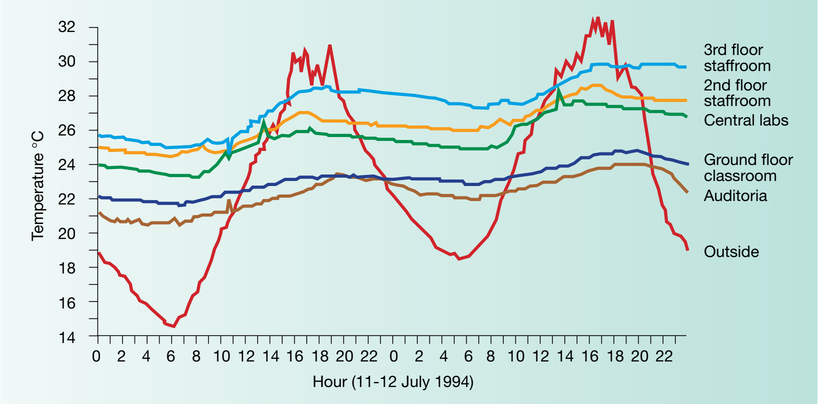


Figure 11 Summertime temperatures profiles (11-12 July 1994)

The vertical temperature gradient over the raked seating reaches 2-3°C at low ventilation rates, but this has not been a particular problem, as average room temperatures have not risen above 22°C.

User response

A fair indication of occupant reaction to the Queens Building can be taken from the fact that De Montfort's property services department has received only two complaints: one about the third floor staffrooms being too warm because the opening mechanism for the roof ventilators was omitted and a broken three-port valve prevented proper isolation from the main heating circuit; and one regarding a mechanically ventilated laboratory that was too cold. More significantly, there were no other complaints of overheating during the summer of 1995, one of the hottest on record, and of all the University's 250 000 m^2 building stock, the Chief Engineer stated that the Queens Building was his first choice for refuge from the heat.

PERFORMANCE IN USE

Energy use

Energy consumption for the first year of operation, based on gross floor area, equated to 114 kWh/m^2 for gas and 43 kWh/m^2 for electricity with a corresponding CO_2 emission of 53 kg/m^2. Referring to DOE yardsticks**[5]**, this is about half that of a typical university academic building (figures 12 and 13). The avoidance of mechanical ventilation results in a significant reduction in the use of electricity, although the electric lighting demand could well be lower if the automatic controls were fully operational. More unusually for a passive building there are also considerable savings in heating energy consumption, probably due to the building's form, fabric insulation levels, the use of a condensing boiler, and the CHP.

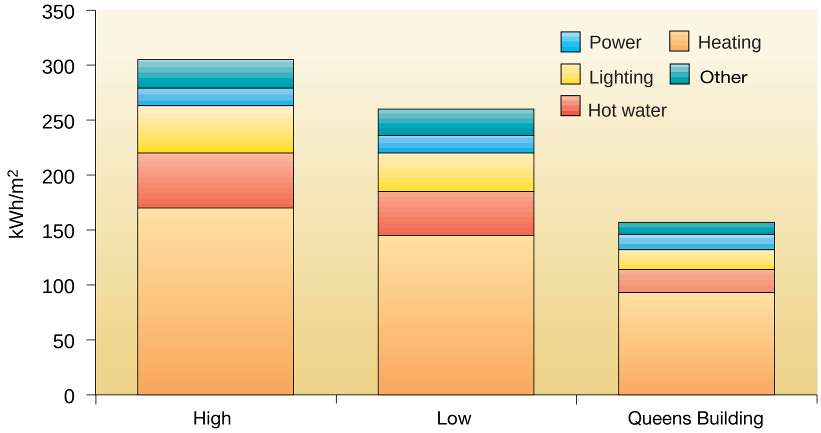


Figure 12 Annual energy consumption compared to DOE's 'low' and 'high' yardsticks

