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Daylight use in open-plan offices: The opportunities and the fantasies

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Summary

Interest in daylight in offices is growing, for both amenity and energy-saving purposes. Low-energy designs often stress good daylight penetration and daylight-linked controls. However, energy consumption estimates are based on guidance derived from research undertaken 10-20 years ago in offices of shallow depth, with simple furnishing plans, and few if any VDUs.

Recent surveys suggest that, even with automatic controls, lights in many open-planned offices are on much more than lighting requirements would dictate. Reasons for this are explored, including: poor window design; complex furniture layouts; VDU screen visibility; limited understanding of occupant and management requirements and behaviour; poor implementation and commissioning; misplaced sophistication and poor ergonomics. Office buildings and office work today can also be very different from the contexts in which the original research was done. The paper outlines some general impressions gained from recent case study projects and draws some conclusions for design, management, product development and future research.

1 Introduction

Lighting is often the largest single individual component of energy cost in an open-plan office building [1], and today can often exceed the heating cost. Internationally lighting is said to account for more that 30% of annual electricity costs in commercial buildings [2].

Design studies for low-energy offices identify large potential savings from maximising daylight penetration and including daylight-linked automatic controls. The recent passive solar design studies for urban offices [3], predicted that efficient and well-controlled lighting would reduce energy cost and carbon dioxide emissions by more than any other item.

However, occupant surveys and case studies suggest that in many open-plan offices the lights are on much more than one would predict, and that user satisfaction is compromised by daylight-linked automatic controls. Many shortcomings result from poorly-designed windows and poor control design often readily diagnosed in hindsight but not easily designed-out unless greater attention is devoted to ergonomics. Others are related to occupant perception of lighting and its control, and to contexts of office buildings and office work sometimes very different from those in which the original research was done.

The paper concentrates on open-plan offices. In cellular offices manual switches by the door alone be can be quite energy-efficient, owing to the close relationship between the control and the people using the room and because the switches are positioned where people entering or leaving the room tend to make their decisions. If the switches are even a short distance from the door, this simplicity and directness is lost and the lights tend to be on a lot longer. In cellular offices, automatic control can also be resented, and is often over-ridden, as at the Building Research Establishment's own Low-Energy Office [9,10]. One of us (WTB) found this out the hard way in a system designed before then for tutorial offices at the University of York.

Procedures currently used to estimate lighting energy consumption are outlined. These are then related to findings from recent pieces of case study research [4, 5, 6, 7], largely for the Building Research Establishment under the Department of the Environment's Energy-Related Environmental Issues (EnREI) programme. However, lighting control was not the prime focus of these studies and a more detailed study into occupant use of lighting controls has now started at BRE.

2 Typical procedure for considering lighting controls and associated energy savings

Estimates made in the UK of savings from lighting controls tend to be derived from research at the BRE 10-20 years ago, reinforced by findings from energy demonstration projects in the early 1980s.

A typical procedure outlined in [4], goes as follows:

1. Lights tend to be switched on by people entering an area.
2. On entry, there is a switching-on probability, related to the minimum daylight illuminance on the working plane at the time of arrival, with a weighting according to orientation, presumably to take account of direct solar contribution.
3. For local switching, *related sensibly to the zones served,* the daylight level in the "worst" part of each zone will determine the switching probability for that zone.
4. Manual switching-off seldom occurs until the last occupant has left. Timed OFF is therefore advocated, at lunchtime for example. Switch-on probabilities after lunch will be lower, as ambient light levels are then normally higher.
5. Additional savings can be made if lights are switched off photoelectrically. Open-loop control is suggested at external illuminances appropriate to the required internal design levels.
6. Further savings can be made with dimmable lights under closed loop photoelectric control to top-up daylight to the design level.
7. Where occupancy is sporadic, occupancy sensors may be added to the above.

Several computer models however seem to assume “perfect”, control, ie: either the lights will be off when the required horizontal illuminances are exceeded, or dimmed perfectly to provide the required illuminance levels. The assumptions used in models can often be optimistic about the extent of out-of hours use by occupants, cleaners etc..

[4] and related references including [2] give very little detailed information on the appropriate deployment of lighting controls. However, details can be critical to performance in use.

