Passive refurbishment at the Open University

Achieving staff comfort through improved natural ventilation

GENERAL INFORMATION REPORT 48

BEST PRACTICE PROGRAMME

ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

CONTENTS

1 INTRODUCTION AND BACKGROUND

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1.1 Purpose of this Report

This Report demonstrates that natural ventilation can provide comfort in a modern office with high heat loads from information technology (IT) equipment. The Report looks at naturally ventilated offices at the Open University, Milton Keynes; in particular at the design studio, where staff comfort was achieved without the need for mechanical cooling.

This Report supports the key messages described in Good Practice Case Study 308 (GPCS 308), 'Naturally comfortable offices – a refurbishment project'[1]. The Report also looks in detail at the temperature monitoring, energy consumption and user surveys undertaken by the School of Architecture, Oxford Brookes University.

1.2 The buildings

Many of the Open University's administrative offices at Walton Hall were built in the 1960s and 1970s to a standard pattern. The buildings were originally two or three storeys high, with concrete floors and flat roofs. They are concrete-framed brick-clad and linked by stairs and service towers. Each floor has an internal depth of 13 m and a ceiling height of 2.7 m. Most floors are partitioned with an off-centre corridor, cellular offices to the narrow side, and a mixture of cellular and open-plan offices on the deeper side. Some are open-plan right across their width (see figure 7). The principal elevations are single-glazed with continuous strips of aluminium patent glazing 1.8 m high. Ventilation was provided by centre-pivot aluminium windows in approximately half the bays (see figure 1). Heating was by double-panel steel radiators.

At a later date, lightweight steel-framed mansard roof extensions were added with an average ceiling height of 3.1 m. They were poorly insulated and have coverings of mineral felt and artificial slates which are dark in colour, resulting in high summer heat gains. Glazing was provided by low-level double-glazed centre-pivot roof windows with trickle ventilators.

In the 1980s, the 50 mm wall cavities were filled with blown mineral fibre, and thermostatic radiator valves (TRVs) were fitted.

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Figure 1 Typical elevation before refurbishment

INTRODUCTION AND BACKGROUND

1.3 Background to the study

All buildings were prone to overheating in warm and sunny weather due to the large areas of glazing on the lower floors and design of the lightweight top floors. Over the years, conditions gradually worsened because of increases in occupancy densities and the use of IT equipment. This was exacerbated by the introduction of personal computers (PCs) for all staff in 1990.

In 1991 the University invited building services consultants to consider options for reducing summertime temperatures in one building block and mechanical cooling was recommended. The University might have chosen to adopt this proposal with its assured performance, seeing it as safer than a package of measures, each of which would bring small improvements to the thermal performance of the building fabric.

However, research and field studies suggest that workers prefer well-designed naturally ventilated buildings to those with mechanical cooling[2]. The perception of comfort is not tied simply to the actual values of temperature, air movement, relative humidity and so on. It is also related to the ability of occupants to have control over the internal environment of the building in different weather conditions[3,4].

Despite this evidence many designers and managers still believe that mechanical cooling, an expensive option in management and energy bills, is necessary for summertime comfort[5].

The University, however, commissioned a second group of consultants to review the potential for improving comfort levels without recourse to mechanical cooling.

This review included a site survey and an assessment of a range of options to decrease summertime temperatures. For each option, annual hours of overheating were simulated using computer modelling techniques. The conclusion was that reasonable summertime temperatures could be achieved on all floors, except the mansard. Here there was little opportunity to limit solar gain or to utilise the thermal mass of the building, so comfort cooling was the only option.

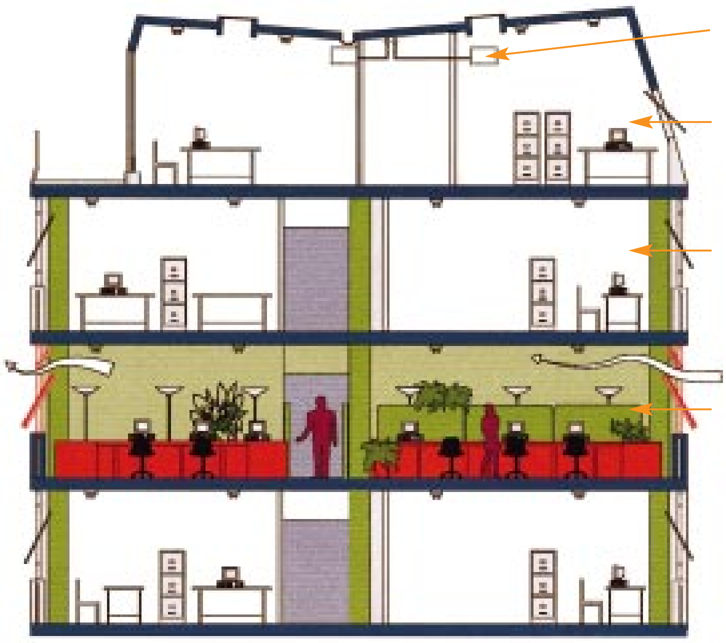

Figure 2 Typical cross-section

The following measures were recommended on the other floors:

- reducing solar heat gains through windows by reducing their area and providing appropriate shading
- modifying the window system to provide better ventilation, particularly at night
- installing energy-efficient lighting with better control.

The key structural elements that contributed to the potential success of the natural ventilation pilot scheme were:

- a high internal mass
- relatively high ceilings
- the option of opening windows.

2 IMPLEMENTATION OF THE RECOMMENDATIONS

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2.1 The pilot scheme

The second floor of Block B of the Wilson Building was used as a pilot to test the viability of using natural ventilation for providing comfort without mechanical cooling. In the summer of 1992, the University modified the windows in six rooms: halving the glazed area in four rooms by replacing the fixed panes with insulated panels; and shading all the glass by fixed external louvres in the other two rooms. These rooms also had new bottom-opening 'hopper' windows installed above and below the original centre-pivots to provide secure ventilation, which could be left open at night to let out heat accumulated during the day. Fly-screens were fitted to the openings.

Figure 3 Modified windows in pilot scheme on the second floor

The performance of the pilot scheme was monitored by the University over two years. Information about this pilot scheme was fed into the Energy-Related Environmental Issues (EnREI) programme, sponsored by the Construction Sponsorship Directorate of the Department of the Environment, Transport and the Regions (DETR). Its purpose was to assess the current status of theory and practice in low-energy building design in the UK by monitoring twelve naturally ventilated office buildings.

The results are useful to those who are designing or considering non-air-conditioned buildings. They are summarised in General Information Report 31 (GIR 31), 'Avoiding or minimising air-conditioning. A report from the EnREI programme'[6].

Results of the pilot study (Building R in GIR 31) show:

- summertime peak temperatures were reduced from 28ºC to 26ºC and that staff considered themselves comfortable
- occupants did not like fixed external shading because of the permanent reduction in daylight and view
- reflective films were also tried by the University but the occupants disliked them, commenting that they 'made it look like November all the time'
- modifying the existing windows was not a long-term solution, therefore, replacement was recommended.

Figure 4 The new window system is the principal element in the refurbishment of the design studio on the first floor. It optimises the glazed area, in this case by halving it, and is triple glazed to reduce heat loss. Mid-pane venetian blinds control solar heat gain and glare, and incorporate a remotely operated 'hopper' window, which opens inwards, for secure cross-ventilation and night ventilation.

IMPLEMENTATION OF THE RECOMMENDATIONS

2.2 Refurbishment of the design studio

In 1993 the open-plan first floor design studio was to be refurbished, including new furniture. This provided an opportunity for incorporating a natural ventilation strategy, putting into practice what had been learned on the pilot study on the second floor in the Wilson Building.

