Evaluation of lighting controls in office buildings

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Abstract: - Application of lighting control technologies has increased the public interest. Although these technologies have been promoted during the last years their successful use in buildings has been accomplished in a small percentage of new projects. Some of the reasons are the belief that occupants dislike automatic lighting control and the wrong perception that automatic dimming controls are unreliable or just don't work properly. The paper focus on the occupant satisfaction and acceptance in relation to the control of electric lighting in daylit offices. Three office buildings with automated lighting control were examined. These buildings were chosen because of their installed daylight responsive system. A questionnaire was given to the occupants and a study of their preferences in regard lighting controls was conducted.

Key-Words: - Daylight, Lighting controls, Photosensors, Occupancy

1 Introduction

Lighting controls with photosensors have not been widely installed by building contractors despite the great potential for energy savings in areas with high levels of daylight and despite case studies documenting energy savings from dimming [1-6]. This is because of the added cost of the equipment and installation labour. In addition, there is a perception that automatic dimming controls are unreliable, although, various studies have described their proper functioning. [7-16]. The users' reaction to indoor environment is a crucial factor not only for daylighting design and the potential for its harvesting but also for the optimum use of the lighting controls. The benefits in terms of higher productivity of office users in regard a more pleasant working environment are high [17]. Consequently, there is a need for a comprehensive understanding of the occupants' needs, beliefs and preferences in daylit spaces with lighting controls [18].

In this paper a method to study the user reactions for daylighting and lighting control has been used. It is based on a questionnaire including not only attitudes to daylight, windows and lighting control but to the total physical environment [19, 20]. Many buildings have been evaluated over the years but in almost all cases a different type of questionnaire for occupants' evaluation has been employed. It is thus very difficult to assess which method is the best and to compare different buildings on the same scale. From the experience reported in previous studies [21-23] a questionnaire for evaluation of the daylight and other parameters of the office work environment was designed. The design of this questionnaire started in the Joule II project Daylight Europe [24] and was based on questions used in former post occupant evaluation studies. The questionnaire has been already used in some case studies of office buildings [19].

However, this questionnaire wasn't regarded as the only and complete set of questions to use in this study. In this case, some questions that weren't relevant were deleted and some that were relevant with lighting were added [20]. The questionnaire was modified to specifically focus on the lighting controls of a building. This questionnaire was given to the occupants of three different office buildings and a study of their preferences in regard lighting controls was conducted. Whole the set of questions was preserved from one building to the next. In this way the knowledge about different buildings could be expanded and compared. The results can give a quality profile of the building to be used when evaluating the total merits of the buildings and comparing differences that could be the basis for the different user opinions.

2 Case studies

Three office buildings (A, B and C) located in Athens (Greece) were examined. These buildings were chosen because of their installed daylight responsive system. A summary of the features of the lighting systems of the examined buildings are given in Table 1.

Table 1.Summary of the lighting system

Building	Type of light fixture	Control device
A	600mm square downlights with 4X18W fluorescent lamps	Photosensors for a group of luminaires
B	Downlights for ceiling installation with 2X18W fluorescent lamps	External protosensor for interior zones for one part of the building and photosensors for a group of luminaries for the rest of the building
C	600mm square downlights with 4X18W fluorescent lamps	Stand alone photosensors for each luminaire in the perimetric zone of the building

2.1 Building A

Building A is a typical 2-storey office building. The fenestration consists of ribbon (continuous) windows running from 0,8m to 2,2m above floor level at the north, east and south façade of the building. External shading devices are used at the south and east façade. The view from the windows is unobstructed. The offices in the first floor are in open space and located at the south and east façade of the building (Figure 1) while the offices in the second floor are for one or two persons. The lighting fixtures are separated in small groups and each group is controlled from a photosensor through the BMS of the building.

Both floors were selected for studying the occupant preferences. The areas that were chosen for the study were the offices in the perimetric zone of the building. The questionnaires were given to the users that were working in the daylit zones that were controlled by photosensors.