3 Problems found in case study offices

INSUFFICIENT ALLOWANCE FOR INDIVIDUAL CHOICE
When the original research into lighting control was done, office work was largely paper-based. Now most people do a mixture of VDU and paper-based work, excess daylight can be a nuisance. If the controls are not sufficiently finely-grained, ideally one zone per workstation, conflicting requirements can cause all the lights in a zone to be on because one person needs light, perhaps because they have their blinds down to avoid glare. In several buildings where the lights were zoned in bands according to daylight availability but took little account of likely workstation positions, it was not unusual to find nearly all the lights on on a bright day.

BLINDS DOWN, LIGHTS ON
If daylight or solar gains are excessive, or if visual discomfort occurs in any of its many manifestations, people will want to adjust the lights and the blinds. When it is bright, people may switch lights on to improve uniformity [eg: 12, 13]. While occupants of cellular offices can often adjust blinds to avoid glare while still working in daylight; in open-planned areas the diversity of requirements of different individuals makes this much more difficult, and it often proves easiest to close the blinds and switch on the lights. Even the lights are not switched on when the blinds are first adjusted, if daylight levels then fall, the easiest route to get sufficient light back is often to switch-on the lights rather than to adjust the blinds, again particularly in open-plan areas. While studies at BRE suggest that in cellular offices people often open the blinds the following morning, in open-planned offices the surveys suggested that this was much less common, and that the inertial state of blinds down-lights on (BDLO) often persists unless they are opened routinely by cleaners, security, or automatically.

PHOTOELECTRIC CONTROL
Once blinds are closed, open-loop photoelectric control becomes inappropriate, as does closed-loop if there are not enough local sensors. The consequent nuisance switching then leads to complaints to the management who, after a time, had very often abandoned photoelectric control altogether. Where closed-loop was used, the surveys sometimes found people putting the blinds down in front of the photocells in order to keep the lights on.

In any event, even if the blinds are not closed, many systems do not have enough sensors and zones to take account of local variations in daylight (eg: from orientation, trees, obstructing buildings, etc.), a problem reported ten years ago at the BRE low-energy office [9].

Such problems frequently led to photoelectric switching control being disconnected. Where this had happened, we also gained the impression that difficulties had been reinforced by the lights going off at what people saw to be random times. In buildings where photoelectric switching decisions were made at known times, say at 11 AM, 1 PM and 3 PM, user response appeared to have been much better.

“Ideal” photoelectric control itself is not without some technological problems, particularly related to sensor position, sensitivity and switching levels. To be relatively un-noticeable lights should not go off until the illuminance level is above, say, twice the design level, while they need not come on again until it is darker. Two-level switching is preferable but not always used, sometimes manufacturers rely on time lags alone. Photocells themselves can also saturate and the control points drift.

GLARE, PARTICULARLY FROM UPPER WINDOWS
Tall windows are often advocated to bring light deeper into a space: a common rule of thumb is that if you cannot see the sky you will often not get enough daylight. However, a sky view brings with it the risk of glare unless workstations are correctly orientated with respect to the windows. Usually those who suffer the worst consequences sit some distance away, and are not in direct control of the blinds. While not energy-efficient, BDLO is often the easy way of obtaining harmony.

RIBBON WINDOWS
For partitioning flexibility, ribbon windows often run right round the perimeter of modern offices, making it difficult to avoid situations which create visual discomfort, particularly in relation to VDU screens. Where offices have glass partitions, second-hand glare situations (both direct and reflected) are difficult to manage, increasing the probability of BDLO.

AUTOMATICALLY-CONTROLLED BLINDS
One possible answer to glare control (and to the BDLO problem), and one increasingly advocated to avoid overheating in low-energy office buildings, is automatic blinds. However, case studies suggest that:

- Operation of automatic blinds is highly noticeable and is often seen to be a nuisance. One individual at one moment will find sunshine welcoming and cheerful, at another irritating and disabling: since an automatic system cannot tell which, it is virtually guaranteed to cause annoyance by operating at what is perceived as the wrong time. -Local manual over-ride controls are essential where the blinds directly affect people at their workstations, and people often seem to prefer control to be handed over to them entirely during occupied hours, viz [14]. Automatic control is more acceptable out of hours, and in public and circulation areas, which are nobody's particular territory and where individuals are inhibited in making manual adjustments in any event.
- Seldom are lighting and blind controls correctly coordinated, so in practice lights often stay on whatever the status of the blinds.