The transition from paper-based to electronic desk top publishing technology, and occupancy densities of 9 m^2 per person, resulted in high internal gains (see section 8.4). The equipment heat gain was estimated at 27.5 W/m^2 in 1993 and measured 25 W/m^2 in 1995. This heat gain is almost twice that of a typical open-plan office when compared with 1997 benchmarks'[7]). Furthermore, all the computers tended to be switched on for the whole working day, and one or two overnight. This put the design studio internal heat gain at the top end of the estimates originally made. Extra care would therefore be needed if comfortable summer internal conditions were to be achieved by natural ventilation. If measures adopted in the design studio worked, the same approach would be successful in all the other offices on the University site because of lower internal gains. With support from the design office staff, the University decided to proceed.

The refurbishment measures suggested by the consultant were designed to reduce heat gains and losses, while improving heat removal. This also provided staff with improved control of the internal environment. The measures were predicted to reduce peak summertime temperatures by some 4°C (over and above the reductions made by removing printers and photocopiers from the space) and seldom exceed 27°C, a common design target for natural ventilation[8].

Refurbishment measures implemented to reduce internal heat gains in the design studio

- A relatively small window module was chosen so that it could be installed from inside the building. This saved the cost of scaffolding, which would have been necessary if the windows had to be installed externally.
- New triple-glazed, centre-pivot timber-framed windows were installed. They had aluminium cladding for minimum exterior maintenance and high-level inward-opening bottom-hung hoppers (see figure 4).
- Three in every seven window spaces were infilled with highly insulated blank panels.
- Captive venetian blinds were located in the space between the outer single-glazed pane and the inner double-glazed sealed unit of the window.
- An espagnolette locking system for the centre-pivot windows had two positions for secure night ventilation.
- Remote worm-gear control for the hopper windows provided ready access and easy operation, and meant that windows could be left open for secure night ventilation.
- Acoustic ceiling tiles-on-battens were replaced with sprayed acoustic plaster, exposing the thermal mass of the concrete ceiling slab to the room.
- Ceiling-mounted fluorescent lights were replaced with free-standing compact fluorescent uplighters with electronic ballasts; and individual on/off and high/low levels improved choice with less energy consumption.
- Switch controls were fitted which allowed all lights to be switched off from the exit doors, but only the corridor lights to be switched on again from this position. All other lights are switched locally.
- GLS tungsten task lighting was replaced with fluorescent task lights.
- The shared laser printers were grouped with an extractor hood above, permitting warm air and fumes rising from the units to be drawn from the office.
- The photocopier was placed in an independent room with an extractor fan. This was also recommended by the University's ergonomics advisers.

3 DESIGN CONSTRAINTS AND CHOICES

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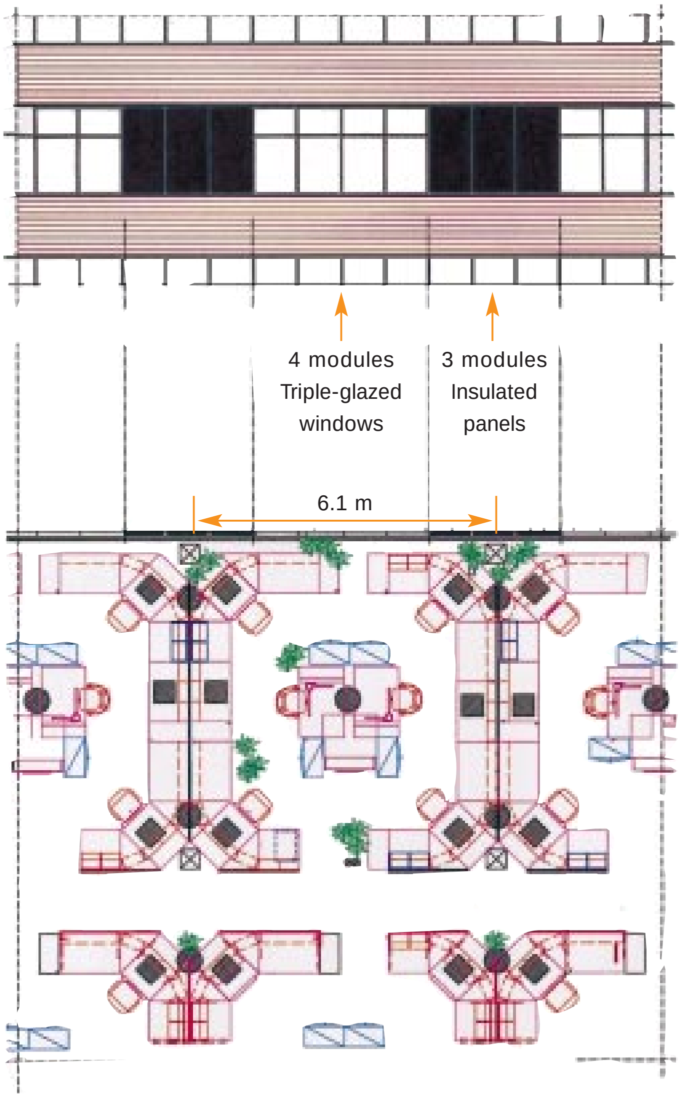
3.1 Staff involvement

Design studio staff were continuously involved in the process of deciding how their refurbished office would look, including its layout, the preferred type of lighting system and choice of furniture. This involvement of staff is important because it increases their sense of control over the workplace. Studies have shown this is beneficial[9].



KEY

Uplighters

Computers

Figure 5 Floor plan of the refurbished design studio, showing location of furniture, computer screens, windows and uplighters, together with an elevation of the new window layout

3.2 Window layout

Figure 5 shows the floor plan of the design studio. Modelling was used to predict the optimum glazing distribution to maximise daylighting and minimise heat gains/losses. The ideal arrangement was then compared to the actual window opening in the building, taking into account office use. The office had 6.1 m structural bays with seven windows. The 'best fit' was to keep four out of every seven windows. Therefore, some windows were filled with insulated panels and others had the new window system installed. It was found necessary to cluster the blank panels in threes and the windows in fours in order to provide a neutral backdrop to the computer screens near the window wall, and a suitable low-glare area against which the screens could face. Although the resulting daylight distribution is not the optimum, the resultant solar gains were minimised. The effect of less than perfect daylighting is to slightly increase electricity consumption by extra use of lights, as identified by the monitoring phase of the project (see section 8.3).

3.3 Electric lighting

Staff chose uplighting to illuminate their office. Originally this was installed with 250 W metal halide uplighters. Owing to their poor starting characteristics, staff used to switch the lights on early and leave them on until the very end of the day[10,11]. Various alternatives were considered as part of the refurbishment, but uplighting remained the preferred choice of staff, used in conjunction with the low-energy fluorescent task lamps previously used on their drawing boards. Because of this practice of giving staff the choice, ceiling-mounted low-energy high-frequency (HF) fluorescent lighting was not chosen.

To reduce the installed capacity of the lighting system, the metal halide lamps were replaced with compact fluorescent uplighters including electronic control gear and four 55 W U-tubes. They are located as shown in figure 5 and typically give a desktop illuminance of 400 lux.

The uplighting arrangement is relatively inefficient, and at 18 W/m^2 the installed power density of the new lighting was 50% higher than the design target of 12 W/m^2.

3.4 Lighting controls

With such a high installed lighting load, effective lighting control is an essential element in minimising internal heat gains and minimising lighting running costs. A combination of manual and automatic controls was adopted, incorporating features to provide staff with control of the local environment and, at the same time, avoiding use of unnecessary lights. Key features were:

- switches by the two main doors switch on the corridor lights only
- lights can be switched manually at any time, with the tubes in each uplighter being locally switched in pairs, so users can select high or low brightness
- all the lights can also be switched off (but not on) from the doors, providing a 'last out, lights out' facility
- a time controller switches any remaining lights off at the end of the day.

Daylight linking could have been incorporated if different lighting arrangements had been provided.

