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Using night cooling in a temperate climate

FERGUS NICOL*, PAUL ROBINSON AND MARIA RITA KESSLER

Oxford Brookes University
School of Architecture
Gipsy Lane Campus, Headington,
OX3 0BP, Oxford, UK.
jfnicol@brookes.ac.uk

Abstract

In 1993, the Open University in Milton Keynes, UK, refurbished the open-plan first floor Design Studio in their Publishing Department to use natural ventilation to keep the interior cool. At the same time the third floor, which was not suitable for passive cooling, was fitted with mechanical comfort cooling units and the intermediate floor was not changed. This paper compares the thermal performance of the three floors and discusses the results of a staff-satisfaction survey conducted among the occupants. It shows that despite conditions being cooler on the third floor in the very hottest weather, the passively cooled floor was preferred overall. Lessons can be drawn for the successful use of passive cooling in temperate climates.

INTRODUCTION

Air conditioning means higher energy and maintenance bills as well as an increased burden for our environment.

In a temperate climate like Britain's, the use of air conditioning can be avoided in a well designed naturally ventilated building. Night time cooling is an important strategy for such a project. It cools down the structure of the building overnight allowing it to absorb daytime heat loads to keep internal temperatures lower during working hours. The Open University used this system when refurbishing its Design Studio in Milton Keynes.

In the summer of 1995 Oxford Brookes University monitored electricity consumption and temperatures and surveyed staff reactions in three floors of block B of Open University's Wilson Buildings. This work was done on behalf of Brecsu - EEO whose Best Practice Programme promotes passive refurbishment and natural ventilation to minimise energy use in the UK. The passively refurbished open plan Design Studio on the first floor was compared to the unchanged second floor and the lightweight third floor with comfort cooling. The cost of the two cooling strategies was similar.

The published results ([1], [2] and [3]) are intended to help in the design of naturally ventilated new and refurbished offices, and to encourage the adoption of night time cooling. This paper extends the discussion of this important UK experience to a wider context to respond to a world-wide legacy of post-war concrete buildings and over-sized glazed "international style" facades in similar climates.

BACKGROUND INFORMATION

The building as it was

The lower three floors of the Wilson buildings, Block B, were built in the 1970's and have an internal depth of 13m and a ceiling height of 2.7m. The external walls are cavity brickwork with 50 mm cavity fitted with blown fibre insulation . The structure has concrete ceilings and floors. The windows are continuous ribbon glazing, with single fixed and centre pivot panes in aluminium frames of 1.8m height. They face north-east and south-west. Internal curtains or venetian blinds control solar glare.

The Design Studio on the first floor is an open plan studio with two cellular offices. It had acoustic ceiling tiles covering its thermal mass. The second floor is divided into cellular offices by internal brick partitions and has a painted ceiling exposing its thermal mass.

The third floor was added later with a lightweight structure in a mansard roof with black artificial slate tiles, and 50mm polystyrene insulation internally lined with plasterboard. The average ceiling height is 3.1m. It has cellular offices to one side of the corridor and a large open plan space to the east side with a few adjacent cellular offices. All partitions are studwork. The windows are individual centre pivoted Velux double glazed units with trickle ventilators and captive venetian blinds.

The problem

Large areas of glazing (60% on the main facades) make the offices prone to overheating, particularly B block which has windows facing NE and SW. This problem has increased in recent years as occupancy and levels of IT equipment have risen.

In 1991 the Open University (OU) were considering ways of reducing excessive summertime temperatures.

Comfort cooling was proposed as a first solution but staff were opposed to mechanical air conditioning or cooling. The OU also has a policy of reducing energy consumption wherever possible. Maintenance and energy costs of mechanical options also had to be taken into account. The University sought a second opinion from experts in natural cooling.

After recording internal temperatures and recording simulations, an independent consultant concluded that with modified window design allowing natural ventilation, secure night ventilation and a more efficient lighting system, reasonable summertime temperatures were achievable on the lower floors but not on the lightweight top floor.

A first test was set using second floor offices, with exposed ceiling thermal mass, as a case study. Summertime temperatures were monitored in eight offices of the Wilson Building, four of which with the original aluminium windows and the other four with upper and lower hoppers added to the original windows to allow for better natural ventilation and night time cooling. The monitoring supported the consultant's assessment, but window replacement, rather than modification, was recommended.

