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A field study of occupant controlled lighting in offices

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A study of 14 open-plan offices equipped with occupant controlled general lighting recorded achieved workstation lighting conditions at a number of times of the year. The results confirmed the occurrence of a wide range of workstation lighting levels, many significantly below CIBSE Code recommendations, with average electrical loadings due to lighting in the order of 55% of maximum. System configuration had a significant influence on luminaire output, illuminances and energy consumption. In general the lowest luminaire outputs were in buildings where the default reset level was to a low output, with the highest outputs being in buildings having high reset levels and large control groups. In addition locally sited control devices were associated with lower luminaire output.

1. Introduction

Lighting control systems bring a number of potential benefits to the office environment including energy savings, enhanced user comfort and productivity, operational flexibility and better facilities management. Occupant controlled systems are those where luminaires are controlled in groups, typically of two to four luminaires, the output of each group being directly determined by the occupants. The control devices, usually hand-held infra-red transmitters, rocker switches, potentiometers or telephones, send signals to a receiver in or close to a luminaire which then communicates with a dimmable ballast. This allows occupants to dim or brighten lamps typically over the range 10%–100% of maximum output. In addition, most systems also permit switching off of lamps.

Conflicting evidence exists as to the pattern of use of this type of system. Studies in the UK indicated that occupants given control over lighting often select low levels, with studies in the Netherlands indicating preferences for higher levels. In addition, considerable variability is evident between individuals.[1,2] The UK study indicated potential for reducing the energy consumption of lighting if it could be shown that increased control led to the use of lower lighting levels than provided by current norms, without adversely affecting occupants' perceptions of their luminous environment.

This paper describes a study of 14 open-plan offices equipped with occupant controlled general lighting. The achieved workstation lighting conditions and luminaire outputs were measured at a number of times of the year. A number of facilities management issues are described. The influence of system configuration (control devices, switch-on regime and control group size) on illuminances and energy performance is set out.

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2. Current state of knowledge

Current guidance for office lighting in CIBSE Lighting Guide 7: 1993 Lighting for Offices and CIBSE Code for Interior Lighting 1994 recommend a desk-top illuminance of 500 lux for general offices, and a range of 300–500 lux for computer work station.[3,4] This is a compromise between the requirements for reading working documents, which may be of poor quality, and a comfortable illuminance for operating display screen equipment. Lighting Guide 7 also recommends a higher level of 750 lux for deep-plan offices and open-plan offices.

Research investigating links between user comfort under controllable lighting, economic benefits (productivity) and social benefits (energy efficiency) has been documented. Slater[1] noted that in lighting installations with local control users appeared often to select levels below 300 lux. Similarly Berutto's study of 50 workers using VDUs found occupants freely chose an average illuminance of 269 lux (range 61–547).[5] Kimmel and Blasdel[6] and Horst *et al.*[7] also showed user preferences for relatively low levels of illuminance. Begemann *et al.*[2] on the other hand, found that under controlled conditions people express preferences for lighting well in excess of recommended levels for office lighting (typically in excess of 1500 lux). These findings are supported by other laboratory studies but conflict with those of Slater and Berutto.[8–10] One plausible explanation for this could be the effect of VDUs on viewing conditions. VDU based tasks tend to be visually easy, using high contrast self-illuminating screens. Keyboards are large with high contrast and the tactile nature of their use means they present few visual problems. Further, the screen being vertical widens the field of view rendering users sensitive to light sources and room surfaces in terms of their effect on task:surround brightness ratios and ceiling reflections. The effect of the VDU may be the reason why post occupancy evaluations of lighting installations tend to reveal that occupants are on the whole satisfied with the levels of light they receive which tend to be of similar levels (300–600 lux) to current recommendations.[11–13]

Building Use Studies[14] concluded that having control (or more precisely the perception of having control) lead to increased occupant satisfaction. The same study alluded to increased user productivity when user satisfaction with environmental conditions was high, and reduced productivity when users perceived conditions over which they lacked control as uncomfortable. Control for control's sake was advanced by Bordass *et al.* as being as important for user satisfaction as the actual conditions.[15] They found that although automatic controls were capable of producing 'better' conditions they are not as appreciated as much as freedom to choose. A number of researchers noted that automatic controls were commonly disabled by users, often leading systems to default to high energy states.[1,16] Dilouie in a parallel investigation of both automatic and manual controls found that a combination of manual controls and occupancy sensors was able to yield energy savings of up to 75%, a greater level than realized by photoelectric controls and occupancy sensors.[17] The reason for this was that people took umbrage at the automatic controls and sought ways to render them ineffective.