3.5 Solar shading

The pilot study showed shading was necessary. The University was concerned about the maintenance, window cleaning, and planning implications of using external shading – particularly as the buildings were to be refurbished piecemeal. Internal blinds could not provide the required reduction in heat gains, therefore user-adjustable inter-pane blinds were chosen.

The blinds had to be retractable and easy to maintain. The choice was between venetian, roller and pleated blinds. Venetian blinds were selected because they gave a greater variety of choice between control of daylight, glare and view.

4 WINDOW DESIGN IN DETAIL

4 WINDOW DESIGN IN DETAIL

The windows on the first floor needed to:

- be secure, particularly at night
- provide improved (and better controlled) day and night ventilation
- reduce solar heat gains by a combination of a smaller area and better shading
- provide good daylight and glare control.

The night ventilation facilities were also to be capable of being fitted with fly-screens, although they are not currently included.

Ideally the window system should have had three independently controllable elements comprising: an upper opening for cross-ventilation, buoyancy ventilation and secure night ventilation; a lower opening for local ventilation, trickle ventilation and as an air inlet for natural buoyancy ventilation, and a central opening for view and for rapid ventilation.

However, a three-element window was found to be prohibitively expensive, requiring a thicker transom which would block the view for a seated person.

For the main windows, centre-pivots were chosen because they provided effective ventilation, were consistent with the design of the old windows, and could be made secure. Options reviewed and rejected included:

- vertical sliding sashes – rejected for security reasons and because they did not accommodate inter-pane blinds
- tilt-and-turn – insufficient fine control and limited opening area when tilted
- top-hung – poor security and less ventilation in the night ventilation position
- casement – worries about draughts, security and letting rain in.

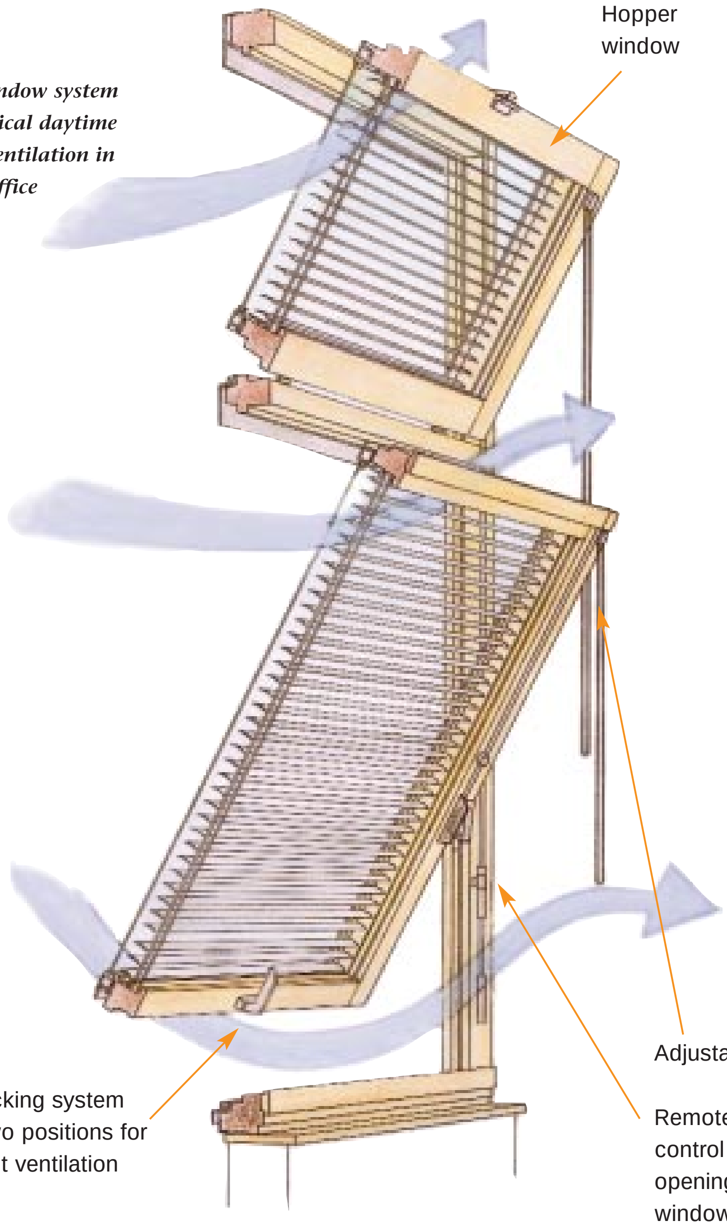


Figure 6 Window system showing typical daytime cross-flow ventilation in the design office

For the upper windows, the choice was between:

- louvres – low cost and simple to operate, but only available as single-glazed and considered a security risk
- top-hung – preferred for weather resistance but did not meet the design aim of directing incoming air over the ceiling
- bottom-hung – the best for security, control, air direction, and cleaning from the inside of the building.

A specification was sent to six manufacturers. Only two proposals met all the requirements. Both proposals included windows made of timber, externally clad with aluminium, and both were cheaper than the all-aluminium alternatives. Of the two proposed, the windows chosen were of individual modules that could be installed by hand from inside the building, avoiding scaffolding and cranage over an adjacent glass roof. The windows were available in a double-glazed and triple-glazed version and, as there was only a 2% cost difference, the triple-glazed version was chosen.

Position control of the upper windows is achieved by a manually operated worm-gear control chosen with the help of the window manufacturer. Electric operation was not affordable within the budget (see section 9.2).

5 COSTS

5 COSTS

The installed cost of the new window system in the design studio was £55 000 including controls and blinds. The cost of the new sprayed plaster ceiling and the lighting was £25 000 and was part of the design studio's budget for redecoration (the old lights and ceiling tiles were in need of replacement) and so did not fall upon the building refurbishment project.

The comfort cooling system for the top floor cost £82 000, including £22 000 for the steel platform for the air-cooled condensers.

6 MONITORING PERFORMANCE

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6.1 Summertime temperature recording

Summertime temperatures were monitored to assess the performance of the refurbishment. Air and globe temperatures were measured using thermistor sensors. A 40 mm diameter black globe on some sensors provided air and radiant temperature measurements from the perspective of the human body[12]. Accurate to better than 1ºC, these sensors were connected to data loggers which took readings at 30-minute intervals. Data was downloaded to a portable computer for further analysis at Oxford Brookes University.

Twenty-four sensors measured internal temperatures on the first floor at 16 sites, seven on the second and five on the third. Most sensors were between 0.7 m and 1 m above the floor, to simulate the centre of a seated person, with others at varying heights in order to measure temperature stratification. Surface temperatures of the ceiling soffits were also monitored. Records of air velocity were made using specially modified Ice-spy dataloggers: four on the first floor, and two each on the second and third floors. A Light Laboratories Mini-Lab was used for occasional checks of air temperatures and air velocities. Further ceiling surface temperatures were recorded using a hand-held Digitron infra-red thermometer.

The distribution of the sensors is shown in figure 7.

The external temperature was measured in a Stevenson Screen near the building. Further sensors were placed 300 mm from the east and west façades at first floor level to measure the temperature of the air just below the windows. Meteorological data for the area – temperature, relative humidity, wind speed and direction, and horizontal solar radiation – were obtained from Milton Keynes Borough Council's weather station.

Figure 7 Sensor locations on each floor

MONITORING PERFORMANCE

6.2 Typical hot weather conditions

Figure 8 shows external temperatures during a hot spell in the period 16-21 August 1995. During these six days the external air temperature officially recorded at Milton Keynes fluctuated between 15ºC and 28ºC. At the University, the local outside air temperature was similar or slightly higher. Just outside the two façades, the peaks in air temperature were higher still, owing to solar heating of the flat roof to the east and particularly the brick wall to the west. This effect would have been reduced had the external surfaces been lighter in colour.

