# Using Daylighting Controls in Offices? Post Occupancy Study about their integration with the Electric Lighting

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ABSTRACT: It has been noted that in the opinion of experts on daylighting control systems, most systems were not working. A survey has been undertaken in which actually 80% out of 15 offices studied had the system switched off.
There is clearly poor integration between solar protection and daylighting controls. No integrated sun-tracking and daylighting control has been found successfully operating in an office environment. The choice of blinds and a proper use of the photocell will be the main area of study. 40% of the cases studied have automated internal blinds installed operated with photocell, of which 66,6% have been switched off or changed to manual drive. BMS linked photocell controlled lighting is used in 40% (6 of all cases). The photosensors were disconnected in 50% (3 of the sample).
The experimental work of this PhD research is based in a post-occupancy office evaluation by measuring both luminance and illuminance, around a desk position (ceiling-desk-partition-floor), colour temperature, colour reflectance and a user survey completed in different workplaces. The impact of blinds was also analysed in terms of type, position and internal luminance of blinds and ceiling. We found a relationship between luminance and colour temperature amongst different surfaces. Finally, we present some early ideas on what we should be controlling.

Keywords: Daylight linking, Photosensors, POEs, Integration

## SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| POE | Post Occupancy Evaluation of Daylight in Buildings. |
| E | Illuminance (Lux) |
| Ld | Average Luminance on desk in the paperwork zone. |
| Lf | Luminance on floor in the user's view of field. |
| Lc | Luminance on ceiling recorded on the front upper position from where the user is sat. |
| Lw | Luminance from the wall or near partition (average 1.3 m high) in an office lay out. |
| LW | Average Luminance from the rear of a blind or window (brightness from the landscape, sky and ground). |
| CCT | Surface Colour Temperature (ºK). Perceived from user's workstation position. |
| OFF | Current status of a daylight linking function of an office room when it has been de-activated, not working or otherwise it does exist a mechanical or technical failure. |
| DH | Daylight Harvesting position for blinds/shades |
| FeBl | Fix external blinds, shades or louvers. |
| DG | Dynamic Glassing system. It is an Electro- or Photochromic glass whose optical transmittance can be varied with electrical, chemical or photometric stimulus. |
| MeBl | Manually operated external blinds or louvers |
| MiBl | Manually operated internal Blinds or shades |
| PhiBl | Photocell operated internal/interstitial blinds |
| PheBl | Photocell operated external blinds/louvers |
| TiBl | Timer/clock operated internal blinds |
| TeBl | Timer/clock/ operated external blinds |
| PhL | Photocell operated lights |
| PIRL | PIR operated lights in working hours. |
| AL | Automated system operated lights via a specific programmed system but separately from the rest of the building facility management. Dimming or scene setting are some of its option. |
| DALI | Digital Addressable Lighting |
| BMSL | Business Management System operated lights |

## 1. INTRODUCTION

There have been many questions raised in the light community concerning the success of lighting controls. This presentation is part of ongoing PhD research and it continues the paper presented last PLEA 2005 about "Social Implementation of Lighting Control Systems in Architecture" [1].

In the first paper it was asked why many buildings that integrate different intelligent energy savings systems do not meet expectations. After seeing how cybernetics can face problems of saving money and comfort, the paper suggested that different needs, requirements and social behaviour of UPOs (user-person-occupants) have not been totally considered.

In a further step, and with the aim of evaluating what the real situation is, the study is now focused on lighting in UK office environments and how it is perceived and controlled. Complex concepts like users behaviour and perceived lighting comfort have been analysed.

To this end, 15 offices following a lay out type and with so-called automatic daylighting control have been inspected in the UK. 101 users have been surveyed in total. During the survey, field measurements from each user workstation were taken for comparison with the respective occupant's questionnaires.

This study emerged from the necessity to evaluate the performance of systems and elements like photocells, blinds mechanisms and switching systems and demonstrate their effectiveness before they go to the market in order to be correctly and widely adopted. Also concurrently demonstrate the potential of these systems for saving energy with the artificial lighting by taking UPOs into consideration.

