probe 4

Queens Building

Roland Asbridge and Robert Cohen report on how de Montfort University's Queens Building has performed since its completion. To understand the building's detailed design readers should refer to the original building analysis 'Learning curve' which appeared in the October 1993 issue of *Building Services Journal*.

The fourth article in the PROBE series revisits the Queens Building the award winning School of Engineering and Manufacture completed in 1993 for de Montfort University in Leicester. Today the building represents a benchmark in natural ventilation, daylighting and passive solar design.

The original brief called for an innovative solution to reflect the creative nature of the new university. Designed by architect Short Ford Associates with Max Fordham Associates as the services consultant, the Queens Building provides academic facilities for 1500 full-time students. Predominantly naturally ventilated, the whole building is characterised by the exposure of its thermally-massive structure with fair-faced brick and blockwork walls, and exposed soffits to the concrete floor slabs.

The 10 000 m^2 structure comprises the central building, the mechanical laboratories and the electrical laboratories. A full-height concourse in the central building acts as a light well and thermal buffer zone for adjoining spaces.

The mechanical laboratories are flanked on the western facade by a two-storey block of mechanically-ventilated specialist laboratories. The electrical laboratories are housed in two shallow plan, four-storey wings, either side of a narrow courtyard which forms the

main pedestrian entrance.
Building handover was delayed until 13 August 1993, compressing the initial commissioning and fit-out into the six weeks before the start of term in October 1993. As the commissioning of passive systems is not always straight-forward, the design team intended to undertake extended monitoring and fine tuning of the control algorithms embedded in the building energy management system (bems) during the first year of operation.
Unfortunately the main contractor has not dealt as swiftly with the list of agreed patent defects as fast as the University would have liked. The building has therefore still not been fully commissioned and for the first two years of operation has operated with defects in critical elements of the mechanical and control systems, of which more anon. Certain items which were allocated to the fitting-out budget were postponed, as the University was not prepared to authorise funds until the main contract was finalised.

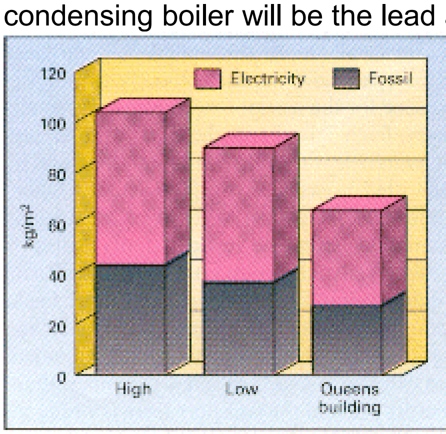
services issues

Lack of space prevents a full building description, but details of the building's design and servicing appeared in the October1993 issue of *Building Services Journal*[1,2]. Readers should refer to those articles to gain the best understanding of the building, and also this month's BRE report which covers the daylighting strategy for the electrical laboratories.
The architect's concept for the Queens Building was for a highly insulated, thermally-massive envelope with both a shallow plan and generous ceiling heights to facilitate natural ventilation and daylighting.
The ground floor classrooms and the auditoria are ventilated by the imposing chimneys, while laboratories and staff areas on the upper floors should be 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. The only mechanical ventilation is in the specialist laboratories.
The 1thw heating system is fairly conventional except for a 38 kW combined heat and power (chp) unit and a condensing boiler as lead heat sources. Hot water is supplied from central calorifiers. Low energy lamps are used throughout the building with manual or occupancy sensor switching.
Despite the overall simplicity of the building services, the complexity of the natural ventilation strategy demanded automatic controls and a comprehensive bems, which has a dual role as an educational tool. So while some spaces rely on simple cross ventilation through openable windows, the majority have low level air inlets and stack or ridge exhaust ventilators generally controlled through motorised dampers which are modulated by the bems simply to maintain room temperatures.
During the first winter of operation an aluminium actuator arm sheared off the opening mechanism on one of the rooflights. This may have been due to the rooflight being frozen in position, but to avoid the risk of this recurring some have been disabled until an appropriate solution has been identified.
The rooflight in the third floor staff area has openable sections, but the installation of the actual mechanism was allocated to the fitting-out contract. This has not yet been undertaken due to the same unresolved actuator specification. Not surprisingly the lack of means of ventilation has been a factor in this area experiencing much higher summertime temperatures than anywhere else in the building.
The internal doors to the breathing buttresses in the mechanical workshops cannot easily be opened as they interfere with apparatus on the workbenches, although the consequences have seemingly been mitigated by lower than expected use of the