In 1993, the first floor Design Studio was to be refurbished. The Studio was growing in staff numbers and in area, and it was changing from drawing boards to computers. It was being fitted with new furniture and powerful large screen workstations. Each designer was given a computer with an A3 screen for design and publishing work, and shared a second computer with their neighbour for text work. The computers were expected to be on all day and one or two to be left processing overnight. Internal heat loads increased considerably.

The OU decided to use the design studio for a full scale pilot project based on the early recommendations from the consultants, even if high internal gains made it a borderline case.

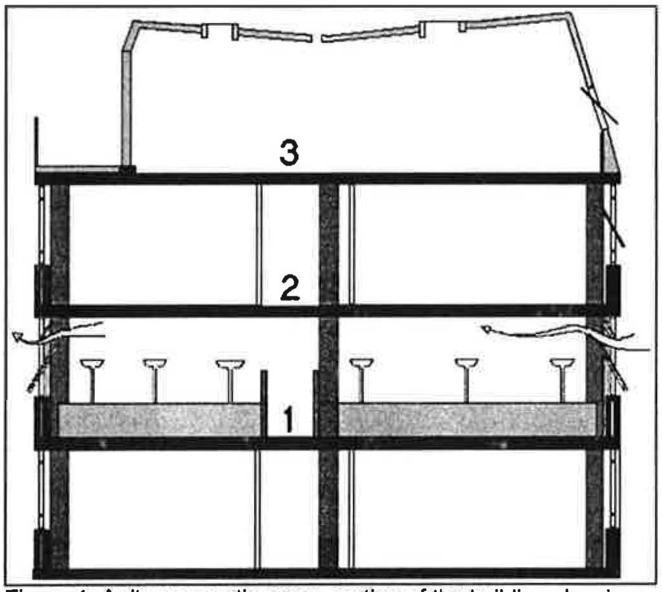

Figure 1. A diagrammatic cross-section of the building showing: 1- first floor cross-ventilation strategy; 2- original cellular offices in the second floor; 3- added third floor.

The chosen solution

To achieve a comfortable internal environment through natural ventilation the refurbishment of the Design Studio follows a three pronged strategy:

1. Control of the building envelope, heat gains and losses, and control of incoming airflow according to the outside temperatures.
2. Improvement of the ceiling's thermal capacity for night time cooling and as a heat sink for daily internal gains.
3. Low energy lighting and equipment and zoning of equipment to minimise heat gains to the office space.

As a complement to the cooling strategy additional measures were introduced to improve the atmosphere in the studio: new layout with small groups of workstations and access to the window and blinds controls, plants, cool colours and indirect lighting.

The refurbishment of the Design Studio

The project of the first floor refurbishment included:

- Reducing glazed area - three in every seven windows being replaced by blank insulated panels - to reduce glare and heat gain.
- Replacing ribbon glazing with centre pivot windows and high level inward opening hopper windows, to allow access to cool night air and direct it onto the ceiling.
- Replacing simple window catches for a locking system, which allows secure opening for night ventilation.
- Including remote worm-gear control for the hopper windows, readily accessible and operable by occupants.
- Replacing internal curtains and blinds with captive venetian blinds within the window system between the outer single glazed leaf and the inner double glazed sealed units, in order to control glare and heat gain.
- Removing acoustic tile-on-battens from the ceiling and replacing them with sprayed acoustic panels to expose the thermal mass of the concrete ceiling and improve the aesthetic effect of uplighters.
- Replacing ceiling mounted fluorescent luminaires with free standing compact fluorescent uplighters with individual choice of on/off and high/low levels.
- Include controls which allow all lights to be switched off from the exit doors, but only the corridor lights to be switched on again from this position.
- Low energy fluorescent task lights to prevent unnecessary use of uplighters.
- Grouping photocopiers and laser printers in side rooms with extractor fans to expel warm air and fumes.
- Introduction of new furniture, plants, neutral colours and indirect lighting to create a cool and relaxing space.
- Careful desk layout to make window and blinds controls accessible to all.

PERFORMANCE EVALUATION

To ascertain whether the refurbishment provided comfortable conditions for the staff without the need for air conditioning, the performance of the building, with respect to temperatures and electricity consumption, was monitored over the summer of 1995. During the same period monthly staff surveys indicated the level of satisfaction on each floor.

Monitoring energy use

Half-hourly KVA and power factors were recorded. Similar data was recorded for the second floor. The energy consumption for comfort cooling on the third floor was recorded. Consumption data at 15 minutes intervals was stored for each day of the monitoring period.