2.2 Building B

Building B is an 8-storey office building. The fenestration consists of ribbon (continuous) windows running from 0,8m to 2,4m above floor level. No external shading devices or light shelves are used. The sky view to the north is partially obstructed by a 3-storey building. The offices are in open space and located in the perimeter of the building (Figure 2). An atrium is located in the core of the building. The lighting fixtures in the southwest part of the building are separated in small groups and each group is controlled from a photosensor through the BMS of the building while the northeast part of the building is controlled from an external photosensor.

Floors 3 and 4 were selected for studying the occupant preferences. The areas that were chosen for the study were the offices in the perimetric zone of the building. The questionnaires were given to the users that were working in the daylit zones that were controlled by photosensors.

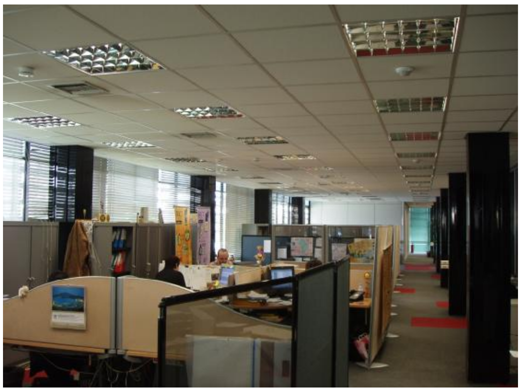

Fig. 1. Interior of Building A.

Fig. 2. Interior of Building B.

2.3 Building C

Building C is a typical 4-storey office building. The fenestration consists of ribbon (continuous) windows running from 0,8m to 2,3m above floor level. No external shading devices or light shelves are used. The sky view to the north and south is partially obstructed by two 4-storey buildings in the same complex. The offices located in the perimeter of the building (Figure 3). Each luminaire in the perimeter of the building was controlled from a stand alone photosensor.

Floors 2 and 3 were selected for studying the occupant preferences. The areas that were chosen for the study were the offices in the perimetric zone of the building. The questionnaires were given to the users that were working in the daylit zones that were controlled by photosensors.

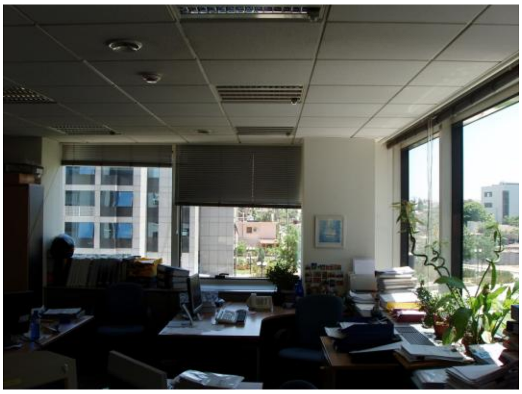

Fig. 3. Interior of Building C.

3 Methodology

In order to reduce the spread in evaluations a homogeneous group of persons as possible in age was selected for each building. For a fairly homogeneous group of users, about 30 persons are needed in each case study [19]. The questionnaire was answered by a total of 122 occupants. Table 2 shows the number of participants in the different buildings.

Table 2. Number of participants in the different buildings

Building	Participants
A	29
B	64
C	28
Total	122

The questionnaire used in this study is presented in Appendix A. The format of the questionnaire was based on rating scales. The rated scales are suited to field based lighting research due to their reliability, ease of administration and the ease with which subsequent statistical analysis may be undertaken. Where appropriate some questions used a tick box approach as illustrated also in Appendix A. The responses to the questions were on a 5-point scale from `too much' to `too little' for the part of lighting quantity and from 'important' or 'full control' or 'satisfied' to 'unimportant' or 'no control' or 'unsatisfied' for the part of lighting control.

Questionnaires were collected during visits at the same time of day within working hours for each building, in the period March-April 2005.

4 Results

4.1 Lighting quantity

Figures 4-7 show the average responses to the lighting quantity questions for each building, while figures 8-11 show analytically the occupants' preferences. The average occupant responses show similar reactions for the users of the B and C buildings while the users of the A building have different responses especially for the amount of daylight that reaches the occupants' desk. This can be explained with the use of external shading devices at the south and east façade of the A building.