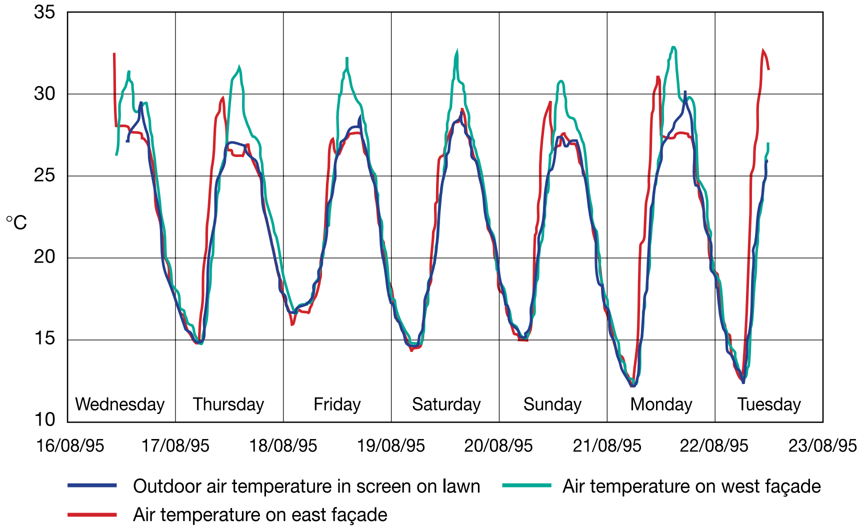


Figure 8 External and façade temperatures in hot weather

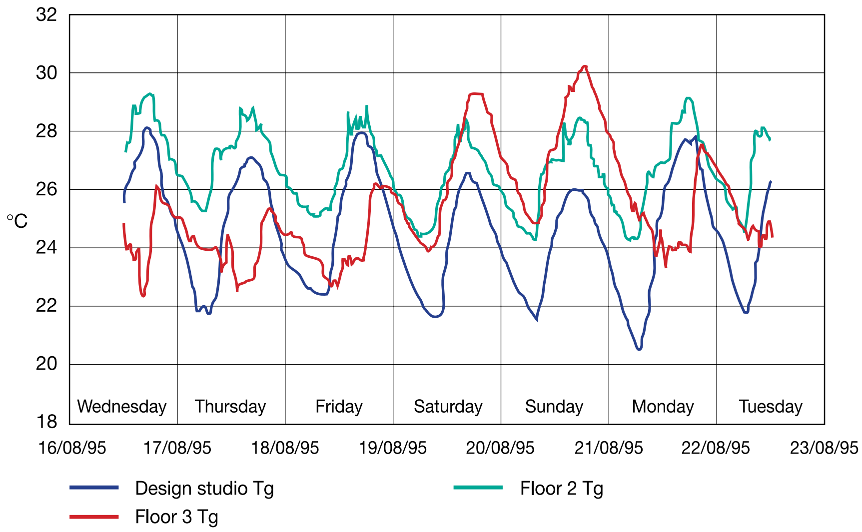


Figure 9 Internal temperatures in hot weather, over a week period. At the weekend internal gains are lower, but on the top floor the comfort cooling is switched off

6.3 Comparing temperature performance of the three floors of B block

In general, the design studio performs well, with peak internal temperatures below peak outside air temperatures, which is essential for a building with natural ventilation alone. Nevertheless, high internal heat gains and relatively low thermal mass does mean that it heats up quite rapidly, at typically 0.6ºC per hour. Peak temperatures could potentially be lowered further by automating the window opening to enhance night ventilation and by further reducing the internal heat gains. Automating window opening would also avoid over cooling the studio on some mornings.

The fabric of the design studio is less able to absorb excess heat (ie has less thermal mass) than the second floor because it does not have the brick partitions. Despite the higher heat gains from occupancy and equipment, temperatures in the design studio were typically 2ºC lower than on the second floor during hot days and 4ºC less at night.

Temperatures in two of the second floor offices in which the modified windows from the pilot project had been retained were generally similar to those in the design studio. This confirmed the success of this interim measure, albeit in offices with greater thermal mass (they have brick partition walls) and lower internal heat gains.

Figure 9 shows the average internal globe temperatures (Tg) on the three floors for the same period. The weekend days show the superior passive performance of the design studio in relation to the second and, in particular, the third floor where the comfort cooling is switched off. On working days the comfort cooling keeps the third floor day time temperature down to 23.5ºC while the design studio peaked at 28ºC in the afternoon. It should be noted that these excessive peak internal temperatures only occur about three times a year.

6.4 Ceiling soffit temperatures

Replacing the ceiling tiles in the design studio with acoustic plaster allows the mass of the concrete floorslab to be exposed to the space. Heat flows slowly into the slab from the room during the day, and is drawn out by the ventilation air at night. Figure 10 shows the stability of ceiling surface temperatures in hot weather. At typically 2ºC or more below peak air temperature and 2ºC cooler than on the second floor, this radiative effect helps to make the studio more comfortable on a hot afternoon.

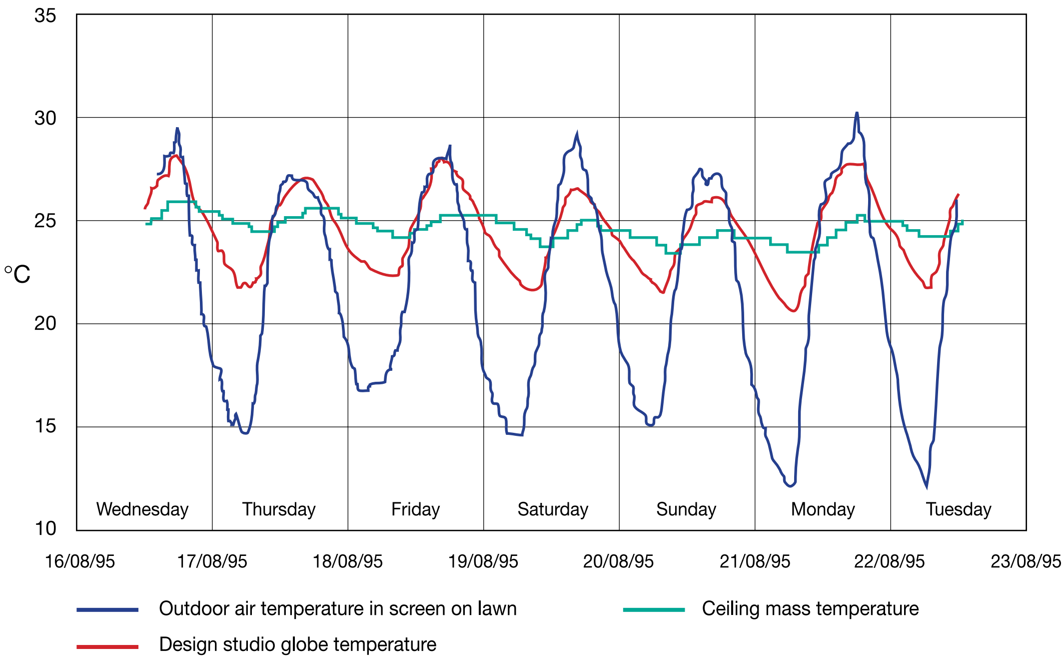
The results confirm that the passive refurbishment measures were performing as anticipated.

- Heat gains during the day had been reduced.
- The thermal mass of the ceiling soffit was cooled below daytime temperature, providing both a radiant temperature cooling effect and helping to cool the air by conduction.
- The window system encouraged night-time cooling, as is apparent from figures 9 and 10.