Floor 1 - Design Studio - Electricity consumption per unit treated floor area was estimated, by extrapolating for a full year, to be 85kWh/m^2/y. Approximately 58kWh/m^2/y is consumed by equipment and 27kWh/m^2/y by lighting. Night time and weekend electricity base load is high at about a fifth of the weekday daytime peak load. Approximately 50% of the electricity consumption in the studio is outside daytime office hours.

Floor 2 - Lighting and small power use totalled 36kWh/m^2/y. This is estimated to break down to 20kWh/m^2/y for small power, and 16kWh/m^2/y for lighting

Floor 3 - Lighting and small power consumption is estimated to be similar to that on the second floor, but, in addition, floor 3 office space was observed to consume in the region of an extra 135-200kWh on hot summer days for comfort cooling. This is equivalent to 0.37-0.55kWh/m^2/d (treated office area) for comfort cooling.

To set the observed electrical energy consumption into context, Floor 1 (naturally ventilated, open plan, Design Studio) was compared with that of BRECSU Type 2 office space (naturally ventilated, open plan). Figure 2 shows this comparison for typical and good practice cases. This classification of office space and representative energy consumption is detailed fully in Energy Consumption Guide 19 (ECON 19) of the Best Practice Programme [4].

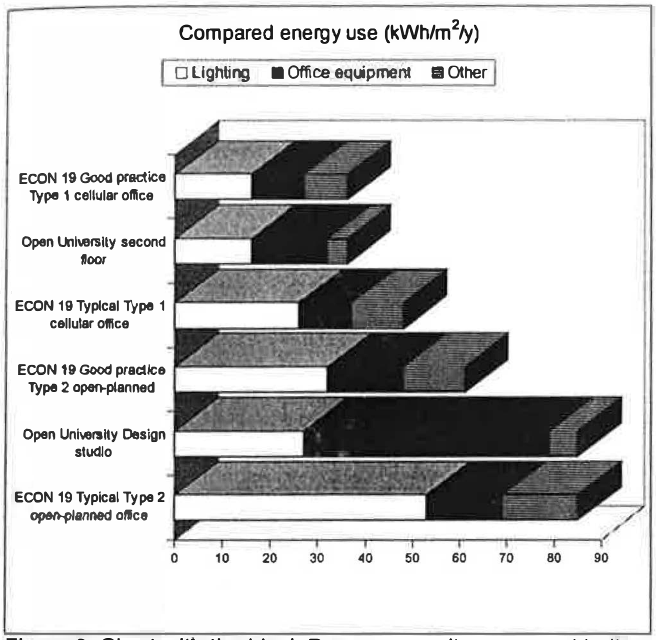

Figure 2. Chart with the block B energy results compared to the ECON 19 yardsticks.

Monitoring temperatures

Internal mean radiant temperatures and air temperatures were measured using thermistor sensors. Half-hourly readings were taken and stored on small, portable data loggers with independent power supply. Down loading of data took place every few weeks.

Figure 3 shows the temperatures monitored between 16 and 23 August 95; they were some of the hottest days of that especially warm month.

The figure shows the effect of the window system, introduced thermal mass and night cooling strategy on indoor temperatures. In the studio they were typically 4K below those on the second floor at night and 2K in the day time in spite of higher occupancy and equipment heat gains, and less thermal mass (no partition walls) within the open plan space.

On the third floor, outside office hours, when the comfort cooling is not running, daytime temperatures are 3-4K higher than in the studio. During office hours the comfort cooling reduces indoor temperatures to an average of 2K below the temperatures in the studio (see Figure 3).

During office hours, the mean peak globe temperatures in the Design Studio are comparable with external peak air temperatures, whereas those on floor 2 are 1.5K above ambient. At weekends, the Design Studio mean peak globe temperature is 1K less than ambient air, but Floor 2 is still 1.1K higher.

On the second floor, the two cellular offices where high and low level hopper windows were installed as a retrofit measure to improve single sided ventilation, are 2-3K cooler than the ones with the original windows. This indicates some success for the measure. The staff of these offices are enthusiastic about this refurbishment strategy and take care to also manage the blinds to minimise solar gains in summer.