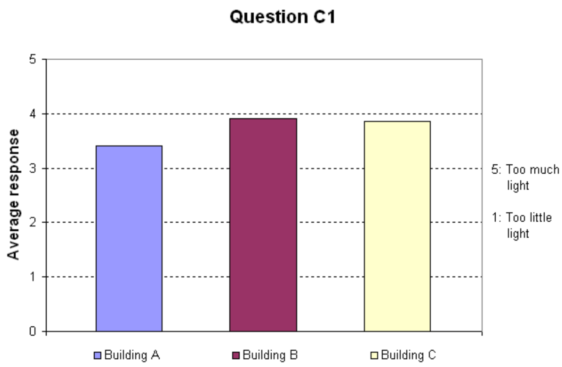

Fig. 4. Mean ratings for the amount of light on the occupants' office

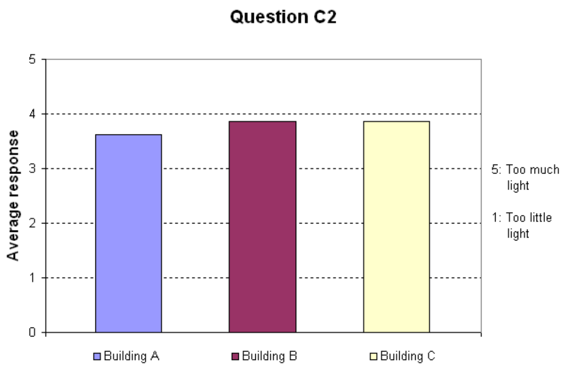

Fig. 5. Mean ratings for the amount of light on the occupants' desk

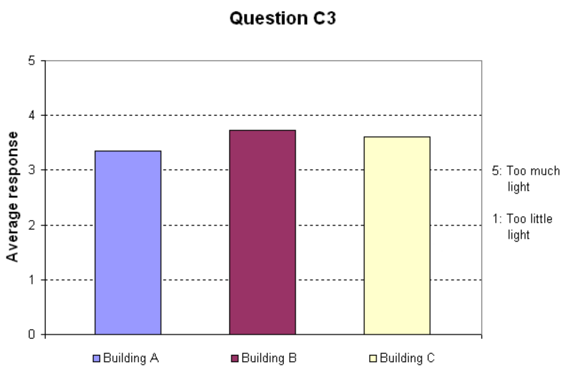

Fig. 6. Mean ratings for the amount of light on the occupants' monitor

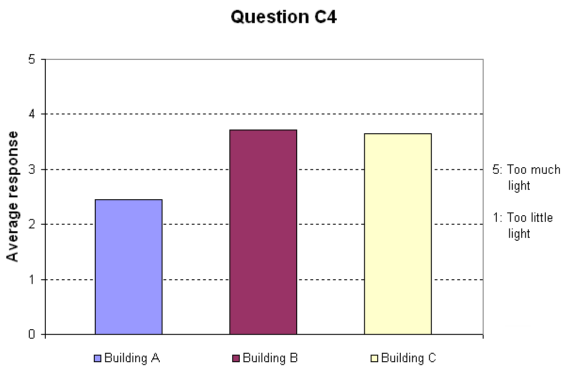

Fig. 7. Mean ratings for the amount of daylight that reaches the occupants' desk

Figures 8 and 9 show that in the examined buildings there is a tendency to report receiving too much light on the desks and in the working areas. A proper commissioning to the photosensor of these areas could result not only to lower illuminance levels without sacrificing the visual comfort but also to greater energy savings.