DIMMING CONTROL
While detailed investigations have not yet been carried out, there are hints of dissatisfaction with dimming controls designed to provide constant desk top illuminance. The brighter it is outside, the brighter people seem to want it inside, which is hardly surprising given the way the eye works.

OCCUPANCY SENSING
Occupancy sensors have much improved in sensitivity and reliability over the past decade, but in offices some problems remain:

i The movements of people doing concentrated tasks such as reading, writing, or typing intensively are not always sufficient to be detected, causing the lights to go out irritatingly.

ii On the other hand, passers-by can cause nuisance triggering.

iii The systems are most frequently arranged to switch on automatically. While this works well in situations where people cannot easily operate the lights (eg: carrying goods into a store), or in spaces which depend entirely on artificial lighting (internal toilets, for example), occupants of daylit spaces often regard it as unnecessary and wasteful for lights to come on whether they want them or not.

iv It often proved difficult to locate them to suit user requirements.

CIRCULATION AND ANCILLARY AREAS

Guidance material says little about control of circulation lighting. Consequently, perhaps, it tends to be a weak spot. In particular:

- i Circulation areas are often over-lit, inefficiently lit, or both. In one building, energy consultants gave detailed advice on the main offices and achieved a very low-energy installation. However, circulation and ancillary areas were overlooked, and the lights here ended up using more energy per year than in the offices themselves.
- ii If early arrivals in the morning cannot easily identify how lights are switched, they end up turning on far too many, both in office and circulation areas.
- iii The visual experience of people on entering a space (eg: encountering window glare on arrival, or emerging from an over-lit corridor) may make them switch the lights on, even if once seated they would have found daylight sufficient and glare under control.
- iv Frequently control and switching does not take proper account of the variations in daylight along the circulation route, so many lights have to be on unnecessarily. For example, in one building, corridors ran between double-banked office and then alongside a daylit atrium, but the lights in the atrium length were not separately switched.
- v In some buildings, operating the lights in any room also brought on all circulation lighting along the exit route, and sometimes for the entire building. This practice seems to be on the increase: it may be safe but it is very wasteful. Further thought and design guidance is required on reaching an appropriate compromise.

Sometimes time switch control was installed in the toilets, and run to the same programme as the offices. Usually this led to complaints and was abandoned, except perhaps at the very end of the day, and even then it was not very satisfactory as people often call in at the toilets on their way out. Sometimes it had been replaced by local switches or occupancy sensing. However, occupancy sensing in partially-daylit toilets and corridors often led to unnecessary use of the lights.

HIGH INTENSITY DISCHARGE LAMPS

The extended run-up and restrike times of these lamps make them unsuited to flexible daylight and occupancy-related control unless arrangements for instant light are also included. Not surprisingly, their energy consumption tends to be high, with lights often being switched on before occupancy and left on “just in case”. When used as uplighters, in bright daylight people are also not always aware when they have been left on mistakenly.

INDIVIDUAL SWITCHING DECISIONS

Except where safety is involved, a good general rule is “manual on - manual and auto off”. However, switch functions and locations also need to be thought about in relation to asymmetries in occupants’ preferences and behaviour. For instance, while the best place for people to decide whether they want the lights on is usually from their workstations, they may only notice that lights are on unnecessarily when leaving the room; while they might switch off everything from the door, they would not do the rounds of every workstation.

Even small details can be significant, for example in one office with HID uplighting, local switches were on the ballast units, which were usually on the floor. This inaccessibility, plus in many places a need to have several lights on in order to get enough local illumination, meant that most lights were switched on by secretaries etc. very early in the day and left on until an automatic OFF signal, long after most people had gone home.

SWITCHING DEVICES

Frequently switches and controls did not give clear indications of their function and status. For example:

- They were not intelligibly laid out or marked to designate their function. Multi-gang switches and remote infra-red controllers could be particularly obscure, the latter probably because they are multi-functional devices made for an international market.
- They did not operate in an intuitive manner. For example, rocker switches are often used like push-buttons. Why not have push-buttons?
- They gave no feedback on status, so if the result of a switching was not instantly obvious, people did not known if anything had happened. Why not have more switches which light up like lift call-buttons?