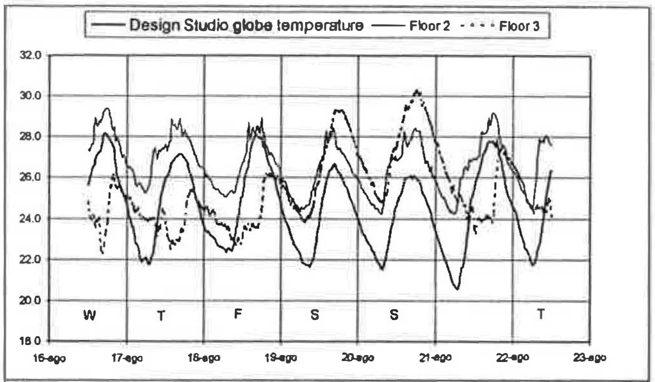

Figure 3. As discussed above, this figure shows the monitored temperatures of the three floors during a very hot week of the hottest summer this century.

Staff surveys

User surveys were conducted at monthly intervals in August, September and October 1995, together with the monitoring of the building. At that stage, short questionnaires specifically asked the staff's perception of comfort in the previous two weeks.

In November a final survey was conducted to find the overall reactions of the staff in relation to their work environment.

As those results are analysed in depth in other publications ([1] and [5]), and this paper is dedicated to the night cooling strategy, we are limiting ourselves to a brief discussion of the key findings:

1. The staff at the Design Studio feel that their environment provides better thermal conditions than the unchanged second floor, especially in hot weather. They felt this in spite of the fact that it has a greater heat load and that open plan spaces are more often criticised.
2. They also feel that they have more control over their environment than those on the second floor, especially if they are seated by the windows.
3. Staff perceive 'aisle' workstations, away from the windows, as having inferior conditions to the workstations by the window (this result is in accordance with other studies on "perception of thermal comfort", [5], [6] and [7]). There is less control of temperature, ventilation and light, it feels cold and draughty more frequently, and is more often poorly lit.
4. The comfort cooling on the third floor appears to give the occupants a particularly powerful sense of control over temperature in very hot weather (in this climate such very hot weather represents less then one percent of the working hours in a typical year [8]). As the weather got cooler their favourable perception of thermal comfort was no higher than in the first floor Design Studio.
5. The results show how reactions change as the weather moves from very hot to cooler [5].

6. The provision of adequate control over the thermal environment has a powerful effect on the occupants' overall satisfaction with their environment.
7. The November survey shows that the Design Studio staff are pleased with their summertime conditions in the office. There are no "sticky" memories from the hottest summer in the century, giving a fair measure of the success of the refurbishment.
8. It is important to report that the staff of the second floor, whose offices were fitted with low and high hoppers as a first attempt to use night time cooling and better levels of ventilation, are happier about their environment than those whose offices have the original set of windows. Their level of satisfaction and the improved monitored temperatures of those offices confirm the window design as a critical step towards thermal comfort. It also reinforces the success of the design strategy.
9. In comparison with the findings in the Design Studio, staff on the third floor are less positive about the effects of their refurbishment.

CONCLUSIONS

1. Night time cooling can successfully avoid the use of air conditioning.
2. Night time cooling is an effective tool to reduce internal temperatures in hot weather despite high internal loads. The cooled thermal mass of the ceiling works as a sink for those extra internal heat gains and keeps indoor temperatures comparable to the outdoor ones at peak time.
3. This result adds to the research on night time cooling in temperate climates as thermal comfort can be achieved without the need for a sealed environment during daytime ([9] and [10]). The fact that open windows and natural ventilation can contribute to the comfort of staff (and especially to the perception of comfort and the perception of control over one's environment [5]) is of importance to the design of new or refurbished naturally ventilated offices in temperate climates. To this matter one should add that not just climatological specifications should be considered but cultural ones (e.g. , working hours in the UK), and site constraints (e.g. , pollution, noise).
4. This survey emphasises the importance of staff's participation on the choice and day-to-day management of their working environment. As most of the problems that staff experience could be overcome with simple acts of management or co-operation, a knowledge of the building is a vital asset for the success of a low energy strategy.
5. Overcrowded and highly equipped offices with high internal heat gains are an increasing problem for office managers and designers. This study suggests that although comfort cooling gives more control during very hot conditions, such conditions represent less than 1% of normal summertime weather in this area [8]. The well-planned naturally ventilated building can give more control and satisfaction for a much greater part of the year, and in addition uses less energy and is more economical to maintain.

ACKNOWLEDGEMENT

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