Another hypothesized benefit is that low levels of illuminance are conducive to positive mood. McCloughan[18] noted that an individual is more likely to behave positively when under lower illuminances (300 lux) than higher ones (750 lux); Baron *et al.*[19] made similar discoveries. However these psychological benefits should be considered in the context of the body of work which suggests there are biological benefits from higher lighting levels, for example in helping to regulate biological rhythms[20] or to prevent or alleviate the symptoms of SAD.[21] To date it is unclear which of these sets of benefits has the most advantages for office workers.

It is possible that a link between user control and low illuminance may not be cause and effect, but rather that an alternative stimulus causes people to dim their lighting. Many commentators believe that luminance and patterns thereof are central to lighting quality, thus relegating illuminance to a by-product of luminance. Loe for example found preferred choice of lighting conditions to be a factor of both brightness of surfaces and their minimum to maximum range.[22] In addition the task:surround luminance ratio has been advanced as a component of lighting quality.[23,24] Given that typical office tasks are visually quite easy it does not seem unreasonable that when selecting lighting levels occupants consider more than just working plane illuminance and task visibility.

From the above it is apparent that the lighting community is a long way from consensus on the various issues relating to lighting quality, and further away still from understanding how these issues are affected by the notion of control. Only limited investigation of the influence of user controlled systems has been undertaken with detailed quantitative investigation being mainly confined to laboratory studies. The field studies described in the literature set out some of the factors that may influence perceptions of, and use of control systems, but tend to offer conflicting evidence to gained from laboratory work as to preferences for illuminance. This paper addresses the issues of illuminance preference and energy performance by means of field study.

3. The surveys

The 14 buildings in the study were located in the UK and contained modern lighting equipment and controls. Ten of the buildings had accommodation that was approximately 12 m wide (window to window). The remaining four buildings were deep-plan with a width in excess of 20 m. Floor to ceiling heights ranged from 2.7 to 3 m. Sill heights were of the order of 1 m and all buildings were equipped with either vertical or venetian blinds. All but three of the buildings were constructed in the last decade and housed staff employed by government departments (three cases), financial services (four), manufacturing (four), utilities (two) and media (one). Whole room and workstation views of two of the installations are shown in Figure 1.

The installations were lit almost exclusively by mirrored louvered downlighters with tubular or compact fluorescent lamps. Thirteen of the installations were equipped with central computer control, (although of these only five had front end terminals accessible to facilities staff). For control purposes luminaires were addressed either individually or in groups of two to six luminaires, except one building which had groups of up to nine. The groups were operated by local controls that were either hand-held infrared devices (seven cases) column mounted infrared switches (one), rocker switches (two), potentiometers (two) or telephones (two). These enabled users to switch on/off and to vary levels, typically over the range of 10% to 100% of lamp output, either continuously or in steps. A summary of the features of the installations is shown in Table 1.

Two visits to all buildings each of one day duration were made, the first (the ‘summer’ visit) being in April/May 1997, with the subsequent ‘winter’ visit being in January 1998. Photometric measurements were made during daylight hours during the ‘summer’ visit, and after dusk during the ‘winter’ visit. A third visit (the ‘spring’ visit) was made to seven of the installations during the period January to March 2000 and the survey conducted in conditions of winter daylight. Since the surveys took place in working areas the data collection methods were necessarily limited to those that did not interfere with the running of the organization. Each survey commenced with a structured interview with a facilities manager in which information was collected on the nature and use of the building, design specification for hardware and controls/software, maintenance and system configuration. At most installations two typical areas of about 20–30 workstations were selected for study. Detailed information on office layout, lighting layout, control groups, window and blind details was collected. A single illuminance measurement was made in the centre of the working area at each workstation. In summer and spring this was a combination of electric lighting and daylight. In winter the workstation measurements were for electric lighting only.