## 2. OVERVIEW

2.1 Reduction of Electric Lighting through Photocell Use

It is not totally clear in practical application what the real energy savings benefits are from using photocells linked to light.

During the Mock-up office studies from BRE [2] in the UK to test the photocell performance, the photocells were only for monitoring purposes and did not control electric lighting in the space. The photocell results were not just simply related to the mean sky brightness but also to the brightness distribution of the sky. Actually, BRE in a POE [3] basically concluded that all lighting controls did not perform as expected except those that dimmed and provided control for each luminaire. Users would not tolerate any automatic control of the lighting where they were aware of it visually.

Measurements from the University of Cardiff [4], show savings in lighting consumption when using photocells with high frequency fluorescent fitting. But it was said that in practice, this savings would be reduced by occupants using blinds and other devices to remove glare problems.

2.2 Reduction of Electric Lighting through the provision of Automated Blinds

A study from NCR-CNRC [5] in Canada, shows the energy savings for photocell controls in daylit spaces taking manual blind control into account. The study is based on simulation and compares the results obtained by using two software packages. Results differed from each other amongst other reasons, due to the uncertainty as to how users adjust the shades.

More studies through simulation [6], proved that the use of automated blinds reduce $CO_2$ emission and even 3% more than in comparison with manual blinds.

2.3 Estimated Success of Daylight linking in Practice

The lighting industry practitioners related with the buildings surveyed, in spontaneous talks, suggested there were maybe 20 real cases throughout the UK with daylight linking (photocells, blinds control, etc.) in relation to projects of offices with dimming/sensors but that is difficult to answer.

2.4 What Parameters are Controlled

British Standards [7], for office environments, propose an amount of light of 500 lux on the desk and 300 lux elsewhere. The concept of quality of light in the "task area" is introduced according to the lamp selected and its colour rendering which may be around Ra $\geq$ 80. Part L Regulation [8] encourages the use of energy efficient lamps to control the building emission rate. The Code for Lighting [9] and LG7 guide [10] prescribe illuminance ratios on task/wall and ceiling. Therefore photocell dimming luminaries and lighting controls in general, are based in achieving these illuminance ratios. This POE show how, despite compliance with the illuminance levels recommended, on the task plane people are still feeling unsatisfied.

Luminance control is only introduced in The Code of Lighting [9] in a recommendation for the ratio between the focus of work and its immediate surroundings that should not exceed 3:1 and a ratio of task to general background of 10:1.

This research questions other factors that can be controlled and emphasises the importance of controlling luminance.

## 3. RESULTS

3.1 What Functions are Currently Being Controlled

Daylighting control in buildings has been approached in different ways. Principles like solar protection, glare control, daylight harvesting and reduction of electric lighting have been implemented through photocell technology, selective glassing, dimmers, automatic shades, Brise soleil, etc. We tried to find those cases in the UK where daylight management systems were installed and to check their current status.

We could organise and classify the different control systems analysed in the study as follows (Table 1):

*Solar protection mechanisms;* Fixed or mobile Louvers, Brise soleils, shades and blinds with manual or automated override.

*Daylight sensor*; mainly the broad spread internal photocell, ceiling-mounted "look down" sensor used to control electric lighting. There are also internal "look out" illuminance sensors. External illuminance sensors for blinds/shades are also counted in this classification, as well as the use of external infrared radiation sensors to control the positions of shades.

*Time based controls*; these raise and close the blinds/shades at the time when the office opens or closes or for night free cooling applications.

*Electric lighting controls*; ceiling-mounted passive infrared sensors (PIR) for switching lights on and off, dimming the light, etc. DALI outputs and Dimmers.

*Building Management Systems;* controllers which monitor and control the installation. Control can be through an AL or a BMS.

3.2 The real Situation of Daylighting Controls in the UK

Of 15 buildings studied 12 had the system installed off (or part of the system). Function current status were checked in visits during the period 2005-2007 (Table 1).

