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Comfort, control and energy efficiency in offices

W T Bordass*, MA, PhD, A K R Bromley, BA and A J Leaman†, BA, FRGS

In well-designed and well-managed buildings, comfort and energy efficiency can go together. Occupants should enjoy reasonable comfort under automatic control, but should also be able to alleviate discomfort manually when necessary. BRE studies show that improved controls for temperature, lighting and ventilation will lead to energy savings. This paper will be of interest to building and control system designers, and to building procurers, managers and occupiers.

INTRODUCTION

BRE has been studying user control of temperature, lighting and ventilation in office buildings[1,2], and the opportunities for saving energy by improving the usability of controls for occupants and managers (see Figure 1).

Sixteen offices were surveyed by social scientists and building services engineers. Nine offices were naturally ventilated, five air conditioned, and two mixed-mode — one with both air conditioning and natural ventilation, and the other mechanically ventilated with openable windows.

In 11 of the buildings, detailed surveys covered energy consumption, use of controls by occupants, and overall performance of building services. Managers were interviewed and staff completed questionnaires. The work was undertaken as part of the Department of the Environment Construction Sponsorship Directorate's Energy-Related Environmental Issues (EnREI) programme.

Although the sample is small, the results have reinforced what has been discovered by interview and observation here and in related studies: where control systems have poor interfaces with management and users, much energy can be wasted and discomfort caused, particularly in the more highly serviced buildings, and where there are unclear divisions of responsibility between landlord and tenant.

Figure 1 More usable controls can improve comfort and save energy. Effective control of windows and blinds helped to allow air conditioning to be avoided in this office refurbishment at the Open University. The upper windows, which permit secure night ventilation in the summer, are being adjusted

* William Bordass Associates, London

† Building Use Studies Ltd and University of York, Institute of Advanced Architectural Studies

Building Research Establishment

Building Research Establishment
Garston, Watford, WD2 7JR
Telephone 01923 894040
Fax 01923 664010