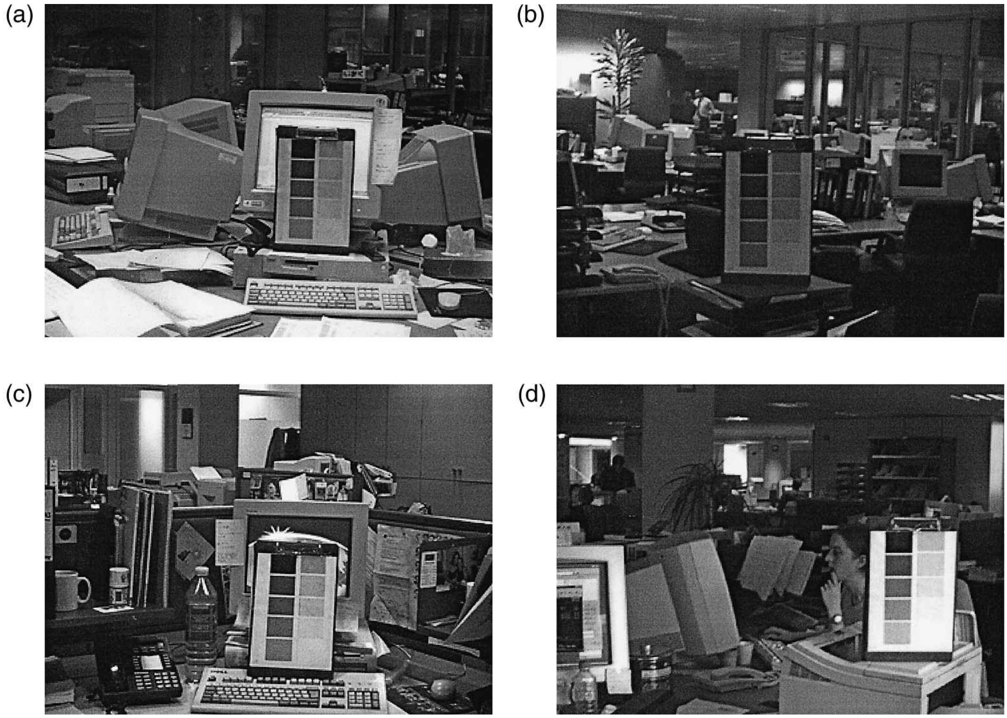

Figure 1 Whole room and seated views of typical areas surveyed

The occupants then filled in a questionnaire giving personal and employment details. The output level of each luminaire within the survey area was determined. This was done either by interrogating the control software or by comparison of lamp luminance with that of a lamp operating at maximum output.

4. Results

4.1 Facilities management issues

Those responsible for systems ranged from qualified electrical or control engineers to persons with no engineering training at all. All liked the flexibility of the systems and the ability to accommodate changes in workstation layout without changes in hard wiring. Those with experience of their installations under unified switching remarked on the apparent reduction of complaints regarding lighting. Many of the features of the systems, notably monitoring functions, were not being used, apparently because systems were seen as too complex to operate. A deeper problem was that the lighting controls were not compatible with other control systems (e.g., BMS) due to different bus protocols.

Policies regarding local control varied widely, some organizations distributed handheld controllers to individuals but they were more commonly stored in a prominent location or with a designated person. There was considerable variation in policy on reset levels. Six installations reset to the previously selected level. Six reset to default levels (between 20% and 90% of maximum) from which users were expected to dim down or ramp up. At two installations there was no explicit reset policy. Interestingly all installations bar one used a form of automatic switch-off suggesting that designers were aware that occupants are good at switching systems on but are less good at switching off.

Table 1 Summary of installations

Building	Hardware	Software	Control Device	Control group size	Switch-on regime	Switch-off regime	Degree of control	Blinds	Other information
1	Down and uplighters 600 mm square	A	Column mounted IR controllers	2	To 90% at 06:45 (nominal 300 lux)	By sweep at 20:15	40–100% or off	Opaque, manual within double glazing cavity	Perimeter lights Daylight linked from 09:30
2	1200 mm linear satin cross blade louvers	Local	Potentiometers	4	To previously set level	Left to users	10–100%	Internal manual vertical	Daylight linking unless users intervene, when on set at nominal 600 lux
3	1500 mm linear, satin cross blade louvered	A	Hand-held, IR kept in holsters on most columns	4	To previously set level	Evening sweeps	5–80% (80% to save energy)	Perforated, venetian manual Ext. sun shades	Software perceived as user friendly
4	600 mm square and 1200 mm linear downlights	B	Column mounted rocker switches	3,4,5,6	Users switch on upon arrival Lights come on at 100%	Sweep at 20:00	10 steps from 0–100%	Internal manual venetian	Deep plan
5	600 mm square semi-matt louvers	A	Column mounted rocker switches	6	On at 60%	Time sweep at 22:00, then hourly till 02:00	20–100% or off 10 steps	Internal manual venetian	Excessive lamp failure furniture mounted task lighting at workstations
6	600 mm square downlights	C	Hand-held, IR	2	Users switch on upon arrival	Timed off at 20:00	20–100% output or off	External, manual venetian Ext. sun shades	Perimeter lamps daylight linked though users may override this Software hard to program
7	600 mm square downlights	C	Column mounted IR control	3	Two configur-ations. 25% output or nominal 500 lux	Sweeps at 18,19,20 at 00:00	Six steps between 25 and 100%	Internal manual venetian	