- Remote infra-red switches seemed to work well where their operation was clear, zones were workstation-sized and there was one controller per desk. Less-liberal provision of controllers tends to lead to the “Russian bath-plug syndrome”, where people hoard them and there are none to be found. This is not only inconvenient but dangerous.
- Sometimes unfamiliar controls were deployed differently in different areas, for example in the open plan, in cellular offices, and in cellular offices which had subsequently been converted from the open plan. Occupants were confused and avoided using the controls.

Such ergonomic faults all tended to have the same result: the lights were on more often than necessary. Sometimes the outcome could be more serious, for example the probable cause of the Windsor Castle fire was the inadvertent switching of a hidden light [16].

SYSTEM MANAGEMENT

Frequently, the user interfaces were not well understood by the staff responsible; sometimes they were incomprehensible even to the suppliers, particularly if special software had been written by someone who had since moved on. Many managements were therefore reluctant to alter the more complex systems, except perhaps for manual over-rides and occasional changes to routine time programmes. Even where the programming interfaces were reasonably good, awareness of how to use them was often poor, and the often-high cost of specialist attendance by manufacturers also tended to stop adjustments being made.

Consequently, it was not unusual to find lighting controls operating to the programme and settings originally installed, even if these were not entirely suitable. In some buildings, occupants even accepted lights being switched off at regular times regardless of light level, although they often switched them straight back on again, almost as a conditioned reflex. However, control features which had proved troublesome in use were more likely to have been degraded or abandoned than investigated and enhanced.

In several buildings where control had been problematic, the management had never attempted to make the occupants aware of the systems, how they worked, or the implications for energy and cost saving. Here different people on the same site (for instance the facilities manager, the services engineer and the security staff with the central control unit in their office), often gave conflicting descriptions of the system and its settings. Management’s perceptions of success sometimes differed greatly from those of individual occupants, who were usually more critical. This lack of understanding extended both to the hardware (some occupants did not realise, for example, that if a switch was pressed twice it would turn on extra lights or avoid them going off automatically next time), and to explaining the rationale of the system.

Conversely, in the smaller number of buildings which had good, communicative and responsive managers, sub-optimal systems gave an effective performance.

FLEXIBLE WORKING HOURS

More varied patterns of office work today make time switch control more difficult to implement than in the early 1980s. With widespread flexible working hours, the day often starts earlier and finishes later and has no fixed lunch-hour, so in many buildings lunchtime OFF was a source of irritation and often abandoned. In several buildings, however, occupants tolerated lights being switched-off at lunchtime, and sometimes more often, regardless of illuminance level, because they appreciated that waste was being avoided. Often they got up, almost as a conditioned reflex, to switch them straight on again.

MULTI-TENANTED BUILDINGS

In multi-tenanted offices, systems were often designed as if the building was in single ownership. However, it is one thing for your own management to switch off the lights and quite another for a third party to. While in multi-tenanted buildings with excellent management (usually by the main tenant) controls could work well, even minor failures in performance or in communication between tenant and building management often led to systems being abandoned.

FIT-OUT

The trend to separate responsibilities for the design of building and fit-out seems to have made it much more difficult to achieve integrated designs which make effective use of daylight and lighting controls. Even good designs could be swept away in the fit-out, for example in several fit-outs and refurbishments we found that lighting controls had been degraded (eg: by grouping local switches into clusters by the door) or removed altogether, sometimes to the explicit instructions of the occupier. Sometimes this seemed to have happened because those making the fit-out had or perceived no responsibility for the subsequent energy costs.

FURNITURE LAYOUTS

Daylight is perhaps most easily used in traditional plans, with windows on two sides only and furniture perpendicular to the window walls. This arrangement can accommodate VDUs with the viewing axis parallel to the window plane [12], or - where windows are holes-in-the-wall - placed facing and backing onto blank areas of outside wall. Acoustic screens are also used to control VDU glare, though often at the expense of daylight, view and natural air circulation.