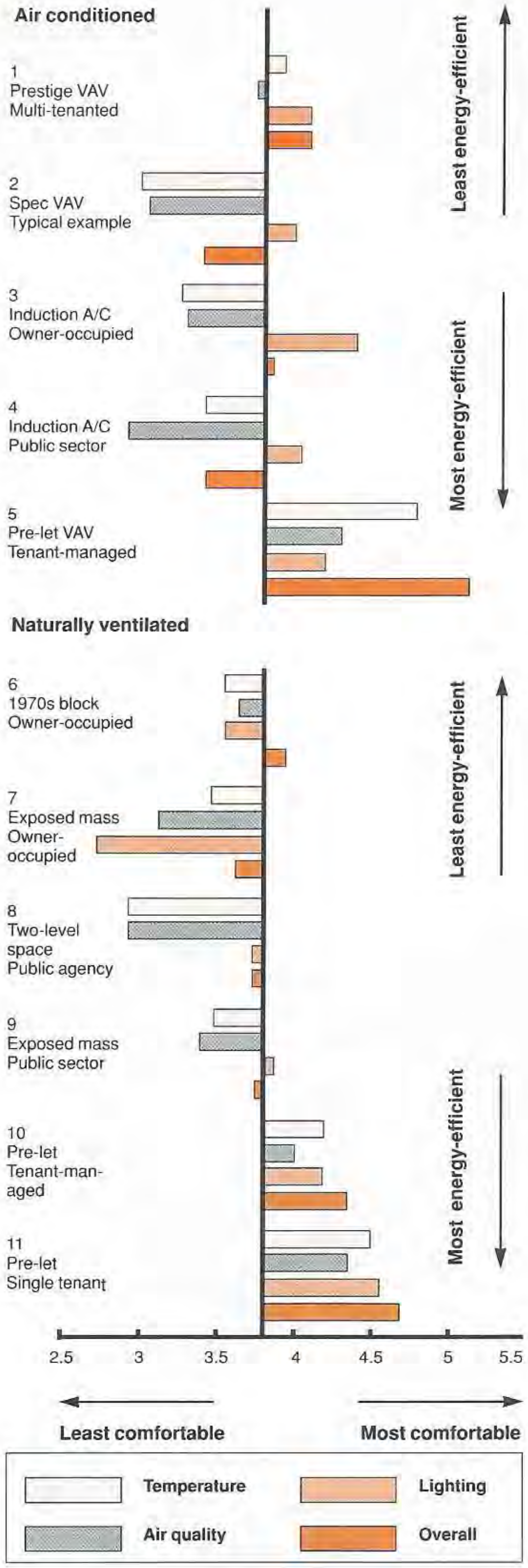


Figure 2 Perceived comfort scores from questionnaires completed by occupants in 11 buildings. (Comfort scores are hinged at 3.8, the average score for comfort from 50 buildings[3])

GENERAL FINDINGS

Comfort and energy efficiency

Figure 2 shows how the occupants of the 11 buildings perceived their own comfort levels. The buildings are divided into two groups, with five air conditioned offices at the top of the diagram, and six naturally ventilated ones at the bottom. Comfort is on a seven-point scale, from 1 = uncomfortable to 7 = comfortable. The buildings in each of the two groups are ranked by energy efficiency, with the least efficient at the top.

In both groups of buildings, and particularly in the naturally ventilated group, the most comfortable buildings also tended to be the most energy-efficient. Staff satisfaction and comfort can also be linked to better health and productivity[4], so 'virtuous clusters' begin to emerge, where comfort, control, productivity and energy efficiency all go together.

Management

Energy-efficient buildings are not automatically comfortable. In the buildings in which comfort and energy efficiency did go together, the unifying reason appeared to be good management — not just of energy, but of the entire process of procuring, occupying, operating and maintaining the buildings. However, in some buildings where energy efficiency had featured in the brief, the design or the building selection process, comfort and energy performance were disappointing, as in buildings 7, 8 and 9. Here, the intentions had not been followed through and systems were often poorly matched to the way in which the building was actually occupied and managed.

Some of the offices with air conditioning, for example buildings 1 and 3, were reasonably well managed, quite comfortable, but not energy-efficient. Here, the management did not regard energy efficiency as important, and sometimes had a poor understanding of building services and their controls. In the multi-tenanted offices, tenants frequently had little or no direct influence over the efficient operation of their landlord's services.

Procurement system

In both the naturally ventilated and air conditioned categories, the buildings rated 'best' for comfort, control and energy were pre-lets, while speculative offices were usually rated 'worst', with owner-occupied offices in between.

Was the relative success of pre-lets just a quirk of the sample, or of more general interest? One possible explanation is that the prospective tenants of pre-lets are better able to concentrate on aspects of the building which really concern them, while leaving the rest to the developers. Owner-occupiers, on the other hand, need to spread their attention across the whole project, and may also require special features which in practice create more obstacles than benefits.

The process of tailoring the building to the occupants' needs works best where there are active and positive relationships between design teams and the building managers, and a good understanding of organisational needs and occupants' requirements. Conversely, where this management role is absent, the occupants are less likely to be satisfied.

Complexity

Complex energy-saving technologies can sometimes be too complicated for their management (and sometimes even for their designers), and use more energy than simpler, more straightforward systems. For example, buildings 1 and 5, although similar in occupancy and in general specification, were respectively the least and the most energy-efficient air conditioned offices. Building 1, however, with a more impressive list of energy-saving features, had energy costs for heating, ventilation and air conditioning (HVAC) and lighting 2.5 times higher than those of building 5. In building 1, the electronic building management system (BMS) and its management were poorly tailored to the operating needs of a multi-tenanted building, the heat recovery system had not been monitored effectively and no longer worked properly, and the lighting and its controls were inefficient.

Perceived control

In both the air conditioned and the naturally ventilated offices, the perception of being in control appeared to be as important as having objectively good comfort conditions.

Perceived control depended not only on the presence, design and placement of control devices, but also on the overall effectiveness of control strategies, the attitudes and actions of management, and the way in which physical and human management systems operated together.

Perceived control also depended on local context. For example, it was lower where people were exposed to discomfort which the available systems and their controls could not adequately ameliorate, and where local controls, although available, were not readily operable by the individual affected (for example when subjected to glare from a distant window in an open-plan office).