Continued

Table 1 Continued

Building	Hardware	Software	Control Device	Control group size	Switch-on regime	Switch-off regime	Degree of control	Blinds	Other information
8	600 mm square downlights	A	Hand-held, IR	4	Come on at 70% when users turn on in morning	Timed off in the evening	10–70%. 70% = nominal 470 lux Over 70% on request	Internal, perforated rollerblinds	Deep plan. Software perceived as particularly user friendly Wall washers present
9	155 mm linear downlighters, Semi-spec cross blade louvers	A	Hand-held, IR	1	Users on active IR switch on to previous levels	AIR dims after 12 mins. Off after 5 more	0–100% in steps	Internal, manual venetian Ext. sun shades	All luminaries daylight linked to give nominal 300 lux. Users may override. Some desk lamps used
10	600 mm square semi-specular	C	Hand-held, IR and wall mounted on/off switches	2	On 100% at 05:30 dim to 50% 08:00	Active Infra red sweeps at 18:30, 21:00 and 23:00	0–100% continuous	Manual venetian within double glazing cavity	Deep plan. Software hard to program
11	1200 mm linear downlights	B	Telephone	3	Users switch on upon arrival	Timed off	0–100%, 10 steps	Internal manual venetian	
12	600 mm square downlights	A	Hand-held, IR	1	Users switch on upon on arrival.	Timed off		Internal manual venetian	
13	600 mm square downlights	A	Telephone	1	Timed on to previously set level	Timed off	0–100%, 5 steps	Internal manual venetian	Deep plan, software percieved as being user friendly
14	1200 mm linear downlights	Local	Rotary switch on columns	3,4 or 6	Timed on to previously set level	Timed off	0–100% continuous	Internal manual venetian	Control groups arranged in linear rows

Table 2 Summary of data from visits 1,2 and 3

Building	Average working plane illuminance (lux)			Average power consumption as a percentage of maximum		
	Winter	Spring	Summer	Winter	Summer	Spring
1	137	n/a	233	68%	83%	n/a
2	183	n/a	516	47%	41%	n/a
3	300	433	465	68%	43%	58%
4	503	n/a	672	64%	80%	n/a
5	452	430	594	90%	71%	69%
6	273	233	312	45%	30%	38%
7	240	536	458	54%	30%	59%
8	350	391	450	74%	61%	84%
9	429	n/a	427	57%	53%	n/a
10	113	101	134	37%	41%	45%
11	189	280	615	49%	38%	36%
12	413	n/a	300	60%	52%	n/a
13	187	n/a	216	51%	50%	n/a
14	243	n/a	467	69%	44%	n/a
Mean	287	343	419	60%	51%	56%

4.2 Achieved lighting levels

Table 2 summarizes arithmetic average of workstation illuminance and average electrical load at each installation. Half of the shallow-plan offices have average illuminance for the winter condition below that of the CIBSE recommendations for general offices containing computer work stations (300 lux), whilst in spring one third fall below CIBSE recommendations. All of the deep-plan buildings had average workstation illuminance below the CIBSE Office Lighting Guide recommendation of 750 lux and in one case the average was substantially below 300 lux. Table 3 shows the percentage of occupants found to be working below, above, and within the recommendations set by CIBSE in each season. (The results from each installation have been normalized to avoid differences between the number of occupants surveyed at installations distorting results.) Average illuminance values were generally in a descending order of summer, spring and winter due to the seasonal daylight contribution. The exceptions to this tended to be in buildings that were either deep-plan or where blind use was extensive. There appears to be no relationship between plan form and achieved average illuminance values in that high and low values occur in both shallow and deep plan buildings. The minimum illuminance values are notable for the levels set, even in summer there were a significant number of values below 100 lux (approximately 10%).

Table 3 Percentage of occupants working below, above and within CIBSE recommendations in each season

Range of illuminance	Season		
	Winter	Spring	Summer
Below 300 lux	59%	52%	43%
300–500 lux	24%	30%	27%
Above 500 lux	17%	17%	30%

Table 2 shows that within buildings where similar occupants are doing similar work, workstation illuminance and electrical outputs are very different. If some of this variance can be explained by factors other than personal preference then the potential exists to design systems so as to maximize energy saving potential. Analysis of building related factors such as depth of space, percentage of glazed area and the degree of obstruction indicated they had no effect on outputs. This was perhaps not surprising since the buildings studied were largely similar.