In recent years freer-formed furniture systems have become widespread. These create a wide range of geometrical relationships between workstation and VDU screen to windows, in which individuals may also find it difficult to make even minor adjustments to seat and screen orientation, particularly where furniture is inter-connected structurally and by cabling systems. The problems in using daylight in such situations does not seem to be fully appreciated by designers of low-energy buildings in the UK, though a recent German publication [11] recognises it:

> *"In a modern team office ... furnishings are positioned for maximum communication so they may face in any direction .... To permit free and flexible workplace arrangements ... the first task for the lighting planner is to control the effect of daylight ... The daylight incidence lost has to be compensated by artificial lighting"*

AIR-CONDITIONED OFFICES

Automatic lighting controls tend to be found more often in air-conditioned offices, partly because these have predominated in recent years, partly because remote-controlled systems can reduce the wiring alterations when spaces are re-planned, and because in such higher-budget buildings lighting controls are relatively more affordable.

However, case studies, eg [15] indicate that in air-conditioned buildings lights are more likely to be on, even when daylight is adequate. This may be partly because the planning and design of air-conditioned buildings generally tends to exclude rather than admit the outdoor environment, and windows are seen primarily in terms of view. Air-conditioned offices often have "all glass and no windows" (as indeed, scandalously, do all the images on the cover of the CIBSE Applications Manual on Window Design!! [8]) and lack the subtlety of good design for natural lighting; the tinted glasses widely used may also have subtle psychological effects, causing people to want the lights on to "cheer the place up". A sealed and anonymously-controlled environment for cooling and ventilation may also affect people's attitudes to lighting too. In high-rent buildings, we have also encountered the attitude "we're paying for this....we want the lights on".

4 Successful installations

Successful installations in open-plan offices from the point of view of both occupant satisfaction and energy efficiency tend to have had five main attributes: straightforward, comprehensible design; intelligible and effective local controls with clear user interfaces; good responsive building management, and of course systems which work reliably!

Open-planned offices in which daylight use was high and lighting energy consumption low were quite rare, and tended to have the following characteristics:

i Interior layouts with desks largely perpendicular to windows.
ii Careful attention to minimising glare by means of light shelves, overhangs, splayed reveals, recessed windows etc..
iii Local controls which were easy to use and understand, readily accessible, and took account of both daylight availability and workstation layout.
iv Blinds which were easy to operate, provided effective adjustment, and needed to be fully closed only in exceptional circumstances, not routinely.
v Interior furnishings which were relatively light in colour.
vi VDU use which was sufficiently low that people could move screens away from locations which were vulnerable to glare.
vii Circulation lighting which was low-energy and well controlled. We also had the impression that if people obtained daylight and views as they moved around the building, they were less likely to put the lights on when they arrived at their workspaces.
viii Occupants who were well-informed about the systems, preferably intuitively but otherwise by management.
ix Any problems which arose were dealt with promptly and effectively.
x It was possible to “tune” systems easily to respond to requirements.

In some offices with rather less daylight available, low lighting energy consumption and good occupant satisfaction was nevertheless achieved by good lighting design, and advanced luminaires and controls. The key features here were:

i Strong clients who had insisted on effective lighting controls, had formulated (or been helped to formulate) their requirements clearly, and were managing their buildings well.
ii Control systems which could respond to individual requirements, with good local switching (often with infra-red units), small zone sizes, and individually-controlled dimming in the lowest-energy systems.
iii Design illuminance levels typically around 400 lux or less.
iv Efficient lighting with high-frequency control gear, and good optics.
v Good availability of daylight for perimeter workstations, whether in the open plan or partitioned, without causing major glare problems for people working inboard.
vi Interesting lighting generally, but without excessive contrast or the oppressive feel of installations with 100% Category 1 luminaires.

Savings came largely from individual choice of both the availability and the level of light, reasonable daylight at the perimeter, and appropriate time-controlled off signals.

Some recently-completed offices with occupancy-sensing dimming systems also had very low energy consumption. Preliminary surveys however suggest that it was quite common for occupants to be irritated with the automatic switching-on (both of their own lights and of other people’s) and at automatic dimming by stepping between pre-set levels. It will be interesting to see whether this irritation subsides as these systems become more familiar.