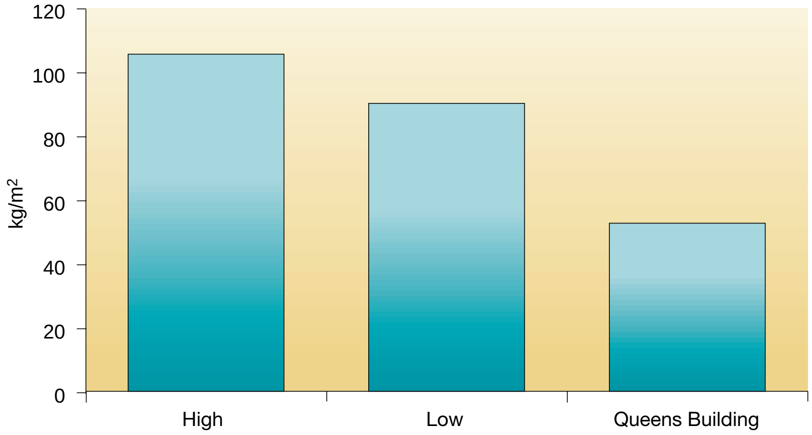


Figure 13 Annual CO_2 emissions compared to DOE's 'low' and 'high' yardsticks

Initial difficulties in use

There are still some outstanding adjustments to be made after two years of operation. The opening mechanisms for the glazed roof ventilators have proved to be problematic and some have been isolated as a precaution after an aluminium drive shaft sheared. In the auditoria, the CO_2 detectors are reported not to be functioning correctly.

Delayed energising of lighting circuits by the occupancy sensors has resulted in this mode of control being largely overridden. The PIR detectors are thought to be insufficiently sensitive, and feeding their signals back through the BEMS imparts a noticeable delay.

In the mechanical laboratories, the aim to replace electric lighting with natural daylighting was not realised, because electric lighting is used whenever heavy machinery is operating, on health and safety grounds. The internal doors to the breathing buttresses cannot be opened easily because they interfere with apparatus on the work benches, although the consequences have been mitigated by lower than expected use of the machine hall.

There is also a tendency to overwind and damage the rooflight mechanisms in computer and project rooms, because the users do not have direct sight of the opening light. This could be overcome with some form of local positional indicator.

Overall, the difficulties encountered seem to be with the mundane aspects of the building rather than with the innovative features.

COSTS

COSTS

Though innovative in its concept, the Queens Building relies on traditional materials and construction techniques. So while requiring closer integration among the design team, the construction process has proved to be no more costly (at £855/m^2) than a more conventional building. This was a fundamental requirement of the Polytechnic and Colleges Funding Council, because it had to fall within the established cost criteria.

Cost breakdowns from the quantity surveyor indicate that the savings on mechanical and electrical services and finishes amount to approximately 9% of the total contract value, but that these were absorbed by higher superstructure costs (figure 14). Maintenance costs are, as yet, unconfirmed but the expectation is that the reduced dependence on mechanical plant will result in consequent savings.

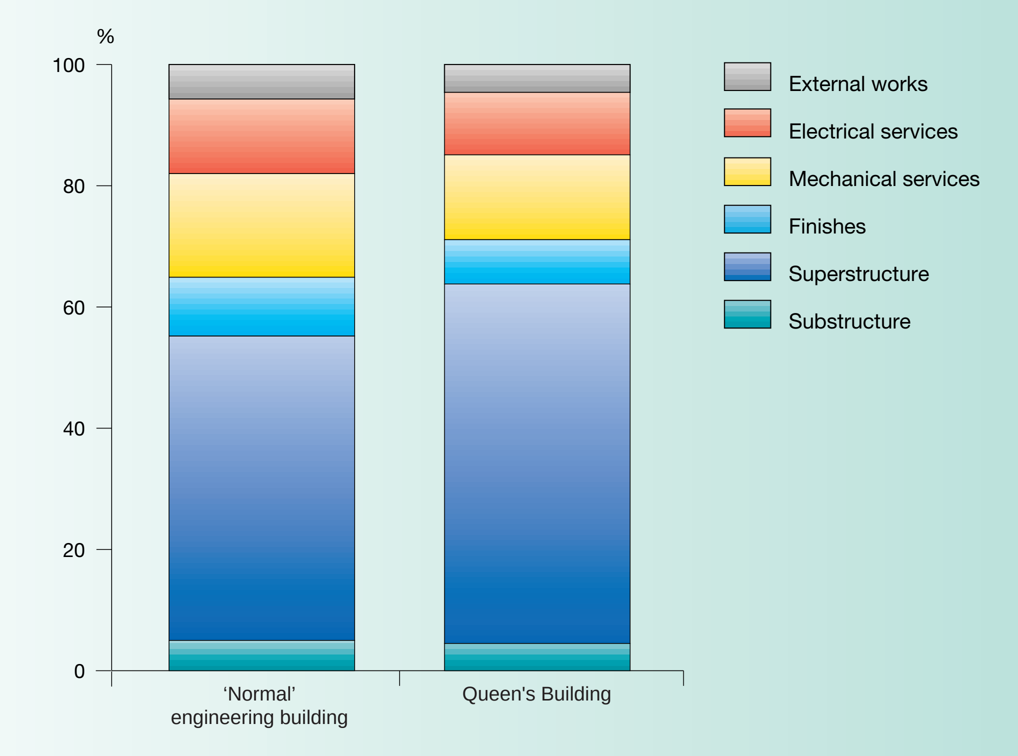


Figure 14 Comparative costs

CONCLUSION

CONCLUSION

The passive approach at the Queens Building appears to have provided an acceptable internal environment during its early operation – the few problem areas being the result of very conventional difficulties, such as broken valves or window openers not being installed.