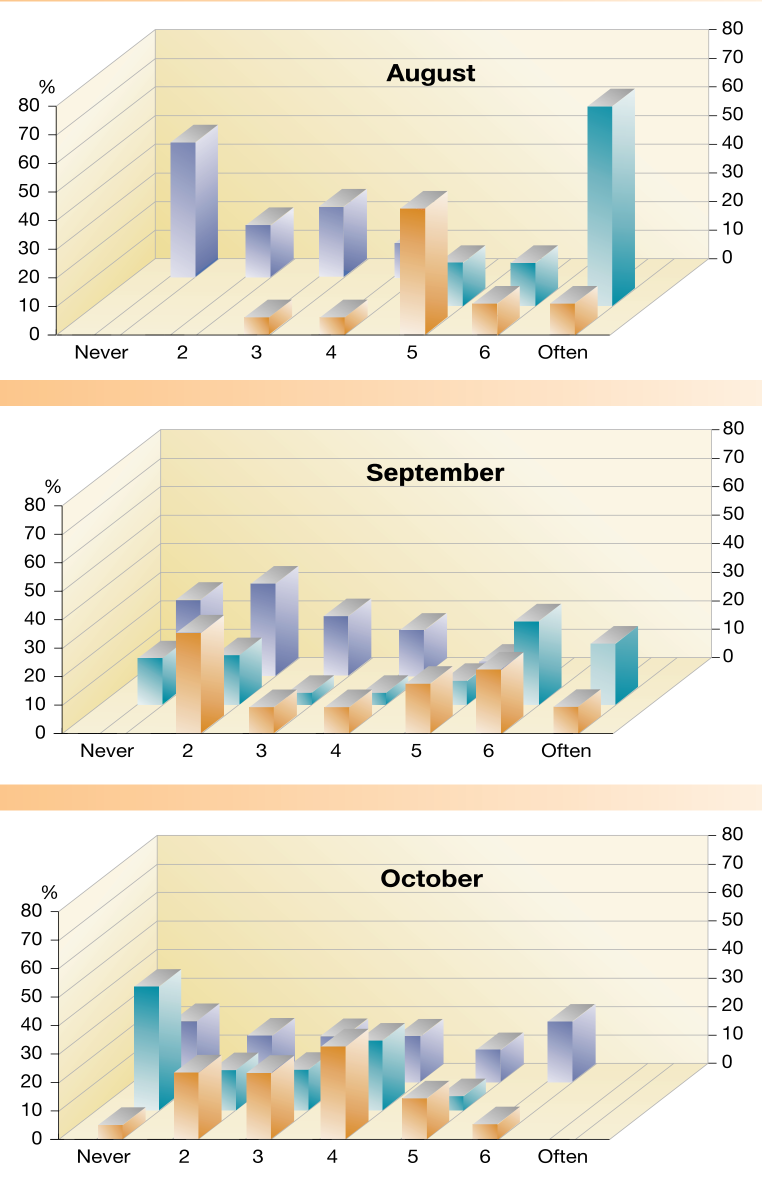
6.5 Air movement

Measurements of air velocity showed greater air movement at workstations in the centre of the design studio than near the windows. There are two main reasons for this. Firstly, those near the windows tended to operate the windows to their benefit, causing nuisance draughts elsewhere, while those in the centre are subject to cross-currents of various kinds. Secondly, cool air entering through the hopper windows first flows along the ceiling and is then 'dumped' towards the middle of the room. Some degree of automatic window operation would have overcome this tendency.

Figure 10 Comparison between outside temperature, internal globe temperature and ceiling surface temperature



7 OCCUPANT SURVEYS



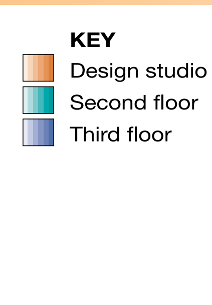


Figure 11 The question asked was: 'How frequently has the temperature been too high in the last two weeks?' The histograms represent the questionnaire results plotted against the percentage of responses. Responses to the left indicate staff were not too hot, and to the right that conditions have been too hot. As the seasonal temperatures fall from August to October the results show the staff on the third floor were less comfortable, while those in the naturally ventilated second floor and design studio are more comfortable.

7 OCCUPANT SURVEYS

7.1 Monthly surveys

Questionnaire surveys undertaken in August, September and October 1995 requested staff for their comments on comfort during the preceding two weeks. Responses from the different floors were compared.

Staff surveys confirmed the monitored temperatures. Additionally, staff in the design studio on the first floor felt that their environment was better than that of staff on the second floor, particularly in hot weather.

In comparison with those on the comfort-cooled top floor, design studio staff felt that their environment was just as satisfactory in the hot August weather and even more so in September and October. However, the comfort cooling on the third floor did give occupants a powerful sense of control over temperature in very hot weather.

Further analysis of the responses in the design studio revealed a significant difference in perceptions between occupants with seats near the window and those with seats near the middle of the room. Those in the middle reported less control over temperature, ventilation and light; felt cold and draughty more often; and were less satisfied with the adequacy of the lighting. Overall satisfaction levels in the middle were more similar to those on the third floor.

As a general rule, occupants of cellular offices (as on the second floor) tend to report greater satisfaction with the internal environment than those in open plan areas.

7.2 Final survey

The final staff survey sought overall reactions to the working environment. It was in four sections:

- background information about the individuals, their work and attitude to the workplace
- perception of the physical environment, including temperature, ventilation and lighting in winter and summer, perceived control and its rate of response, and perceived productivity
- effect of refurbishment alterations on staff satisfaction
- space for other comments.

OCCUPANT SURVEYS

The remaining sections (7.2.1-7.2.5) focus on responses from the design studio, being the area of particular interest for this study. Comparisons with comments from occupants on other floors are made where appropriate.

7.2.1 Temperature and air quality

The final survey showed that staff in the design studio were generally happy with summertime conditions (figure 12), with no memories of being uncomfortable during the hottest summer so far this century. A useful rule of thumb is that when indoor temperatures are high they should still not exceed the peak outside air temperature. The design studio met this criterion and the staff regarded conditions as reasonable.

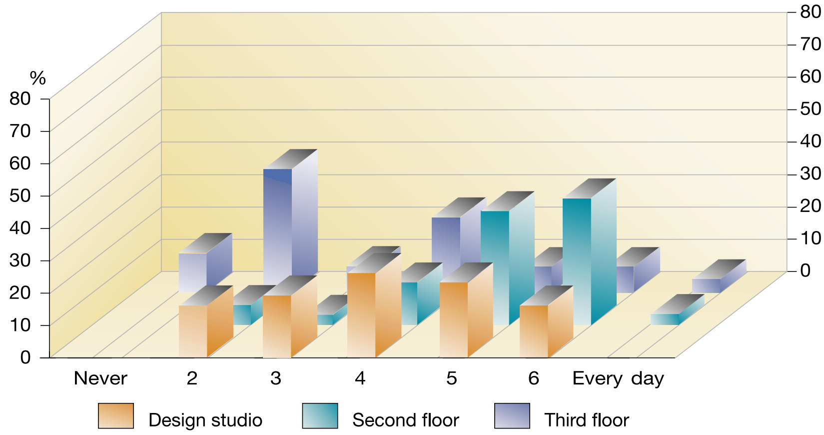


Figure 12 Staff response to the question: 'How often has your office been too hot?'

Air quality was regarded as good, even favourable, to the health of its occupants, particularly those with allergies. However, those with workstations beside the windows did report that their desks were sometimes dusty.

Staff away from the windows sometimes felt cold on summer mornings and reported more draughts, both in summer and winter. Air currents originating from the upper windows could be one of the problems (see section 6.5). Being more remote from solar gains and perimeter heating, aisle workstations could also be slower to warm up early in the day. Some automatic control of night-time ventilation could help with this problem.

7.2.2 Lighting

Staff near the windows were almost unanimously satisfied with the natural light. Staff further away reported problems of insufficient daylight and glare[13] from their computer screens. The problems are linked.