machine hall.
The two auditoria demanded more intricate air flow paths and more sensitive control than is the case for the rest of the building. Fresh air enters from louvres in the north facade via plenums below the raked wooden floor, and is exhausted by two 133 m high chimneys. In the winter the intake air is heated by finned tubes positioned behind the vertical supply grilles.
When an auditorium is occupied, the basic requirement is for a minimum supply of fresh air, as determined by CO_2 sensors, with increasing air volume to meet the cooling load provided that external is less than internal temperature. Sensors prevent the dampers from opening to more than 50% if there is a risk of entry of wind-driven rain. If the inlet damper attempts to go below 10%: the stack dampers will close instead to prevent air turbulence and noise at the inlet.
To avoid draughts, dampers are further modulated to limit the air velocity within the stacks. The stack dampers close if the stack temperature is sensed at less than 12°C. Punkah fans operate if the average temperature in the auditoria exceeds 25°C and is at least 2°C above the external temperature, although in practice conditions in the auditoria have proved to be satisfactory without the need to run the fans.
Longer term monitoring of the two auditoria has recorded air temperatures remaining stable between 20°C and 22°C. Air change rates appear to have been in general accordance with basic stack effect theory, and air velocities in the room have been within comfort criteria. However problems have been identified with uneven air distribution, which could be overcome by baffles on the inlet grilles (as was envisaged as part of the fit out) or independent damper operation of each inlet and stack.
Noise levels are reported not to be intrusive as the road is not heavily used, but getting access to the plenums for cleaning is difficult. Filters and additional attenuators would obviously improve both situations but the increased pressure drop would compromise air flow rates.
Down draughts have been experienced from the stacks when dampers are partially or fully closed. This is likely to be a result of circulation within the stack itself with cooled air falling back down the stack to the room below. Not surprisingly there is a 2-3°C temperature gradient from the bottom of the room to the top seating position, which is more marked in winter when little outdoor air is admitted.

heating issues

The main heating plant consists of a38 kWe chp unit, a condensing boiler and two high efficiency boilers, sequenced in that order. The chp unit will always take priority as long as there is sufficient demand for electricity, otherwise the chp unit will switch off and the condensing boiler will be the lead appliance.



Heating circuits are weather compensated, with two-port motorised valves and room thermostats providing local trimming. Emitters are generally radiators or natural convectors except in the central concourse which has under floor heating. LTHW heater batteries are used in ahus serving clean rooms, welding rooms etc.
The stems on three of the main three-port control valves broke soon after completion. Because of a protracted dispute with the contractor these have only recently been replaced. However they subsequently broke once again which raises a question over their suitability for the particular application.

The major problem this caused was circulation of hot water through the heating distribution pipework during summer. Even though the pipework is well insulated, the high level routing through the third floor staff areas contributed to overheating problems. In an effort to overcome the problem the boilers have been manually isolated during the summer of 1995 and the immersion heaters in the central calorifiers used for hot water generation.
The chp unit (thermal output 68 kW) was chosen originally to match the hot water load anticipated from the main refectory kitchens. The refectory fit-out was separated from the main building contract and was subsequently substituted by a series of vending machines with no direct hot water usage.
This has not only significantly reduced the potential hours of operation for the chp unit, but also makes the use of central calorifiers less appropriate for the widely distributed points of low hot water consumption, which would be more efficiently served by local water heaters.