Few multi-functional facility developments have adopted such a radical design approach as the Queens Building, which demonstrates a real advance in the 'greening' of both university buildings and urban redevelopment. This building has shown that taking such a low-energy design approach does not conflict with the functional aspects of the facility and, indeed, can result in a striking landmark at no additional cost.

The project is testimony to what can be achieved in terms of a low-energy design. In pursuing such ends it is essential, however, that the more mundane aspects are not overlooked, or made to suffer from cost savings.

DESIGN LESSONS

The natural ventilation and daylighting techniques used are all relatively simple and well tested but the Queens Building is exemplary in extending their application. The main lessons to be learnt from this project are as follows.

- Acceptable comfort conditions can be achieved in urban buildings with high casual gains through a combination of extensive exposure of a building's thermal mass and well controlled natural ventilation.
- Form, fabric and spatial planning are all key elements in determining a building's ultimate energy performance.
- The full support and involvement of both client and planning authorities are vital for innovative building design.
- Design analysis tools are invaluable for assessing the relative robustness of different design options, even though these are unable to predict with absolute certainty the eventual conditions within a building.
- Passive design does not limit opportunities for creating stimulating environments and permitting architectural expression.
- The overall capital cost of a passive building need not be any higher than that of a conventional equivalent, but substantially lower energy running costs can be achieved.
- Building services systems need to be readily responsive and controls appropriately selected to realise the full potential energy savings from passive design.
- Ventilation opening mechanisms need to be carefully specified to ensure that they are sufficiently robust for the intended application.
- Commissioning passive systems is more complicated than active counterparts and so allowance should be made for a longer period of post-occupancy monitoring and fine tuning.

REFERENCES

ACKNOWLEDGEMENTS

Design and performance information has been supplied by the architects, Short Ford Associates, M&E consulting engineers, Max Fordham Associates, quantity surveyors Dearle & Henderson and the Chief Engineer at De Montfort's Property Services Department.

REFERENCES

[1] **Chartered Institute of Building Services Engineers.** P Littlefair, 'Daylighting under the microscope', Building Services – The CIBSE Journal, April 1996.

[2] H Eppel, J Mardaljevic and K J Lomas, 'Computer simulation for low energy buildings', ECADAP Group School of Built Environment, De Montfort University, 1993.

[3] G F Lane Serff, P F Linden, D J Parker and D A Smeed, 'Laboratory modelling of natural ventilation via chimneys', Proceedings of PLEA '91 Conference, Seville, 1991.

[4] E M Clancy, A T Howarth and R R Walker, 'Assessing Environmental Conditions in a Naturally Ventilated Lecture Theatre', Proceedings of PLEA '94 Conference, Lyon, 1994.

[5] **Department of the Environment.** Introduction to energy efficiency in further and higher education (EEB 5). London, DOE, 1994.

FURTHER INFORMATION

Building Research Establishment. BRE Digest 399 'Natural ventilation in non-domestic buildings'. Garston, BRE, October 1994.

British Standards Institution. BS5295 'Code of practice for ventilation principles and designing for natural ventilation'. London, BSI, 1991.

BSRIA. TN11/95 'Control of natural ventilation'. BSRIA, 1995.

Chartered Institute of Building Services Engineers. CIBSE Design & Application Manual. 'Natural Ventilation in Non-domestic Buildings'. London, CIBSE, April 1997.

BUILDING DATA

Design team:

Architect	Short Ford Associates
M&E consulting engineer	Max Fordham Associates
Structural consulting engineer	YRM-Anthony Hunt
Quantity Surveyor	Dearle & Henderson

Gross floor areas:

teaching/lab spaces	6390 m^2
computer suite	1600 m^2
offices	1400 m^2
concourse	300 m^2
amenity and dining	160 m^2
Total	**9850 m^2**

Occupancy:

2000 students and staff

U-values (W/m^2°C):

walls	0.29 to 0.36
floor	0.19 to 0.45
roof	0.20 to 0.31
glazing (centre of pane)	2.50 to 3.60

Lighting levels (Lux):

offices and computer rooms	300
circulation areas	150/200
mechanical laboratories	1000
general laboratories	750

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