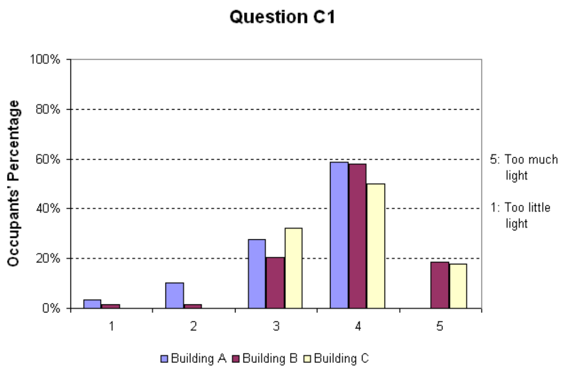

Fig. 8. Occupants' preferences for the amount of light on their office from 5 (Too much) to 1 (Too little)

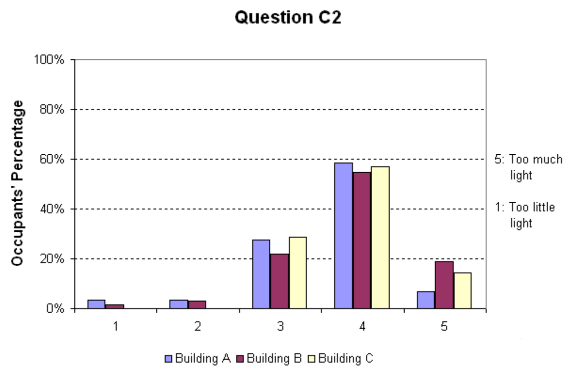

Fig. 9. Occupants' preferences for the amount of light on their desk from 5 (Too much) to 1 (Too little)

Figure 10 shows that there is some dissatisfaction because there is more light at the monitors than that is needed. This dissatisfaction in buildings is mainly caused by glare from daylight. Building A that has external shadings has the smallest dissatisfaction. Glare should therefore receive special attention in daylight design or with the arrangement of the furniture.

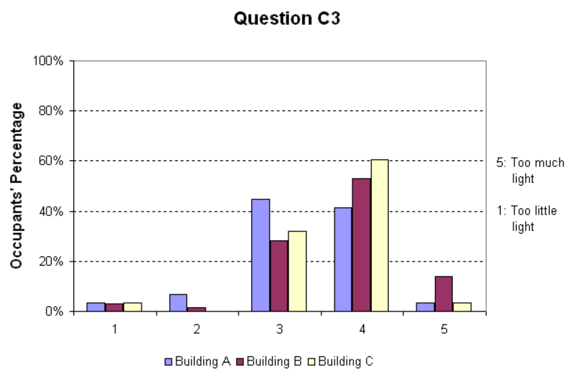

Fig. 10. Occupants' preferences for the amount of light on their monitor from 5 (Too much) to 1 (Too little)

Figure 11 shows that the users of the A building fell less daylight. As mentioned above, this is because of the use of external shading. The use of light selves along with the external shades may lower this dissatisfaction.

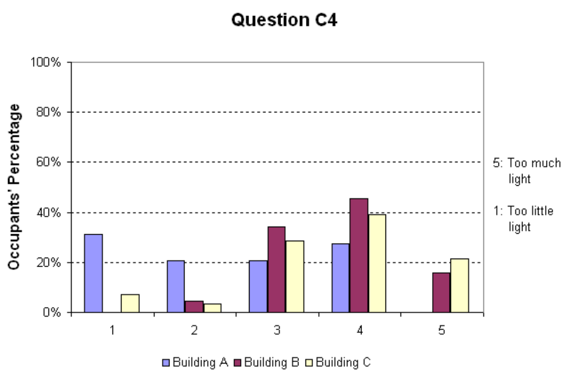

Fig. 11. Occupants' preferences for the amount of daylight that reaches their desk

4.2 Lighting control

Almost 21% of the users didn't know that in their office was installed any kind of control. More analytically 10% were in Building A, 16% in Building B and 43% in Building C. Furthermore only the 11.5% of the total number of the users had dissatisfaction with the lighting control (17% for Building A, 12.5% Building B and 8% Building C). The quick fluctuation of the dimming levels of the lighting system was the most important reason for the dissatisfaction of the lighting system. A proper setting in the sensitivity of the time response of the installed photosensor could solve this problem

Figures 12 to 16 show the average responses to the lighting control questions for each building, while figures 17 to 21 show analytically the occupants' preferences. The average occupant responses show different reactions for the users of the buildings. Only for the degree of control that the occupants have over the electric lighting above their workstation, the users of the A and B building had similar responses (Figure 13). Average responses to questions relating to control (Figure 12 and 15) indicate that occupants believe that it is important to be able to control lighting. However they seem rather satisfied with the degree of control of the lighting system that they have (Figure 14).