- A lower level of daylight is normal at some distance from the window.
- The orientation of the façades to ENE and WSW makes them particularly susceptible to glare from low sun.
- The angling of the screens at 45° to the windows exacerbates the problem.

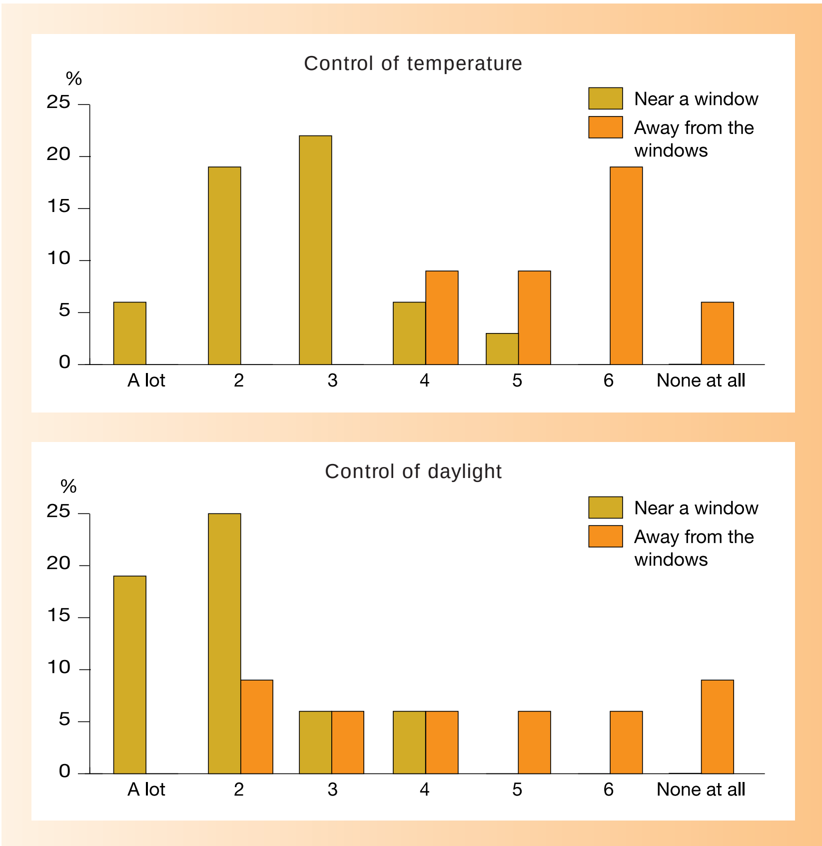


Figure 13 Design studio staff responses to: 'How much control do you feel you have over temperature/daylight of your environment?'

Once the blinds in the upper windows were closed, they often remained closed for long periods, hence reducing the available daylight. Better control of this top blind, or a fixed device is needed to admit some light while eliminating glare. Better awareness of how to operate the blinds would go some way to overcome this problem. All the staff generally appreciated the electric uplighting.

OCCUPANT SURVEYS

7.2.3 Perceived control and response

The designers intended that the control of comfort would be accessible to everyone. For this reason all controls are placed in the middle of each group of windows, with a gap between the desks to allow easy access. This includes variable window opening for day and night ventilation, with adjustable blinds for solar gain and glare control, and radiators with individual thermostatic valves.

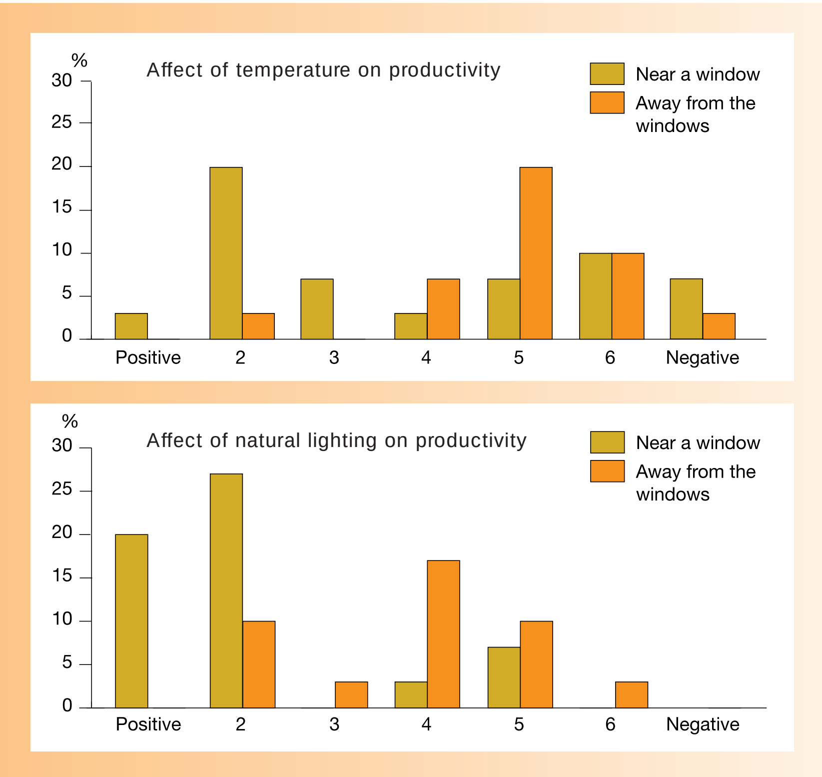


Figure 14 Design studio staff responses to: 'To what extent do room temperature and daylighting affect your productivity?'

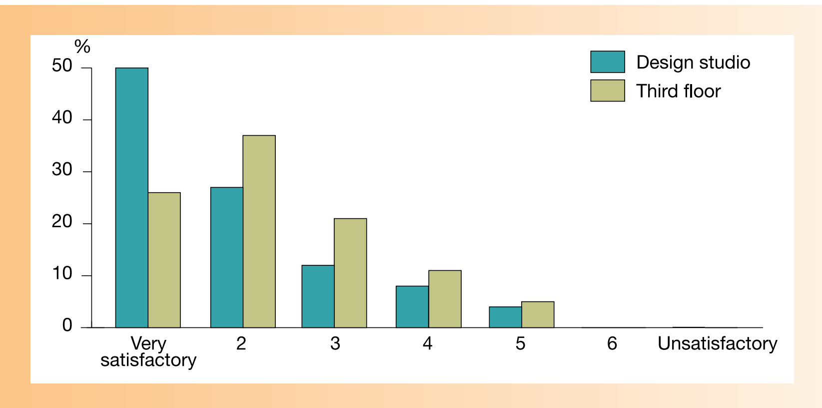


Figure 15 Survey responses to: 'All things considered how do you rate the changes to your environment?'

Figure 13 shows that those nearest the windows feel, and are felt to be, much more in control. Those in the middle of the room not only have less control, but are also more likely to suffer ill effects – glare, draughts and low daylight – and so are more critical of their environment.

Figure 14 illustrates that design studio staff near the windows are most satisfied with the temperature and lighting, and this is reflected in their perception of their productivity. It also shows the effect of temperature and daylighting on productivity were perceived differently.

7.2.4 Attitudes to the refurbishment

Seventy-five percent of design studio staff reported that the refurbishment had significantly improved summertime comfort and the ambience of the office. The reservations of the remainder were related to changes in working practices rather than to temperature, lighting and ventilation.

Design studio staff compared their surroundings positively with the other floors and, in particular, the second floor. Improvements in lighting and reductions in peak temperatures were not their only reasons – they were also reacting to the pleasing interiors including the new windows and ceiling ('well planned, light and airy').

Staff on the second floor, where the pilot scheme was implemented, reported an increase in satisfaction where window modifications were carried out. This concurs with monitored lower summertime temperatures and confirms the importance of improved window design with night ventilation in the refurbishment strategy.