As described earlier the luminaires in the buildings were all very similar thus facilitating meaningful analysis of features related to system configuration namely the location of control devices, switch on regime and the size of control group. The control devices were either remotely sited (potentiometers or rocker switches located on walls and columns) or locally sited (hand-held infrared devices or the telephone). The switch on regime was either a pre-set switch on which was time switch or presence detection activated, or alternatively systems had to be consciously activated by users. Control groups were typically from one to six luminaires, but in one installation groups of up to nine were present. The three system related factors were strongly inter-correlated, systems with high pre-set switch on levels tended to have large control groups and remotely sited control devices. The correlation between pre-set switch on levels and outputs was however very strong (Pearson correlation coefficient 0.497, significant at the 99.9% confidence level) and this factor was a definite contributor to variation in system output, similarly high confidence levels were also observed when the other two factors were statistically controlled for *via* partial correlation. Figure 2 plots the pre-set switch-on level at installations against the luminaire outputs observed at the time of Winter 1998 survey and provides information in the form of boxplots on the average outputs of luminaires based on their pre-set switch-on levels. The average output of luminaires for sites without pre-set levels was 42% for those with locally sited control devices and 64% for those with remotely sited devices.

Switching is also influenced by control group size with larger control groups being associated with less switching. Figure 3 plots standard deviation of outputs, normalized as a percentage of the switch-on level, against control group size, and shows larger groups to be associated with lower standard deviations and therefore less switching.

It is hypothesized that when encountering pre-set switch on levels, occupants are reluctant or feel it unnecessary to alter outputs. There are many reports of office occupants working at low illuminances,[1,25] and of the failure of higher levels of illuminance to improve satisfaction.[11,26] Using Rea and Ouelette's[27] model of relative visual performance, working plane illuminances of around 100 lux would appear to be adequate for the average person carrying out typical office tasks. This reluctance to alter outputs is exacerbated by larger control groups, possibly for reasons connected with self presentation.[28] Also an adjustment affecting large numbers of users will increase the potential for conflict leading to some occupants avoiding use of controls.[29] In the absence of pre-set switch-on levels occupants

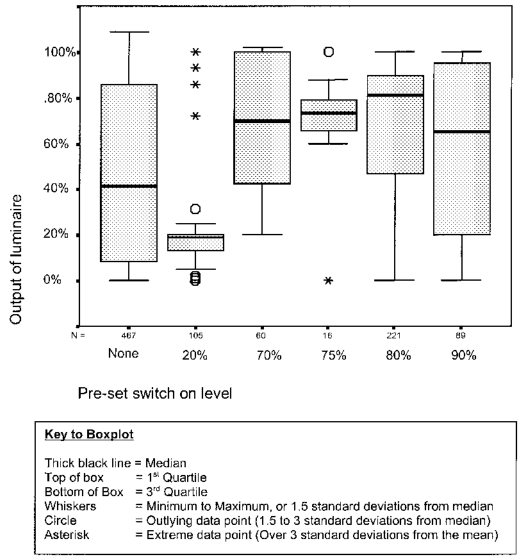

Figure 2 Boxplot showing distribution of luminaire outputs based upon pre-set switch-on levels

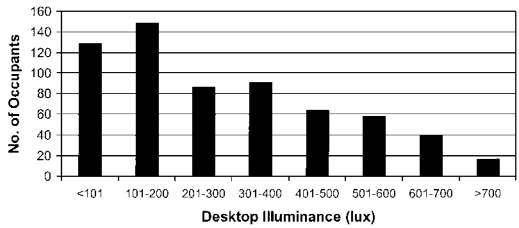

Figure 3 Normalized average standard deviation of luminaire output from pre-set output as a function of control group size

do activate systems (average output 54%), with group size not appearing to influence this.