Speed of response

In both the naturally ventilated and air conditioned offices, individuals appreciated systems which responded quickly when they became uncomfortable or deliberately wanted to change conditions. However, effective responses, as perceived by the occupants, did not always require good individual control devices. A skilled and committed building manager with a well configured BMS and a rapid response to any telephoned request, could give similar results, as in building 5.

Alleviating discomfort

The best buildings, judged by overall comfort and energy efficiency criteria, were well managed and also had two important features:

Feature A: They provided conditions that were within the accepted comfort range for most occupants most of the time (so people did not need to change things much).

Feature B: They also had the facilities to alleviate discomfort quickly when it occurred.

Air conditioned buildings were usually better at providing controlled comfort conditions (feature A), but however good the conditions, if they could not be adapted to suit people who wished to alter them, discontent could follow. Naturally ventilated buildings are usually better equipped for alleviating discomfort quickly (feature B), albeit sometimes only marginally, and in open-plan offices individuals may be constrained by the wishes of others in the vicinity.

Because feature B is so important to occupants, conditions in naturally ventilated buildings which might objectively be regarded as poor or variable were more readily accepted, and sometimes even preferred. However, good straightforward controllability and good outside awareness (being near a window) appear to be essential to this perception, not just natural ventilation alone. (See also earlier research in schools[5].)

Designing naturally ventilated offices of any complexity to perform well can be difficult, and poorly designed naturally ventilated offices can sometimes offer the worst of both worlds. Frequently, insufficient thought is given to simple passive features such as site, orientation, fabric and window design. Fully automatic systems are then often invoked in cases of difficulty, when better user interfaces to manual and automatic systems might have been preferable. Even where the design is all right in theory, controls may not be as easily operable as intended, and this can lead to occupant dissatisfaction.

Occupant controls

In naturally ventilated buildings, the fact that the function and operation of controls are more visible, and that controls are more responsive, can help to lower energy consumption. In mechanically conditioned buildings, systems which operate unnoticed by occupants often consume more energy than they should. Where possible, it is best not to depend upon blanket provision (eg by a landlord's standing operating schedules) for requirements which may not materialise in practice, but to allow occupants to activate or switch off services as required, subject to safeguards against systems being left running unnecessarily.

STRATEGIC DESIGN

In any building the occupants will discover ways of operating their parts of it with the least effort, for a reasonable result in terms of comfort, service and convenience, but usually with little or no regard for efficiency. Where control devices do not work properly (inaccessible window catches, for example), occupants will often take other steps and undermine the original strategy. For example, in building 4 natural buoyancy ventilation of the double-height space required occupants at the lower level to open their windows. However, the upper parts of these were inaccessible and the lower parts caused draughts. The result was the introduction of desk fans and requests for air conditioning.

Designers should therefore seek to make their intended operating strategies obvious, convenient, and effective. It is especially important not to ignore the original control strategy when spaces are being fitted out and refurbished. For example, in the buildings surveyed, access to perimeter controls — be they for windows, blinds or HVAC systems — was often blocked by furniture arrangements.

A strategic diagram

Figure 3 identifies the four main areas in which control systems should aim to perform[6] if they are to combine manual and automatic features. Control functions are classified as manual or automatic (vertical axis), and as reactive or forward-looking (horizontal axis), dividing the diagram into four quadrants. Effective control strategies should aim for good performance in all quadrants.

Control functions that fit in the four quadrants are:

Top left: Automatic reactive control, such as feedback proportional and integral (PI) control that responds to changing conditions