On the comfort-cooled third floor, staff appreciated the reduced summertime temperatures and felt that ventilation had also been slightly improved. However, they were generally less positive about the refurbishment. This suggests that, in comparing natural and mechanical methods of lowering summertime temperatures, reduced temperatures are not the only consideration when staff comfort and satisfaction is to be increased. These issues are illustrated in figure 15.

OCCUPANT SURVEYS

7.2.5 General and individual comments

Overall, the design studio was highly regarded by most of its occupants. Many staff on the other floors also named it as their favoured place to work. This good vote was a consequence not only of its improved temperatures, lighting and ventilation, but its décor, layout, furniture and cleanliness. This also illustrates the importance of taking a holistic approach to design when staff comfort is an issue.

Staff adjacent to the design studio windows reported the best environment. Those at aisle workstations were less comfortable in some respects, but their overall votes were at least as good as those on the other two floors.

Those on the third floor appreciated the new comfort cooling, particularly in hot weather when temperatures previously had been very high.

However, awareness of the natural cooling system among studio staff was less widespread (about 50%) than might be hoped. Greater staff awareness would undoubtedly increase the effectiveness of the natural ventilation strategy.

8 ENERGY PERFORMANCE

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8.1 Energy surveys and monitoring

On the first and second floors electricity consumption in kWh and demand in kVA was recorded at half-hourly intervals using portable meters. Overall energy consumption on each floor was split into end uses by scheduling all devices, determining their energy demand using an HCK portable power meter where necessary, and estimating their hours of use by questioning staff and observation, including a night visit to check electricity consumption.

On the third floor, only the energy consumption of the mechanical cooling system was monitored, using the University's building energy management system (BEMS).

8.2 Overall electricity consumption

Figure 16 compares the annual electricity consumption per square metre of treated floor area on the first and second floor with benchmarks for 'typical' and 'good practice' open-plan and cellular offices, taken from ECON 19[7].

8.3 Lighting energy consumption

Figure 16 shows that annual lighting energy consumption is higher than current 'good practice' levels in the design studio (an open-plan Type 2 office[7]). In spite of this, at 27 kWh/m^2, the design

Electrical kWh/m^2 of treated floor area						
	Cellular office			Open-plan office		
	ECON 19† Good Practice Type 1	Open University second floor	ECON 19† Typical Type 1	ECON 19† Good Practice Type 2	Open University design studio	ECON 19† Typical Type 2
Lighting	14	16	23	22	27	38
Office equipment	12	16	18	20	52	27
Refreshments††	2	4	3	3	6	5
Total†††	28	36	44	45	85	70

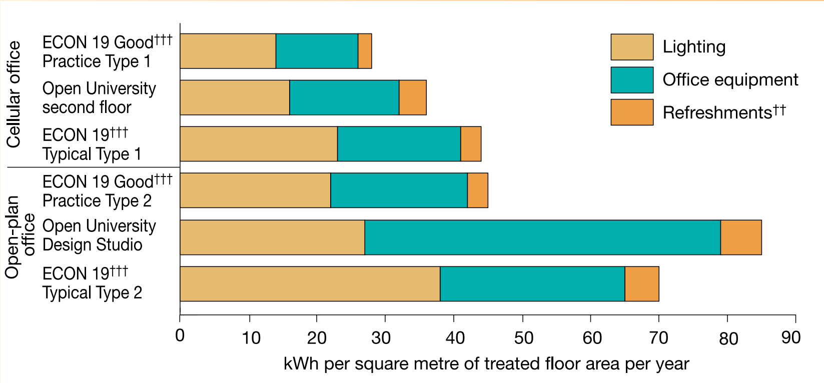

Figure 16 Table and histogram showing electricity consumption comparing ECON 19 benchmarks for naturally ventilated offices

†The figures in ECON 19 were updated in 1997

††Vending machines and kettles, which is defined as 'catering' in Type 1 and 2 offices in ECON 19

†††For comparison to ECON 19, the total excludes 'other electricity', 'fans, pumps and controls' and 'cooling' as the Wilson Building has an external heating main

ENERGY PERFORMANCE

studio's lighting energy consumption is some 30% higher than the designers had expected. There are several reasons for this.

- When staff arrive in the morning – even in summer – they switch on more lighting than is necessary.
- Blinds are often left down from the previous day and staff find it easier to switch on the lights than to adjust the blinds.
- The lamps take several minutes to warm up to full brightness after switching on, so the initial impression given of the light available is somewhat dim, even on the high setting.
- Many lamps are left on at the end of the day until they are finally switched off at 9.00 pm by the automatic control.

If the furniture layout had been more sensible (see section 3.1), and there could have been a more even distribution of window area and less use of blinds for glare control, then the design target might well have been achieved. As is generally common, lights usually stay on unnecessarily as daylight levels rise.

Occupancy sensing and daylight-linked dimming would have helped, though at additional capital cost. Some savings could also be made by encouraging people to take responsibility for switching off their own lights. Changing the programmed lighting control so that the lights were switched off earlier would also save energy.

8.4 Energy consumption by office equipment

The annual energy consumption of the office equipment on the second floor is about 16 kWh/m^2, and 4 kWh/m^2 for other equipment, which is more than the ECON 19 'good practice' benchmark. This is probably because everyone uses a PC. In the design studio, overall electricity consumption by office equipment is considerably higher at 52 kWh/m^2 (58 kWh/m^2 including the print room) – almost twice the 'typical' benchmark. In spite of this, office equipment energy consumption is only similar to that of lighting in a typical open-planned office. This illustrates the savings in energy consumption and the associated heat gains (and hence gains in peak summertime temperatures) which can be made by installing energy-efficient luminaires and controls.

8.5 Night electricity consumption

Electricity is used both during working hours and when the office is unoccupied at night and for much of the weekend. Design studio staff are conscientious about switching off machines at night. Nevertheless, the rate of electricity consumption at night is 20% of that during the day.

Over the year, electricity used outside occupied hours was found to account for some 30% of the total electricity consumption, although this is considered modest in relation to some offices. Equipment left on includes:

- the refrigerator and water cooler
- some corridor lights
- extractor fans
- the file server and printer
- one or two computer systems on test or night runs
- other printers, photocopiers and plotters also remain on standby.

The computer security system also uses typically 8 W per workstation when the PCs are switched off.

8.6 Electricity consumption for comfort cooling

The energy saved by adopting a natural ventilation approach depends on many factors. However, on the top floor the comfort cooling system consumed between 135 kWh and 200 kWh on hot days. Annual consumption for this purpose is estimated from monitored results at between 30 kWh/m^2 and 45 kWh/m^2.

8.7 Heating energy consumption

Heat is supplied from the University's central boiler house and not locally metered. Average gas consumption at the University appears to be close to typical levels of 200 kWh/m^2. It is estimated that the improved windows in the design studio – together with the greater heat gains from the equipment – have more than halved the heat demand attributable to this area.

9 SUMMARY AND LESSONS LEARNT

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9.1 Summary

The refurbishment of the Open University's design studio was a success, and demonstrates how natural ventilation can improve comfort levels and reduce temperatures during the summer. The strategy avoided the need for mechanical cooling through a careful appraisal and computer modelling of heat gains and losses.

The following summary states how a successful refurbishment was achieved at the Open University, and suggests how the methodology could be employed by designers and building services engineers to consider the applicability of the measures for other buildings.

The key components of the strategy were to:

- reduce internal gains through equipment choice and use
- lower external gains by increasing thermal resistance of outside building fabric
- use the building as a thermal store to modulate internal temperatures
- involve staff and increase staff control
- undertake thermal modelling
- compare power consumption to typical benchmarks.

The success of the natural ventilation strategy in the design studio also involved other factors, such as reducing temperatures by storing heat using the thermal capacity of the building, particularly the ceilings, and removing this heat by night ventilation.