lighting issues

Spaces are primarily lit from side windows which are shaded from direct solar heat gain by deep reveals, overhanging eaves or floor soffits and the articulated facades. Multiple small windows are used in preference to large glazed areas to provide well distributed daylighting without the penalties of high heat loss.
Northlights and rooflights are used extensively to meet the combined needs of stack ventilation and daylighting. The full-height concourse lets daylight into the core of the main building, reducing dependency on artificial light sources in the deep plan areas.
The energy and financial savings from good daylight distribution through the building can only be realised if the daylight displaces artificial lighting, which requires responsive switching by manual or automatic means. First impressions are that this has not been wholly successful. High-bay SON lamps in the machine hall maybe efficient, but their striking characteristics do not encourage frequent manual switching. The designers say, with some justification, that the client’s requirement for 1000 lux made SON lamps the only possible solution.
All lighting circuits are fed through contactors which, in turn, are controlled by the bems.

During the core occupied period, lighting circuits are energised by the bems and then controlled locally by manual switches. Outside normal working hours the bems will de-energise any lighting circuit where no movement has been detectedby passive infra-red detectors for longer than five minutes. The original specification also allowed for internal and external light sensors and timer control, so that the circuits would only be energised if there was insufficient daylight and then only for a predetermined period.

It is understood that budget constraints prevented these additional facilities being installed and, in practice, the switching under infra-red detector control has proved to be a problem. To maximise the control options, the sensors are wired back to the bems rather than to the local contactor. This means that both the detectors and the manual switch must both be operated before the lights will come on, and there was reported to be an unacceptable delay before this occurred.

This was apparently particularly confusing on two-way switches where there could be doubt as to whether the manual switch was on or off. This caused a problem for cleaning staff when they entered rooms where there was little spill light from adjacent areas or external sources. As a result the core occupied period, which was initially set from 08.00 to 2l.30, has been extended from 06.00 to 21.30.

A further drawback of the control system in its present format is that if manual switches are left on at the end of the day, lights will be automatically switched on the following morning, even if the room is empty.

At least the bems is ensuring that lights cannot be left on overnight, but the serial connection of conventional manual switches and contactors activated by infra-red detectors via the bems has proved to be an unsatisfactory compromise. Switching according to occupancy is clearly an energy efficient solution for this type of building but it remains to be seen whether the original concept can be made to work effectively by improved sensitivity of the infrared detectors and fine tuning of the bems.

energy issues

Energy consumption data has been compiled from energy bills for the second academic year of operation: August 1994 to July 1995. Based on a treated floor area of 8400 m^2, gas and electricity consumption equate to 143 kWh/m^2 and 52 kWh/m^2 respectively, weather corrected.

This compares very favourably with the Energy Efficiency Office’s ‘low’ target consumption for university academic buildings of 185 kWh/m^2 and 75 kWh/m^2 respectively. Consequently, related CO_2 emissions at 65 kg/m^2 are well below the EEO ‘low’ target value of 90 kg/m^2 (figures 1 & 2).

The low heating bills are probably attributable to the building’s form, fabric insulation levels and to the condensing boiler. Gas use would be lower if internal gains (electrical and people) were higher as may be the case in the future — the present usage of the building seemingly being well below design levels.