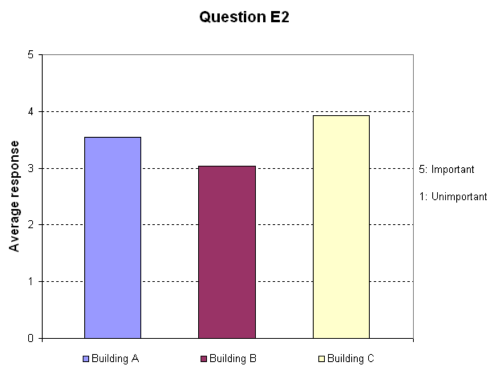

Fig. 12. Mean ratings for how important is from the occupants to control the level of electric lighting over their desk

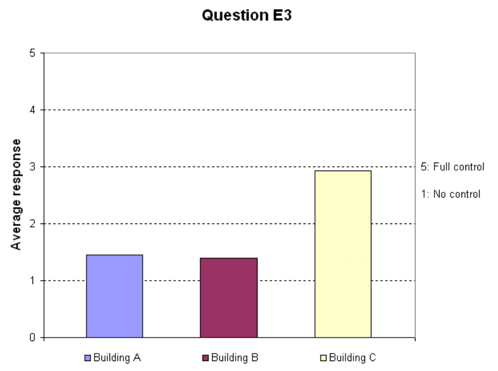

Fig. 13. Mean ratings for what degree of control have the occupants over the electric lighting above their workstation

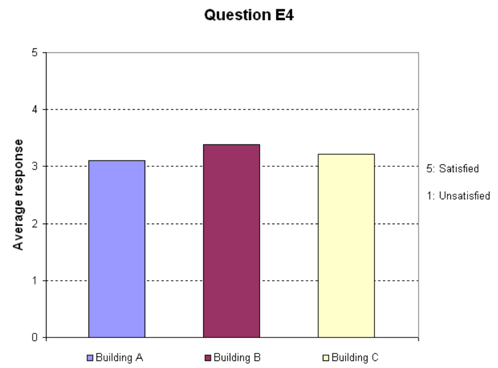

Fig. 14. Mean ratings for how satisfied are the occupants with their level of control

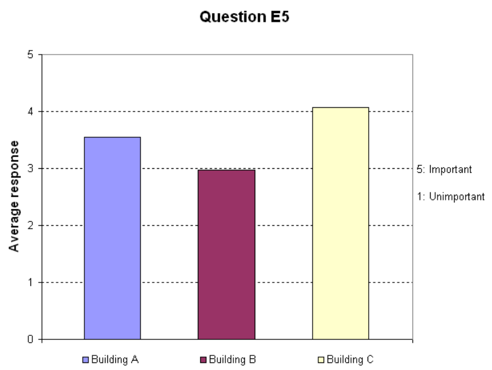

Fig. 15. Mean ratings for how important is the occupants to control the lighting of their desk separately from that of adjacent desks

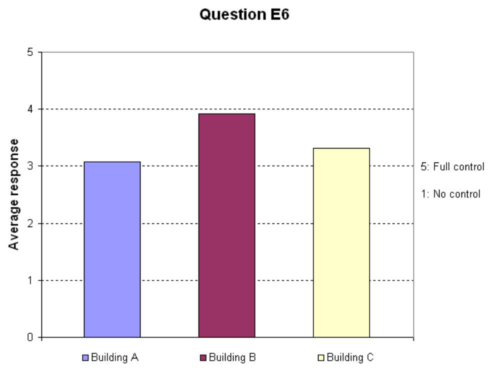

Fig. 16. Mean ratings for the users' control on the amount of daylight that falls on their workstation

Figure 18 shows that both buildings A and B haven't neither override to the lighting control nor choice for manual control from the users (almost 80% of the users). This result in occupants' dissatisfaction, reporting that over 60% of the users for both building want to control the level of electric lighting over their desk (Figure 17).