**Table 1:** Daylight linking functions and their current operational status. X installed; **X** not working, * none existent. Information was gathered from 15 UK case studies surveyed: c1-Lutron HQ, c2-Queens, c3-Arup Fitzroy, c4-Tower Place, c5-BRE, c6-Zumtobel HQ, c7-Roche HQ, c8-Tower Br. House, c9-Wolfson-A Gw, c10-Wolfson-B Gw, c11-Bio/cardio Gw, c12-BBC Gw, c13-RBS ED, c14-BDSP HQ Ldn, c15-Ionica. (Daylight linking functions legend explained in p1 Abbreviations).

| Daylight Linking | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FeBl** | * | * | X | X | * | * | X | X | * | * | * | * | * | * | X |
| **DG** | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| **MeBl** | * | * | * | * | X | * | * | * | * | * | * | * | * | * | * |
| **MiBl** | X | X | X | X | X | X | X | * | * | X | X | * | * | * | X |
| **PhiBl** | **X** | * | * | * | * | **X** | **X** | * | **X** | * | * | X | X | * | * |
| **PheBl** | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| **TiBl** | X | * | * | * | * | * | X | * | * | * | * | * | * | * | * |
| **TeBl** | * | * | * | * | **X** | * | * | * | * | * | * | * | * | * | * |
| **PhL** | **X** | **X** | **X** | **X** | **X** | **X** | * | X | X | **X** | **X** | * | **X** | X | **X** |
| **PIRL** | * | **X** | X | X | **X** | * | * | X | X | * | * | * | X | * | * |
| **AL** | X | * | X | X | * | X | **X** | * | * | * | X | X | X | * | * |
| **BMSL** | * | **X** | * | * | **X** | * | * | X | X | X | * | * | * | * | **X** |

Figure 2 illustrates the results in a bar diagram to overview the situation in the UK. Photocell technology was mainly used to control electric lighting ( 86% of cases -13 out of the sample), 76.9% of systems were not working. 40% of the cases studied had automated internal blinds installed operated with a photocell, of which 66.6% had been switched off or changed to manual drive. BMS linked photocell controlled lighting is used in 40% (6) of all cases. The photosensors were disconnected in 50% of cases (3 of this sample). Internal blinds were currently manually operated in 10 out 15 buildings surveyed.

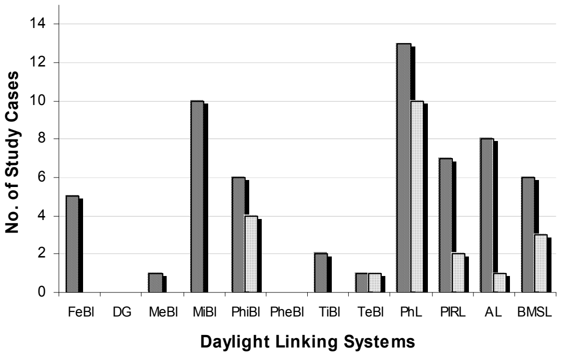


**Figure 2**: Double bar diagram showing frequency of each system used. *Lines*- n$^{o}$. cases found in an office lay-out *dots*- n$^{o}$. cases not working as a frequency of their success

3.3 Experimental Work

The experimental work of this PhD research consists of a post-occupancy office evaluation, carried out by measuring both luminance and illuminance, reflectance and colour temperature (as a measure of surface colour - which will depend on colour temperature of light source for being switched on most of the time and the actual surface colour) around a desk position (ceiling-desk-partition-floor), and a user survey completed in each workplace surveyed.

One of the questions the survey asked the subject was to record their general lighting condition satisfaction by ticking the following Likert scale 1-very satisfied, 2-satisfied, 3-unsatisfied, 4-very unsatisfied.