The location of the control device did not appear to affect outputs when there was a pre-set switch-on level, this being due to the strength of effect of pre-set switch-on levels in precluding further switching. However in the absence of a pre-set switch on level the location of the control device did appear to influence output, with locally sited devices being associated with lower outputs. Average output of luminaires was 64% of maximum at sites with remotely sited devices dropping to 42% for sites with locally sited controls. This pattern of use may be explained through two observations made by Bordass *et al.*[15] First, 'comfort is the absence of discomfort' and occupants require a certain amount of light to avoid visual discomfort. Since adequate daylight cannot be guaranteed, particularly in the winter, most people will require electric light. Secondly, people use controls in the way they find easiest but not necessarily in the manner intended, or technologically desirable. When occupants were controlling from a remote position differences in output may only be detectable once lamps are switched to a relatively high output (due to the effects of obstruction and luminaire cut-off angles). This being compounded by the fact that no control device encountered in the work gave any indication whether change was occurring. This may result in lighting levels higher than necessary for comfort being selected (or at least higher levels being chosen than would have been from the seated position) but as they are not so high as to be uncomfortable they are tolerated. Mannicia *et al.*[30] did not notice this effect when examining use of locally and wall mounted switches, but this work was in cellular offices, where it may be assumed subjects had a clear view of the changing lighting levels on their desks, and further controls even though the wall mounted switches were not far from desks.

The size of these system related effects can be assessed using multiple regression techniques. At sites with pre-set switch-on, pre-set level accounted for 25% of variance whilst size

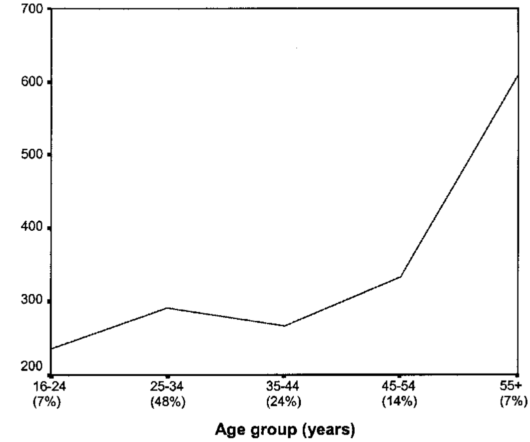

Figure 4 The relationship between levels of working plane illuminance and age

of control group accounted for 5%, these effects being described in statistical terms as large and medium.[31] At the sites without pre-set switch-on level device location accounted for 7% of variance, a medium size effect. In addition age of occupants and the percentage of the time spent using a VDU were also linked to working plane illuminances. Figure 4 shows the relationship between age and illuminance, and Figure 5 that between time using a VDU (gathered from questionnaire) and illuminance. Both relationships were statistically significant, indicating systems are being used in ways which are linked to lighting need. There is a positive relationship between age and illuminance, and a negative relationship between time spent using a VDU

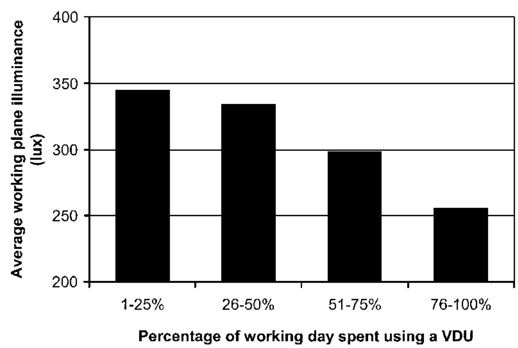

Figure 5 The relationship between levels of working plane illuminance and time spent using a VDU

and level of illuminance (nearly 75% of the sample being in the two high use categories). The sharp take-off of the graph in Figure 4 is interesting as it occurs at the 45–54-year age group, around the age that the performance of the eye starts to become markedly less efficient.[32] Such observations indicate a potential link between office productivity and illuminance. The data for Figures 4 and 5 comes from the winter surveys only, in order to avoid the possible confounding effects of daylight.

To summarize, the range of recorded workstation illuminance values is large, in excess of 2000 lux. Whilst the daylight contribution adjacent to windows may account for some of the variation even during winter darkness variation on workstations ranged from 6 to 846 lux. This confirms that given choice individuals will work in a very wide range of illuminance. It is also interesting to note that only around 20% of lamps were set at outputs between 90 and 100%, many of these being at the installations with a 90% pre-set switch on level. This suggests that the range of outputs available from currently used luminaires is adequate to express the preferences of the majority of users. Figure 6 shows the spread of recorded workstation illuminance for 617 occupants in the 14 buildings during the winter surveys. It also shows that of the order of 20% of the sample would choose to work at a lighting level below the 100 lux recommended by the Health and Safety Executive.[33]

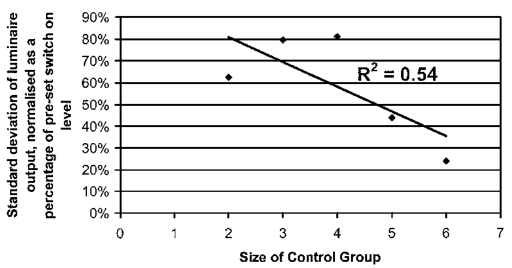

Figure 6 Range of working plane illuminance recorded at the time of the winter surveys