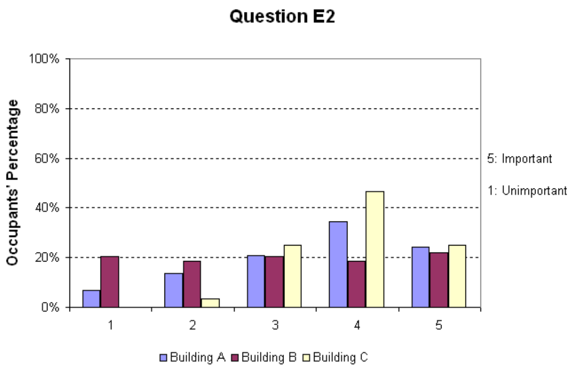

Fig. 17. Occupants' preference for how important is from the occupants to control the level of electric lighting over their desk from 5 (Important) to 1 (Unimportant)

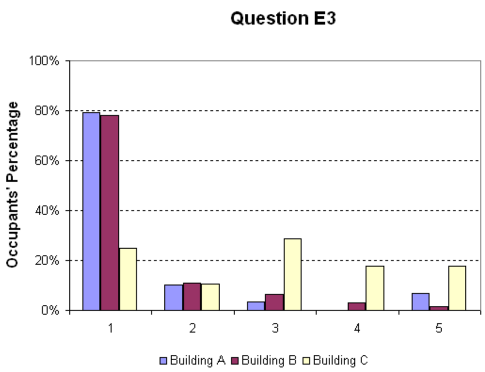

Fig. 18. Occupants' preferences for what degree of control have the occupants over the electric lighting above their workstation from 5 (Full control) to 1 (No control)

The wide individual variation in regard the satisfaction with the level of control perceived by the users (Figure 19) emphasizes that visual environments perceived as being of high quality may not be improved through the addition of controls.

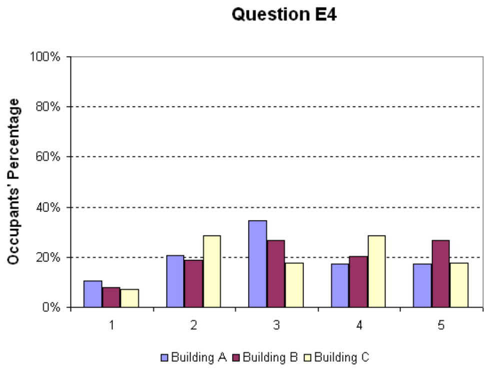

Fig. 19. Occupants' preference for how satisfied are they with their level of control 5 (Satisfied) to 1 (Unsatisfied)

Figure 20 suggests that while it could generally be expected that the desire for individual control would be high, the reality of control especially in areas with shared control groups, strengthens these convictions.

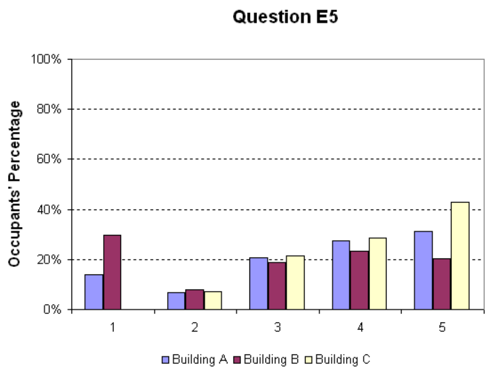

Fig. 20. Occupants' preference for how important is the users to control the lighting of their desk separately from that of adjacent desks from 5 (Important) to 1 (Unimportant)

Most of the users, over the 60% for all the cases, could control the amount of daylight that falls on their workstation (Figures 16 and 21) by using the internal blinds (Figures 1 to3) to prevent direct solar radiation that impinges their desk.