The instrumentation was from London Metropolitan University's Low energy Architecture Research Unit and from Zumtobel Ltd. Readings were taken with a Hagner Digital Lux meter, a Minolta CS-100 and CR-300 Chroma meter and the HDR image technique by using WebHDR [11], LMK2000 and Photolux software. Data presented are relative measurements and no absolute data. All results obtained with the different measuring tools and cameras were put under the same scale of measurement to be comparable. We had first to correct the deviation factor between them. The calibration factor was computed as the ratio of HDR luminances/luminance meter (taken from a real scene under overcast condition).

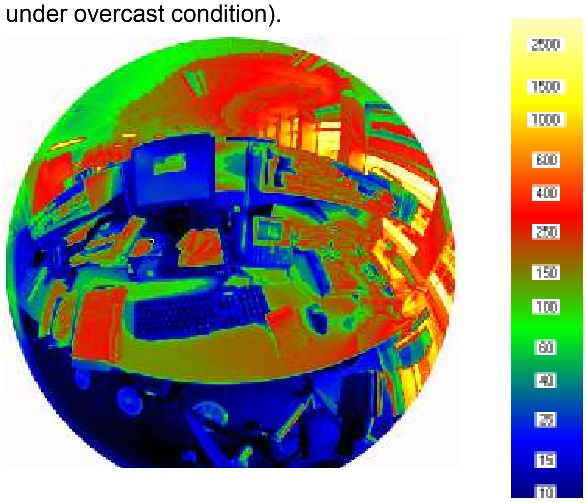


**Figure 1:** Fish-eye view of one workstation-type studied c3 (Arup's office). Picture from user's sight. HDR image representation of Luminance distribution on the surfaces.

Table 2 shows how luminance and surface colour temperature ratios differ when representing these values depending on users' lighting satisfaction response. Otherwise, lighting level on desk plane (E) seems not to be significant different. Note that high luminance from windows are recorded as a users preference as well as high CCT from the ceiling when they are very unsatisfied. Users seems to feel more satisfied with bluish ceilings and warmly lit desks.

**Table 2.** Mean values of Luminance (L), Illuminance (E), surface colour temperature (CCT) and reflectance (R) recorded in those workstation whose users answered feeling very satisfied with their lighting condition and mean results recorded from those who answered feeling very unsatisfied.

| | E (lux) | L (cd/m²) | R (%) | CCT (ºK) |
|---|---|---|---|---|
| ***Very Satisfied*** | | | | |
| DESK | 677.2 | 123.8 | 48.4 | 3600 |
| WALL | * | 51.7 | 29 | 4762 |
| FLOOR | * | 12.1 | 8.6 | 6143 |
| CEILING | * | 207.3 | 76.4 | 4225 |
| WINDOW/landscape | * | 4047.5 | * | * |
| LAMP | * | * | * | 4107 |
| ***Very Unsatisfied*** | | | | |
| DESK | 645.5 | 66.4 | 46.5 | 2600 |
| WALL | * | 34.2 | 28.8 | 2600 |
| FLOOR | * | 8.7 | 6.7 | 4400 |
| CEILING | * | 160.6 | 75 | 3100 |
| WINDOW/landscape | * | 141.6 | * | * |
| LAMP | * | * | * | 5975 |

3.4 How People Perceive the Lighting Environment

In the cases studied, occupants in general, were happy with the lighting condition as 77.4% of the interviewed are *satisfied* and rate the overall comfort as *positive* in 91.1% of the cases. Moreover, 18% would not modify any lighting condition when asked about the possibility of having control of the electric light, daylight level and blind positions. UPOs [1] think their daylighting level is *just right* in 70% of cases and *too little* in only 13% of users.

Another interesting topic is: how do they describe the general lighting environment. The mean CCT of the electric light was around 4582 ºK and the mean CCT recorded on desk was on average 3515 ºK. 54.8% of the respondents described the light as *cool*, compared to the 21% who perceived it as *warm*, 17.7% *intermediate* and 6.9% who did not know what to answer. These results would be expected from the artificial lamps as they were mainly working during the whole day in all cases.

Significant results stand out when comparing people's responses in those buildings with manual or auto drive blind modes. People perceive themselves to have less glare problems and veiling reflections on their computer screens in those buildings with automated blinds than in those with manual blind operation.