Temperatures and power consumption were monitored, recorded and analysed over a period of time to ascertain the building's performance.

The internal temperature of the refurbished building was 4°C lower than previously and was maintained at 2°C below external air temperatures. Internal temperatures rarely peaked at more than 27°C, and staff comfort was achieved despite internal heat gains rising from 27 W/m^2 to 58 W/m^2.

In addition, opportunities for staff to control their internal environment further increased staff comfort beyond that associated with the temperature modulation in the building. The staff were able to vary lighting levels and ventilation rates in response to variations in the external environment. For example, by opening a window occupants could feel a breeze or even the direct warmth of the sun. The quality of the internal décor, including furnishing and plants increased staff perceptions of comfort and well-being.

A key element in the design process was that of occupant involvement and perception. Recent studies show that this can result in improved comfort levels and increased productivity. Design studio staff were involved at the outset. They also helped choose furniture and lighting, and helped to decide the level of control they would have over ventilation, heating and lighting levels.

Occupant perception is subtler, although no less tangible[5]. The perception of occupants on three floors of the Wilson Building is continually changing. This is partly a reflection of the accommodation's ability to deal with the weather with more or less success in different months.

Design studio staff have the greater control over their environment throughout the year and are therefore the most satisfied. Accordingly, those in the design studio who are furthest away from windows, and with less control, are less satisfied.

9.2 Window considerations

New windows were a key element in the refurbishment of the design studio; improving day and night ventilation, reducing solar heat gains, and controlling glare. Lessons learnt included the following.

- The manually controlled upper windows provided effective night ventilation, but sometimes the office was too cold in the morning, and sometimes it could have been controlled better. Automatic control of night ventilation might have been preferable.
- The venetian blinds were not entirely successful in controlling glare – chinks of sunlight got through the suspension holes and around the edges.

SUMMARY AND LESSONS LEARNT

Figure 17 Uplighting on when the blinds are partially closed

- Occupants tended to open and close the blinds, rather than to adjust them finely for minimum glare and maximum daylight, and the blinds in the upper windows were often found completely shut. Automatic control (with local manual override facilities) might have been preferable, if only to return the blinds to sensible positions each morning.

The lights were on more than had been hoped. This was partly a consequence of the window arrangement necessary to reduce glare in computer screens, and the blinds being closed more than strictly necessary.

Good access was provided for all staff to operate the windows. In spite of this, the windows were still seen to 'belong' to those sitting nearest to them. However, staff away from the windows were more affected by light, glare and draughts from the upper windows than those sitting nearby. Providing passive infrared (PIR) controls or a degree of automatic control would reduce this problem.

9.3 Occupant satisfaction

- Overall, occupants of the design studio were more content than those on the top floor where, at similar cost (on a per m^2 basis), comfort cooling had been added.
- In very hot weather design studio staff felt that conditions were still reasonable and productivity unaffected, although staff on the comfort-cooled third floor were more thermally comfortable.
- Even though the refurbishment reduced the window area by over 40%, many people in the design studio felt that daylight and view had improved, showing the importance of quality over quantity.
- Proximity to a window and control over it is an important aspect of comfort in a naturally ventilated building. People near the windows in the design studio reported significantly higher levels of comfort than those further away.
- People away from windows reported more draughts than those adjacent to windows because:
  - they were less in control of the windows
  - draughts could originate from several windows and not just the nearest
  - cold air from the hopper windows could be 'dumped' in the middle of the room.

9.4 Other lessons for future designs

An important contribution to the success of the scheme was the involvement of staff in the selection and evaluation of options, in particular windows, blinds, controls and lighting.

The high temperature of external walls and the building's surroundings due to solar radiation can significantly increase peak air temperatures immediately outside the windows. This effect needs to be considered when making summertime temperature predictions.

Motorised control of upper windows and blinds should be considered, with automatic operation at night and occupant override during the day, readily available to occupants in the middle of the space. The automatic control can also be used to prevent over-cooling at night (which leads to complaints of chilliness in the morning).

Space planners, interior designers and furniture designers should take care to avoid window glare on computer screens. It is best if the view line from operator to screen is parallel with the window wall[2].

10 CONCLUSIONS

10 CONCLUSIONS

The passive refurbishment of the design studio has been a great success, reducing summertime temperatures and increasing comfort. It has met the expectations of the University's Estates Department, staff and the designers. However, the study has raised a number of issues that will be of interest to designers and their clients.

10.1 Who has control?

Earlier studies[4,14] have linked comfort, control and energy efficiency and have pleaded for buildings that are well equipped not only to provide comfort but also to avoid discomfort. Indeed, the design studio refurbishment was designed along these lines. The designers did their best to provide good access to the window controls for all occupants. Nevertheless, and in spite of the shallow plan, occupants of the aisle workstations felt significantly less in control of their internal environment – and significantly less comfortable (though no less comfortable overall than those on the comfort-cooled top floor). The issue of control clearly needs yet more attention if a real success is to be made of a naturally ventilated building. The upper windows have more of an impact on the people in the middle of the space. PIR controls would provide them with good control, but this could generate new conflicts.

10.2 Unexpected air movement

The upper hopper windows were deliberately designed to pass air over the soffit of the ceiling, and hence to improve heat transfer and to remove excess heat overnight. While they did this effectively, they also introduced the problem of dumping cold air on the workstations in the middle of the room, in much the same way that air from a badly adjusted air-conditioning diffuser sometimes does. In general, air velocities were also higher in the middle of the room than at the perimeter workstations. While these attributes might have been assets in very hot weather, they definitely were not when it was cooler – and particularly in the morning. It might have been better to have operated these windows using automatic control for night ventilation when needed.

10.3 Electricity consumption at night

Although the amount of equipment left on at the Open University overnight was relatively small, electricity consumption outside normal working hours accounted for 30% of the annual total. Designers and occupiers need to take this into account: designers, when designing systems and making energy consumption estimates; and occupiers when purchasing, operating and managing equipment and in giving instructions to staff. Some devices consume significant amounts of energy not only when in standby mode, but also when they are nominally off (ECON 35[15] and GPG 118[16]).

10.4 Costs

On the face of it, the cost of the window replacement and of the comfort-cooling systems were very similar. As it happened, the lighting and major ceiling redecoration had been included in the refurbishment plans for the design studio. Although the measures proposed to improve thermal performance were not the cheapest, they were accommodated within the overall budget. This emphasises the potential for adding value by grasping opportunities to undertake an integrated project rather than proceeding piecemeal.

10.5 Benefits

By using a solution based on natural ventilation the University's Estates Department installed a window system which gave the building a new lease of life, improved summer comfort and reduced winter energy consumption. Maintenance and energy costs were not increased by achieving comfort for staff in summer, as would have been the case for a mechanical cooling system.

The design studio staff can benefit from lower summertime temperatures and a whole new visual environment with more environmental control.

Although the design studio still gets hot occasionally, the level of discomfort and loss of productivity is small, and is far more than counterbalanced by the increased feeling of well-being all the year round.

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FURTHER READING

FURTHER READING

BRE

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

Chartered Institution of Building Services Engineers

Applications Manual AM10. 'Natural Ventilation in Non-Domestic Buildings'. CIBSE, London, 1997

DETR ENERGY EFFICIENCY BEST PRACTICE PROGRAMME DOCUMENTS

The following Best Practice programme publications are available from BRECSU Enquiries Bureau. Contact details are given on the back cover.

Energy Consumption Guides

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Good Practice Case Studies

15 Energy efficiency in offices. A single new multi-tenanted speculative building with cost-effective building services. Hempstead House, 2 Selden Hill, Hemel Hempstead

20 Energy efficiency in offices. Refuge House, Wilmslow, Cheshire. New owner occupied offices designed for both natural ventilation and air-conditioning

308 Naturally comfortable offices – a refurbishment project

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