4.3 Achieved electrical loads

In many of the installations, particularly those with low average illuminance, significant areas of the offices had the electric lighting turned to very low levels or even off. This factor contributed to the magnitudes of electrical loading shown in Table 2. In all cases the loading was less than 100%. The winter loads (average for all installations 60%) were usually higher than those for spring (average 56%), these being higher than those for summer (average 51%). Those showing the reverse trend tended to be deep-plan form, have extensive blind usage or both. The influence of system configuration discussed in the previous section accounts for the relatively small seasonal difference in outputs.

5. Conclusions

There was significant variation in system configuration which was shown to have considerable influence on illuminances and energy performance. Where pre-set switch-on levels are present this appears to discourage users from adjusting systems. This inhibitive effect appears to be exacerbated by the size of control group with occupants becoming increasingly reluctant to change an already activated system as control groups become larger. In environments without pre-set switch-on levels, illuminances and outputs are affected by the location of the control device. Locally sited devices are associated with lower outputs, possibly due to it being easier to estimate the desired amount of light when exercising control at the workstation. Thus the energy consumed by systems is directly linked to their configuration, and designers have it in their power to design for minimum energy consumption.

Notwithstanding the effects of system configuration it is clear that a wide range of luminaire outputs are selected by users, and that age and the proportion of the day spent using a VDU affect levels set. As a result workstation illuminance values recorded covered the whole of the CIBSE recommended range and beyond. At the time of all three surveys only around a quarter of occupants were found to be working within the 300–500 lux range recommended for offices. Many users worked at illuminances substantially below CIBSE recommendations — in winter over half the users chose to work at levels below 300 lux — and further significant numbers were working at levels below Health and Safety Executive recommendations. In the winter 20% of occupants were found to be working at illuminances below 100 lux.

In general the lowest average illuminances and energy consumption were in buildings where the default switch-on level was low, and the highest levels were in buildings which had high reset levels and large control groups. The effect of the variation in luminaire outputs was to produce a wide diversity of working plane illuminance which in turn produced uneven illuminance and luminance patterns. In fact in conditions of electric light only two installations had diversities that did not exceed CIBSE recommendations. As would be expected the recorded workstation illuminance values were generally in a descending order of summer, spring and winter due to the seasonal daylight contribution. Daylight contribution also had a small impact on energy consumption. Winter lamp electrical loads were 4% higher than in spring these being 5% higher than in summer, such small differences being attributable to the heavy influence of system configuration. Average lamp output was of the order of 55% of maximum in the installations studied indicating a great potential for energy saving in office buildings.

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Discussion

Comment 1 on 'A field study of occupant controlled lighting in offices' by TA Moore, DJ Carter and AI Slater

GK Cook (Reading University, Dept of Construction Management, Whiteknights, UK)

This is a very useful paper which carries forward a broad range of issues concerned with occupant comfort and lighting provision. The paper also raises some interesting questions concerning the illuminance values currently used in The Code for Lighting 2002.[1]

In order to have a general understanding of the user needs within the offices it would be interesting to know for what proportion of the day the various occupiers were using their visual display units. The recent changes to The Society of Light and Lighting Lighting Guide 3[2], refocused attention on the need to address luminance and intensity distribution of the luminaires but the guidelines concerning occupant use have been removed. Whilst this approach is fairly arbitrary, it would be of interest to obtain this user orientated information. Increasingly older people and people with some vision loss are employed in offices. The paper does not cite precisely the nature of the users since this may not have seemed appropriate in a paper addressing control issues, however since the findings appear to question some of the traditional approaches it would be useful to obtain a general age profile of the users.

A lighting survey by Cook[3] carried out several years ago, showed the provision of less than 100 lux average horizontal illuminance inside classrooms. Although not reported there, the illuminance was deemed to be adequate by people who regularly used the classroom. It is, therefore, not surprising that some of the occupants in offices find a similar value to be acceptable. The issue raised by this paper is how to differentiate between what people would like in their lit environment, and what general guidance needs to be provided so that under a range of control systems and with the possibility of altering the configuration of the room, people can still feel comfortable. This theme of occupant tolerance of values outside traditional practice is shown by the variation in diversity beyond the established norm of around 0.8 which occupants found acceptable. Whilst there is some evidence that people find diversity values of less than 0.8 to add interest to interiors, occupants who have vision problems find them uncomfortable.