3.5 Analysis of the Correlation Between the Different Parameters

The data collected was explored with a range of different statistical methods (Pearson's correlation coefficient and test of significance, analysis of variance ANOVA and chi-squared) to examine what lighting parameters influence the desk plane and their significance. These methods were used to form the basis of our conclusions. Results from measurements are relative and not absolute because they were taken by simulating the user's view of field, so that all variables depend on each other).

A correlation analysis using SPSS software using all parameters surveyed revealed that in terms of daylighting, there is a strong and statistically relationship between E on the desk with L on the ceiling and between CTT on the desk with Luminance from the window.

**Table 3:** Pearson's correlation coefficient, *r*, between Lc with E on desk, vertical Luminance from windows and landscape (LW) with the CCT on desk, E on desk with CCT of lamps, and LW with the Lc.

| | *Number of measured points* | *Number of offices* | *Pearson correlation coefficient, r* |
|---|---|---|---|
| Luminance ceiling-E desk | 74 | 9 | 0.570** |
| L vertical of window/landscape-CCT desk | 51 | 9 | 0.350** |
| E desk-CCT lamp | 50 | 9 | 0.473** |
| L vertical of window/landscape-L ceiling | 89 | 9 | 0.215* |

**Correlation is significant at p<0.01 (one-tailed)
* Correlation is significant at p<0.05 (one-tailed)

In the analysis of variance ANOVA, the linear regression analysis (Figure 3), revealed that the predictor set of luminances significantly–but not strongly predicts the outcome illuminance $F(4,73)=15.466$, $p<0.001$ and explains the 47.3% of the variability of illuminance on desk ($R^2=.473$). After using a stepwise method, it was shown that the most significant predictor is Lc ($\beta=.570$, $p<.001$) explaining 32.4% of the variability of E on desk ($R^2=.324$), followed by the model Lc+Lw ($R^2=.434$). It is interesting to note that LW is amongst the excluded variables. This result shows the importance of redirecting the daylight indoors, above all towards the ceiling.

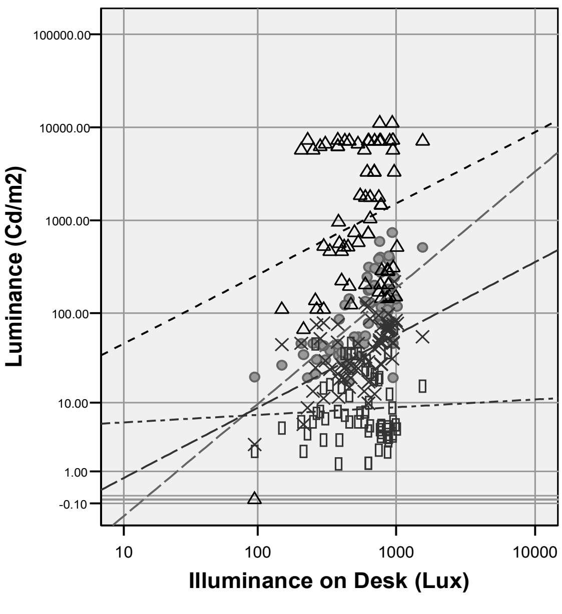


**Figure 3**: Results of examining whether luminance that surround a workstation; • Lceiling, [] Lfloor, x Lwall and ∆ Lwindow, determine relevance of illuminance level (E) on the desk. The ANOVA lines of linear regression are significant (p<.001) for Lc (highest slab). Therefore, • Lc becomes the highest predicto of E on desk .