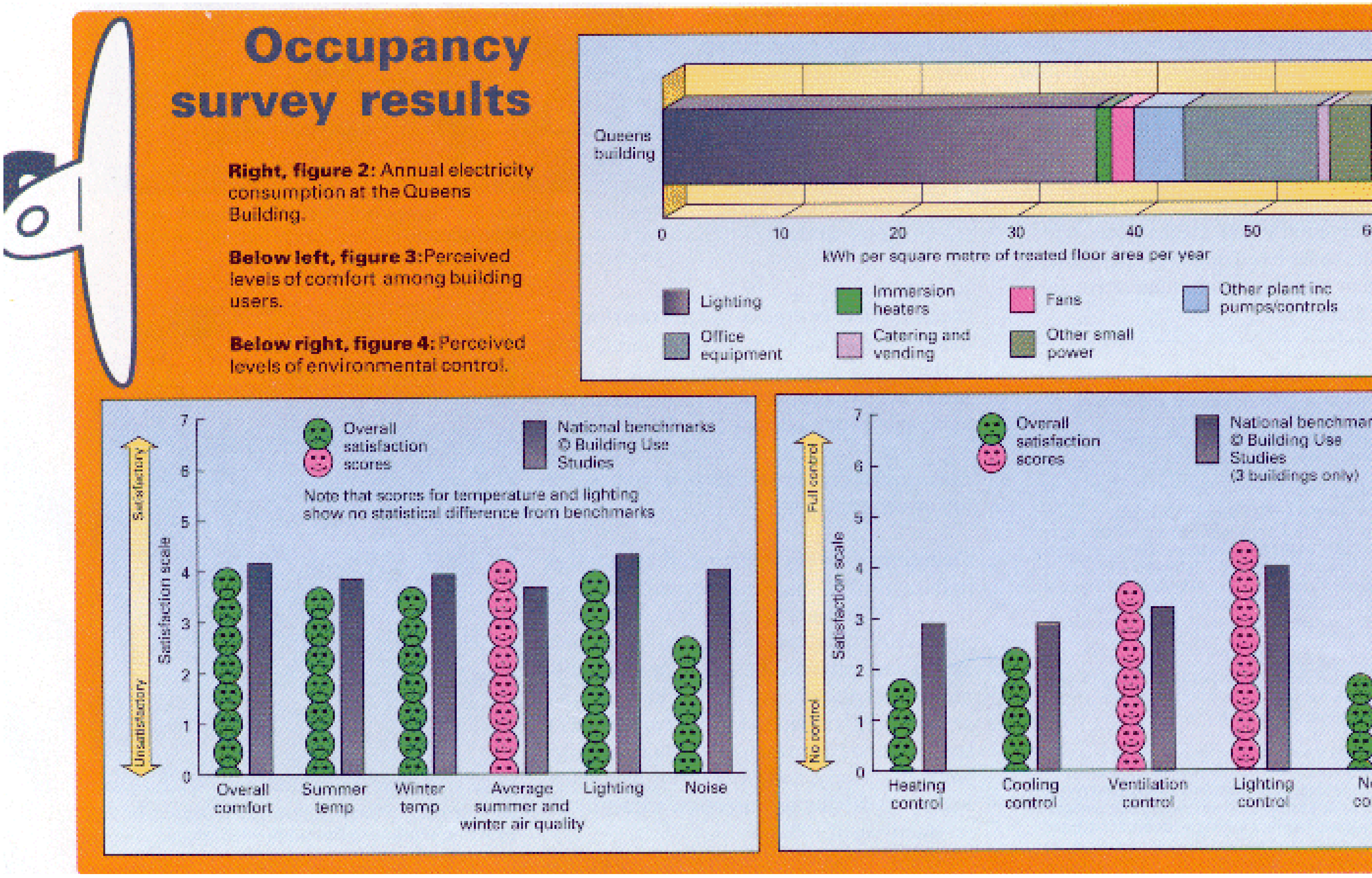
Metered gas consumption indicates that the condensing boiler provided approximately 45% of the annual heat energy, the conventional boilers together amounted to a further 4l%, and the chp unit the remaining 14%.

The combination of a chp unit and condensing boiler can often compromise their individual economic viability as the chp unit will reduce the annual burning hours of the condensing boiler. In this instance the small capacity of the chp unit means that the condensing boiler is still meeting nearly half of the total heat demand, and initial