It would have been of interest to have the views of the occupants concerning their lighting provision and why they adjusted the lighting in the way that they did. In any environment where user control is provided, there is always the potential for psychological factors to overwhelm the more objective operational measures.

Whilst the paper recognizes that daylighting is highly variable, some further information on how this was accommodated within the measurement period, would be helpful. This paper raises a whole series of questions which those involved in lighting design guidance need to take cognisance of. However, in order for this advice to be based on comprehensive data, there appears to be a need for a long term monitoring study. It is essential that the results shown here are not unusual. For example, have the results reported here been produced by evidence of management taking an interest in the lighting. The authors have raised several interesting issues concerning user controlled lighting regimes and their paper has the potential to inform the debate concerning future interior lighting design guidance.

References

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Comment 2 on 'A field study of occupant controlled lighting in offices' by TA Moore, DJ Carter and AI Slater

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This paper provides another indicator that lighting installations of regular arrays of ceiling mounted luminaires, providing a uniform task illuminance and controlled either on or off, are unsatisfactory for the users and likely to waste energy.

From the results, it would seem that there is a need for the office lighting installation to provide task lighting related to the individual, which they can switch on and set the level required, with perhaps automatic switch off when the workstation becomes unoccupied. This approach will also need building lighting to act as a background to the task lighting and a supplement to daylighting, as well as a natural extension to the architecture. If this is correct, then we need to press for this form of lighting to be tried and assessed in terms of user satisfaction, productivity and energy use. But it appears that the potential benefits are considerable.

On a more specific note, it appears that only horizontal task illuminance was measured. It would have been interesting to have an indication of a measure of the subjective lightness of the offices through the average luminance of the horizontal 40° band as described by Loe *et al.*[1] This value is likely to be higher in summer rather than winter because of the higher levels of daylight. This might have been the reason for the required higher task illuminance in summer and be an indicator that the required task illuminance is relative to the 'Visual Lightness'[1] or adaptation luminance.

Reference

1 Loe DL, Mansfield KP and Rowlands E. A step in quantifying the appearance of a lit scene. *Lighting Res. Technol.* 2000 32(4); 213–222.

Authors' response to GK Cook and D Loe

TA Moore, DJ Carter and AI Slater

The authors thank Dr Cook and Mr Loe for their thoughtful comments. It should perhaps be made clear that this paper reports a part of a larger study that for publication purposes has had to be split into detailed papers each describing separate, but related, aspects of the work. Whilst we have tried to make each contribution self-contained some of the questions posed by the reviewers are answered in detail in later stages of the work. We do however try to answer specific points here.

The number of users surveyed in the various buildings totalled 410. Details are shown in Table 1. S_{nc} relates to the data set in this paper.

A long term study of four of the buildings was undertaken and provided evidence that user controlled lighting saves significant levels of energy all year round. The average output of the four systems monitored was 54%, thus confirming the results reported here. A detailed study of user attitudes to these systems has been undertaken in parallel with this work and will be published shortly.

Luminance measurements were made during the surveys at each user workstation using a system based on digital photography and photographic image processing software.[1] The method recorded luminance of a 10-step grey scale placed within a scene at the time an image was captured and used the relationship between luminosity (a value obtainable from the software) and luminance of the grey scale to determine the luminance of surfaces within the scene to an accuracy of within 10%. The luminance distributions were analysed in terms of David Loe's 'brightness' and 'visual interest' (the premise being that the these are associated with preferred environments), and the distribution or skewness of luminance and are summarized here. Generally, luminance in the full field of view, and particularly the far field were below the 30 cd/m^2 recommended for 'commercial interiors' for perception of 'brightness', although significant numbers of occupants' near fields of vision were at around the required level. Due to windows, obstruction and room contents,

Table 1 Occupants' personal data

Median age group (yrs)	Gender % female	Job description % clerical, professional, managerial	Length of service (yrs)	% of day at VDU	% of day away from desk
S_{nc}25–34	64%	52%, 36%, 12%	3.4	78%	16%

almost all occupants experienced luminance variation exceeding Loe's recommendation. Skews were overwhelmingly positive, comprising dark areas with smaller areas of brightness. Average luminance of around 20 cd/m^2 was associated with high levels of satisfaction, but the lack of increased satisfaction for average luminance greater than an average of 30 cd/m^2 suggests that 30 cd/m^2 is not necessary for visual preference in these buildings. A comprehensive description of this study will be submitted for publication shortly.