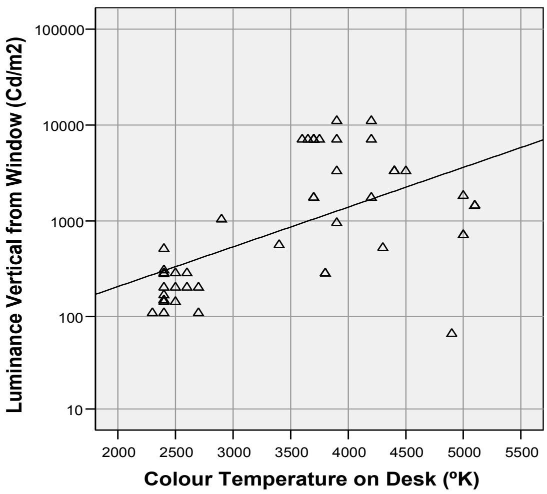


**Figure 4**: Results showing how the CCT on desk (ºK) goes up when Luminance from window is increased. The ANOVA line of linear regression is significant ($p<0.05$) for Δ-L window/landscape .

The regression analysis also show (Figure 4) that the predictor set of luminances (floor-window-ceiling-partition), significantly predicts the outcome of CCT on desk $F(5,50)=10{,}837$, $p<0.001$ and despite being a weak relationship, explains 54.6% of its variability ($R^2=.546$). By using Stepwise method, we saw that the most significant predictor is the luminance from the window LW ($\beta=.350$, $p<.05$) explaining 12.2% of the CCT on desk. It would be also interesting to note that the predictor set LW+Lc explains 20.6% of the CCT variability on desk ($R^2=.206$). Figure 4 shows the dependent variable CCT on the desk and the most significant independent variable of LW fitted in a regression line.

Surface CCT measured on desks is a combination of the CCT of the daylight plus the colour temperature of the electric light. Desks were in a perimeter area at 2 and 5 m distance from the window line. Relative CCT of daylight in those position closer to windows was higher than the CCT of lamps and was affected by the sky condition, glass and fabric solutions. Figure 4 explains the importance of the brightness of the scenery and the sky on these desk' positions as well as the choice of type and colour of blinds. Lighter colours result in higher luminance on the rear of the blinds which will affect the final CCT perceived on the desk.

3.6 Testing the Results. Experiment 2

This research tries to show how a full integrated daylight linked office management is the way to control the energy saved and ensure user's comfort. From the study we saw that if parameters like luminance on the ceiling are controlled, savings on the desk plane (lux) are ensured and therefore the efficient % dimming in offices. Controlling blinds is a way to control, Lw of the rear of the blinds (glare), Lc of the ceiling and CCT and E on the desk in those ratios where people feel more comfortable.

We are currently using one of the offices (where the daylighting system was disconnected) as a trial. The Roche Pharmaceutical HQ in Welwyn Garden City was chosen for its potential to become a good day-lit office in practice [12]. We proved that if the semi-perforated redirecting blinds were automated having different slat inclination -the upper 1/3 top fixed and the lower 2/3 tilted 20º towards the exterior-, on a semi-overcast day, on the south east and south west elevations, ceiling luminance were increased by 3-18 times. The results were brighter interiors, reducing glare but also the average working plane illuminance was increased by 200 lux. (measured 4.5 m in from the perimeter, 670 vs 470 lux). On north east elevation for another tilted position (60º towards the exterior for the middle slats), on a sunny day, brightness from the landscape was reduced to 400cd/m2, on the rear of the blinds, achieving on the ceiling the same luminance penetration as when the blinds were totally up.

We are now in process to install a software that will operate blind positions according to this results linking luminaires and recording the electricity savings.

## 4. REASONS FOR FAILURE

4.1 Reduction of Use of Photocells

Most of the daylight linking surveyed is up till now photocell-based, with software controlling blinds motors and dimming ballast. Most photocell sensors were look-down illuminance sensing types. A lack of appropriate design/understanding in the original design (case c1 and c4), plus commissioning and/or maintenance problems has frequently led to frustration and dissatisfaction of occupants, and subsequently disuse or manual overriding (case c5 and c6 ).

The main limitation comes from the types of sensors available, leading to inappropriate response from automatic controls (case c9,c10 and c11). DALI system has failed in a small but significant number of cases. If solar glasses are used for solar radiation protection, the reduction of visible light reduces the overall effectiveness of the dimming ballast [13].