estimates suggest that the simple payback period for the condensing boiler will be about six years, compared to five years had the chp machine not been installed.
Monitored data indicates that for the 12 month period between August 1994 and July 1995, the chp unit supplied up to 21% of the building's electricity during the heating season, but only ran for 1644 h, due to the lack of base thermal load.
This represents an annual cost saving of a little under £2500 which, so far, has been some £300 more than the average annual maintenance costs. On this basis the chp unit is clearly not going to make any significant financial savings over its lifetime but will at least have made a positive contribution to the reduction of CO_2 emissions by about 30 tonnes/y.
To overcome the problem with the three-port control valves, the boilers have been isolated in the summer months and electric immersion heaters used to heat one of the two 1500 litre calorifiers. This will have shifted the energy use for hot water generation from fossil fuel to electricity by around 1 kWh/m^2.
The loss of the three-port mixing valves on the main heating circuits means that there has been no weather compensation facility. When rectified there could be a potential reduction in gas consumption of up to S kWh/m^2.
Lighting consumes the majority of electrical power. Although the installed load is only around 13 W/m^2, annual electricity consumption for lighting was about 37 kWh/m^2, which is a little above the EEO's good practice levels for naturally-ventilated open plan offices. Electrical power for plant (7 kWh/m^2) is obviously well below the norm due to the passive approach. Fan power is restricted to the air handling plant in the mechanical laboratories.
Average night power consumption is some 40 kW in term time. Up to half of this may be explained as lighting usage for cleaning. The remainder occurs while the building is totally unoccupied and it is suspected that a fair proportion of this load (eg equipment left on unnecessarily) could be avoided.

occupancy survey

A standard PROBE questionnaire, supplemented by questions relating to particular features of the Queens Building, was given to all 75 occupants in the building. This included academic, technical, administrative, research staff and research students, but not undergraduate students who were on reading week — 95% of questionnaires were returned.
Readers should note that the majority of respondents worked in the area which has suffered on-going problems with pipework heat gains from uncontrolled hot water circulation, and absence of working rooflights.
56% of staff surveyed were academic (mainly lecturers) and 21% administrative (mainly secretarial). The rest were technicians (9%) and others such as the building manager and research students (14%).
80% were aged over 30, 75% male, and most (95%) had worked in the building for more than one year and used the same desk or work area. On average staff spent 3·1 h/day using vdus, 4·9 h/day at their desks or work areas, nearly 8 h/day in the building and worked a five day week.
Overall the perception of thermal comfort and air quality is similar to national benchmarks and overall air quality in winter is considered to be significantly better than benchmark. However high summertime temperatures, particularly on the third floor, and stuffiness in both winter and summer were highlighted as being unsatisfactory (figure 3).



Research[3] carried out in 1994 indicated that the combination of thermal mass and natural ventilation was effective at maintaining a comfortable environment for most of the building during the summer of 1994.

There was a variable response to the natural lighting strategy, with a general feeling that there was too much daylight, although certain areas were described as gloomy. However this did not result in the perception of sky and sun glare being any worse than the national benchmark. Glare from luminaires was low.

Despite the reported problems with the automatic lighting controls, the response of lighting controls was considered to be significantly quicker than the national benchmark. 63% said that they normally switched off lights when they felt there was sufficient daylight and 77% said that they switched off lights on leaving an unoccupied room or work area. Observations on the day of the survey, however, showed that, with reasonable daylight conditions outside, nearly all lights were on throughout the building regardless of occupation (figure 4).

Noise was the greatest cause for concern, and stems from the open plan nature of the staff areas which appears to be extremely unpopular with all those who work there.

Half of respondents had requested changes to the heating and ventilation systems. Of these 77% thought the speed of response by building management staff was slow or very slow, and 66% thought that the action taken was not effective. It appears that hardly any of the staff had been made aware of the contractual dispute and the reasons for the delay in remedial works to the building.

Office occupants thought that the working environment had a negative effect on their productivity, with an average rating of minus 10%. This falls within the bottom 10% of all buildings on the Building Use Studies' database.

This evaluation of the Queens Building has been carried out after only two full years of operation and it is still not fully commissioned. The bems is clearly a critical factor in ensuring that the building functions to its full capability and this has not yet been fine tuned with all systems in full working order.

That the building has reportedly maintained satisfactory internal conditions even during one of the hottest summers on record is an endorsement of the passive design approach. Nevertheless, a clear lesson is the need not only for management resources at and after handover, but also for contractual mechanisms which allow faults to be fixed quickly — particularly important in buildings with innovative solutions like this.