5 Discussion

Good control, perceived as well as actual, is vital to energy efficiency, productivity and human comfort but seldom gets the detailed attention it requires when buildings are designed or altered. There is insufficient knowledge on how systems work, what they are supposed to do and how they really perform in use.

Associated research and guidance has often sought universal answers, and not taken sufficient account of the real contexts in which people make, or wish to make, control decisions. Frequently it takes a single decision to put systems into undesirable, energy-hungry states, while agreement on restoring them to desired, low energy states are collective ones and much more difficult to make.

In recent years:

- the range of tasks that people undertake in offices have greatly widened, as have the associated visual requirements
- buildings have become more complex
- furniture and equipment arrangements have become less predictable
- users' expectations of the internal environment have become greater and more varied, and
- Regulatory requirements have increased.

This makes it more difficult to find conditions which suit everybody tolerably well, and makes attempts to provide fully automatic control to suit average needs potentially futile. A better collaboration between the individual, building management and manual and automatic controls of all kinds could provide the environment people want in an effective, efficient and humane manner [20]. Much of this in turn relies on understanding what people really want, developing effective user interfaces which can react simply and effectively to changing needs, and having supervisory systems which attempt to avoid waste and advise management clearly and concisely if anything seems to be going wrong.

In [17], Haigh found that, in schools with controlled environments, teachers were "extremely perturbed by their inability to control their surroundings for better or for worse". She also found that they were less interested in being comfortable, than in wanting instant results if a "crisis of discomfort" was reached. Recent behavioural studies in offices [5, summarised in 18 and 19] have reached very similar conclusions. With lighting, it is very difficult to anticipate what will cause a crisis of discomfort: it could be the sun coming out, it could be automatic blinds operating just after the sun has come out, or it could be the lights going on and off. Best not to second-guess but to provide the means for people to intervene when they feel they need to.

Recent changes in offices and office work have also turned daylight maximization from a benign to a potentially high-risk strategy. Things may change back again in a few years, for example with new display-screen technology, but there are still lessons to be heeded. In concentrating on the single issue of daylight maximization, the side-effects of visual discomfort, particularly for VDU-based tasks, can easily be ignored. But without careful design of windows, blinds and lighting controls such problems - even where they only affect only a few individuals - can easily "crash" an entire office into an unintended and undesirable state, such as blinds down/lights on.

6 Conclusions

We have found widespread, over-optimistic faith in automatic controls by designers and modellers; building managers are becoming more cynical. Often there is no clear analysis of what controls can really do, how they are actually going to work, and how people will operate and look after them. While inadequacies in management have often been identified, designers must recognize that management time is usually much scarcer than, say, money to pay fuel bills, so it is important to design for manageability.

In practice, gratuitously-provided, inappropriate, or over-elaborate measures are readily perceived as disbenefits by management and occupants, and often ignored or decommissioned, in turn increasing the risk of larger systems failing to perform as intended. Further problems occur because systems conflict with each other: daylight with glare and ventilation, for example.

As Einstein is purported to have said, the designer's task is to make the bad difficult and the good easy. Complex solutions can generate a wide range of unintended consequences and failure modes, including placing unacceptable loads on building and organisational management. Straightforward, robust strategies are preferable, or occupants may well discover their own low-effort solutions, often entailing high energy costs.

Good daylight requires good lighting design, not just high daylight factors, and reasonable daylight is a lower-risk strategy than maximum daylight. To paraphrase [15], appropriately-sized, straightforward windows are often a cheaper, better and more robust low-energy solution than larger ones whose performance depends upon the correct operation of the host of ancillary devices required to deal with their potential disbenefits.

Effective controls require clearer understanding of how occupants and management actually behave, coherent design objectives, and the strategies and technologies to meet them. These require both the development of new systems and devices, and the re-discovery of old ones, which can respond in simpler and more direct ways to individual occupants' perceived needs, let occupants and management know what they are doing, and allow energy-consuming systems to default to OFF when they are not strictly required.

Although many of the problems identified arise because existing guidance has not been followed, new information and guidance is required which pays more attention to the contexts in which daylight and lighting controls are used, and how to configure systems and their components to suit the needs of management and users. Many mistakes might have been avoided by attention to ergonomics at the start, for which two central tenets are that one does not take control away from the user, and user interfaces must must be extremely simple and obvious if they are to be used properly.

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