Integrating different daylighting solution does not necessarily mean using the same sensors. In some cases this is made worse by incompatibility between non standard communication protocols or one system (blinds) working against the other (daylighting) (case c13). Photocell technology seems to be clearly failing above all when it is linked to blinds (case c1,c6,c7 and c9).

4.2 Reduction of Use of Automatic Blind System

We found some mechanical failure due to the choice of blinds i.e. material, engines. (case c9).

There is no legislation support that links the use of automated blinds with lighting controls . In the UK Part L Building Regulation [8] and the CIBSE LG7 [10], the use of controls is only encouraged in order to reduce electricity consumption by dimming luminaires. The design standards are reached through the light fittings ( achieving a % DF, and 500 lux on the desk plane) and trying not to exceed in consumption.

Automatic blind projects appear to be frequently designed independently from the interior lighting. Blind requirements come from other directions –like glare control, or to limit solar gain- rather than to improve occupants' visual comfort or to reduce electric lighting energy (case c11and c13).

4.3 Social Component

To avoid possible conflict between the occupants, and the dimming systems, automated blinds, etc, these systems mentioned have the option to manual override through wall switchers or control remotes. (case c1 and c7)

In all buildings studied with BMSL, the control tends to be left in one person's hands, a building manager or the head of maintenance, and his/her criteria is finally the one to prevail over the lighting.

It is shown in the field study that those buildings where users are more sensitive to the knowledge about lighting/comfort and how the office environment is being controlled (case c2 and c6) despite not having the best lighting condition or systems working properly, users are more likely to feel satisfied, achieving these buildings, the highest positive rate about comfort.

There is a lack of collaboration (and probably understanding) between lighting designers (if indeed they are involved), architects, service engineers, manufacturers and contractors. There is a conflict between the different groups' needs and the issue is the difference between what is approved, what is built, commissioned and maintained. At the end we are having good-example buildings-with high rate of BREAM [14] achieved on the project stage- that in practice the systems are not working as originally thought (case c4,c5 and c7).

## 5. CONCLUSION

The POE reveals that 80% of the daylight linking systems installed in the UK are deactivated, failing or not working properly (12 out of the 15 sample).

Findings show that there is clearly poor integration between solar protection and daylighting controls. No integrated sun-tracking and daylighting control has been found successfully operating in a UK office environment. This results are followed by a lack of correct choice of blinds and a proper use of photocells.

Up till now most studies about lighting controls and blind performance are based on computer simulation. The results of this POE support however, other studies about none satisfactory responses of daylighting control systems.

In offices with different daylight linking for blinds and lights, the possible situation found of the system status is: A-one system works against the other and one has to be switched off; B-the lighting system has no photosensors and works completely a part of the daylighting concept and only blinds are controlled; C-buildings with photocell technology in lights in operation, do not have automated blinds being these cases the ones with most success.

It appears that potentially the most successful systems have specially-developed control algorithms which are specific to the project [15], and require purpose-designed software to determine optimum blind tilt/position and dimming lights accordingly.

In summary, we could say that internal photocell dimming luminaires may not be the best daylight linking option. However, new parameters like interior brightness -vertical luminance on the window (brightness of landscape included) and luminance on the ceiling- become crucial to control. This research proves how much and directly these luminance affect to the illuminance on the task plane and the colour temperature perceived on the desks.

Blind choice in general and automatic blinds in particular, perhaps become a key element to be integrated in a successful day-and electric lighting control system. Their benefit is proved in this study as a way to control luminance in the interior, to improve $CO_2$ emissions by reducing electricity consumption and as a result of users response.

We found no evidence that people in offices are willing to control their environment. Occupants sat near to windows prefer to leave the blinds how they find them, or do not manage them correctly for other reasons, e.g., too busy, lost the remote control etc. In this study we found more users manifesting not changing their blinds position (48.6% when manual option) than respondents willing to do it (25% in those cases with automated blinds). Moreover, people seem to have less glare problems and veiling reflection in their computer screens in those buildings with automated blinds than in those with manual operation.

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