References

[1] Bunn R. ‘Learning curve’, *Building Services Journal.* 10/93.

[2] Anon ‘Will natural ventilation work?’ *Building Services Journal*, 10/93.

[3] Stevens B. ‘A testing time for natural ventilation’. *Building Services Journal,* 11/94

Further reading

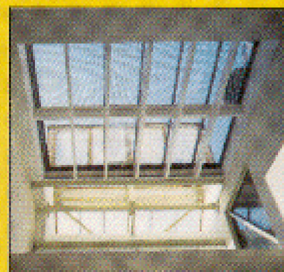
Clancy E M, Howarth AT. Walker R R, ‘Assessing environmental conditions in a naturally ventilated lecture theatre’. Proc. PLEA’94 Conference, Lyon. 1994.

Bowman N T. Cakin AS, Lomas K J, & Moyles B F. ‘Buildability study: engineering workshop incorporating passive solar features. Queens Building de Montfort University’. School of Built Environment, de Montfort University for ETSU, 1995.

The authors would like to thank Richard Bunwell. a student at Loughborough University of Technology, who undertook an energy audit of the Queens Building on our behalf. Ian Wilson. chief engineer at De Montfort University. and Bart Stevens of Max Fordham Associates for their help and cooperation, and Adrian Leaman of Building Use Studies for administering the occupancy survey.

key design lessons

Ventilation Ventilation opening mechanisms need to be carefully specified to ensure that they are sufficiently robust for the specific application, and that there is suitable indication for remote, out of sight operation.



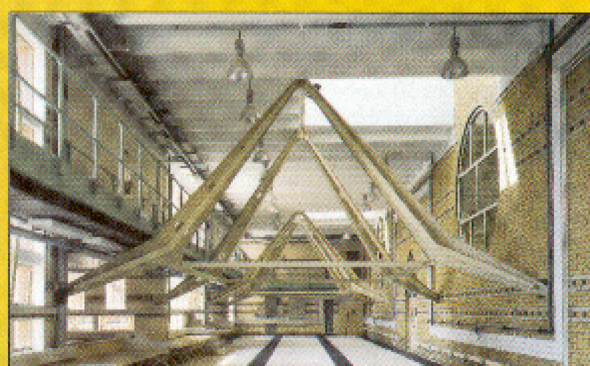
Some of the actuators on the rooflights have been disabled until they can be made more robust.

Lighting control The effort to provide good levels of daylight through the building have so far failed to displace the use of artificial lighting. This appears to be a failing of both the control system and the building's users. Staff are not as diligent as they claim to be in turning off unnecessary lighting, and the responsiveness of the infra-red occupancy controls have led to them being overridden.

Lighting In the machine hall, good daylight factor is achieved without risk of glare or noise breakout, but artificial lighting is used regardless whenever heavy machinery is operating, seemingly on health and safety grounds. While the use of high bay SON lamps is probably the most efficient fitting for the application its striking characteristics do not encourage frequent manual switching.

Good daylight factors are achieved without risk of glare and noise in the engineering halls, but lights tend to remain on anyway.

Passive design Early indications are that the combination of thermal mass and natural ventilation has been effective at maintaining a comfortable internal environment for most of the building, even during one of the hottest summers on record. This must be considered an endorsement of the original passive design approach, despite the operational problems with the active building services.



The use of high bay SON lamps is probably an efficient choice, but striking characteristics do not encourage frequent manual switching.

Energy Energy use in the second year of operation has justified the tag of a low energy building, and fine-tuning of its systems and controls should result in even lower energy use. However, the relatively high night-time electricity use while the building is totally unoccupied could be reduced by ensuring that equipment and computers are not left on unnecessarily.

Occupancy survey Putting academic staff in open plan office space has met with universal dissent. While such a solution may have been proposed to facilitate the natural ventilation strategy and promote the idea of closer departmental integration, staff report that such an arrangement is unworkable. It is considered to have been very detrimental to their ability to work effectively, and those taking part in the survey reported a self assessed reduction in