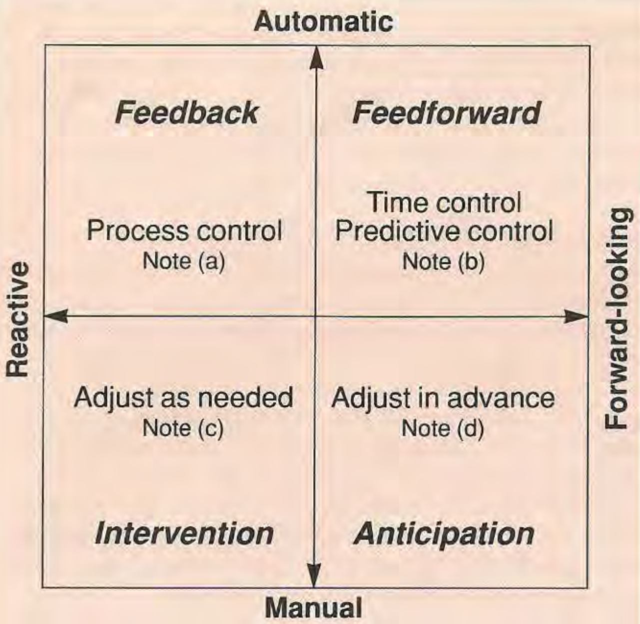
Top right: Automatic anticipatory control using, for example, time switches and optimisers to prepare the system for operation in advance of occupancy

Bottom right: Manual anticipatory control, for example opening a window so that on summer evenings benefit can be gained from overnight cooling; or changing the settings or programme of a controller

Bottom left: Manual reactive control in response to changing conditions, using light switches, window blinds and by opening windows

Historically, there has been a tendency to expect that automatic systems alone will cope, in particular feedback controls (top left quadrant).

Even among automatic controls, anticipatory control (top right) has been the poor relation, and is often limited to time control. Effective anticipation is becoming increasingly important in strategies proposed for tomorrow's low-energy buildings (for example for pre-cooling by overnight ventilation), but it has often proved difficult to get right in practice (for example with optimum start-and-stop heating controls), and is likely to need careful attention.



Notes:

(a) For example: closed-loop PI control to keep measured variables within the required tolerances

(b) For example: optimum start of heating or overnight ventilation, to prepare system for operation in advance of occupancy. Can be difficult in practice

(c) For example: using light switches, windows, thermostats, blinds, etc, to respond to changing conditions. Controls must be simple and easy to use by those directly concerned

(d) For example: opening windows for overnight cooling. Often difficult for management and users

Figure 3 Strategic diagram: manual and automatic control features. Forward looking items need good understanding by users of the functions and purposes of systems, and good feedback information on achieved performance

Appropriate manual intervention (bottom half) can be effective in avoiding waste, discomfort or dissatisfaction. Occupants who can steer conditions towards their preferences appear to be more tolerant of environments which would not be acceptable in sealed air conditioned buildings, or indeed in the climate chambers in which much comfort research has been done[7,8].

Improved control strategies

In order to improve both comfort and energy efficiency, the aim should be to:

- provide comfort — with automatically controlled systems that keep people comfortable without waste for a high proportion of the time (top left of Figure 3); and
- avoid discomfort — with facilities that permit occupants to alter conditions quickly and easily (bottom left), particularly where the comfort band adopted is wide.

More sophisticated systems involving anticipation should have:

- simple, accessible facilities for occupants to adjust controls in advance (bottom right) and for managers to reprogramme automatic controls intended to anticipate changing conditions (top right); and
- effective information feedback to management on the performance of these systems, particularly where they operate unseen or outside normal occupancy hours.

Suitable information feedback is often absent at present. For example, none of the mechanical night ventilation/cooling systems monitored by BRE to date has alerted management if the supply air temperature has been significantly above the outside temperature, as it often has been owing to undetected system faults.

CONCLUSIONS

The studies indicate that in well briefed, well designed, well built and well managed buildings, where control devices and/or building managers respond sensitively to occupants' demands, comfort and energy efficiency can go together.

To stabilise comfort conditions within the desired range under automatic control (feature A), building and control designers have often regarded occupants as unwanted interferences and taken control away from them. However, people who find themselves uncomfortable but lack the ability to adjust conditions to suit their individual circumstances (feature B), can become very unhappy. Ideally, control systems should be provided for both feature A, reasonable comfort under automatic control, and feature B, the ability to alleviate discomfort manually when it occurs. This conclusion is not surprising, as researchers can only define comfort as the lack of discomfort[8], but the implications of this for the effective integration of the user into a control scheme have not always been appreciated.

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