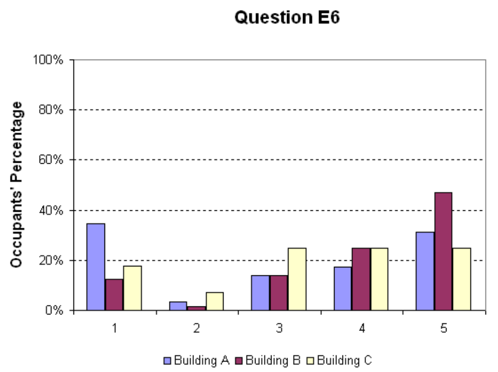

Fig. 21. Occupants' preference for the users' control on the amount of daylight that falls on their workstation from 5 (Full control) to 1 (No control)

5 Conclusion

The aim of an occupancy evaluation study is to carry out a systematic assessment of the performance of a facility once it has been occupied and used. It is to determine if the facility meets the level of expectation that was envisaged in the conceptual stages of the design, in terms of both the human occupants and the building services that it encloses. In this study the questionnaire was modified in order to be focused on the lighting of the examined buildings and more specifically on the lighting control system with photosensors that was installed in all the case studies.

A systematic gathering and analysis of the information collected from within the three selected buildings was done and some features of future use were identified. Furthermore some design features were also identifying that must be avoided.

Light levels in the offices and at the workplace were adequate in most buildings, and a proper commissioning of the installed photosensors could result in to greater amounts of energy savings without sacrificing the visual comfort.

Most occupants appreciated the automatic daylight-linked systems, but expressed a preference for having control over the system and being able to override it, or to switch the light on and off if they needed or wanted to do so. This suggests that occupants preferred to have the capability to choose their own lighting environment rather than having to accept lighting levels chosen for them, even when these lighting levels were ''better'' according to recommendations. However, in the examined buildings with the installed photosensor control, 21% of the total occupants didn't even know that an automatic lighting system was in place.

The results showed that for all the cases the following factors are essential in obtaining the most comfortable lighting conditions along with reduced energy consumption.

- Ease of use of lighting controls
- Occupant awareness to lighting controls
- Occupant training related to lighting controls

The reality is that unless the occupants are totally satisfied with the facility they will never reach their full potential or totally accept the technology, especially if it is not perceived to be of immediate benefit to them.

6 Acknowledgements

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References:

[1] M. Szerman, Superlink, A computer Tool to evaluate the Impact of Daylight-controlled lighting system onto the overall energetic behaviour of buildings, in: Proceedings of Right Light 2, Arnhem, Netherlands, 1993, pp. 673-685.

[2] R. Embrechts, C. Van Bellegen, Increased energy savings by individual light control, in: Proceedings of Right Light 4, Copenhagen, Denmark, 1997, pp. 179-182.

[3] K. Opdal, B. Brekke, Energy saving in lighting by utilisation of daylight, in: Proceedings of Right Light 3, Newcastle, England, 1995, pp. 67-74.

[4] D.H.W.Li, J.C. Lam, An investigation of daylight performance and energy saving in a daylit corridor, Energy and Buildings 35 (2003) 365-373

[5] D.H.W. Li, T.N.T. Lam, S.L. Wong, Lighting and energy performance for an office using high frequency dimming controls, Energy Conversion and Management 47 (2006) 1133-1145.

[6] E.S. Lee, S.E. Selkowitz, The New York Times Headquarters daylighting mockup: Monitored performance of the daylighting control system, Energy and Buildings 38 (2006) 914-929.

[7] F. Rubinstein, Photoelectric control of equi-illumination lighting systems, Energy and Buildings 6 (1984) 141-150.

[8] F. Rubinstein, G. Ward, R. Verderber, Improving the performance of photo-electrically controlled lighting systems, Journal of the Illuminating Engineering Society 18 (1) (1989) 70-94.

[9] R.G. Mistrick, J. Thongtipaya, Analysis of daylight photocell placement and view in a small office, Journal of the Illuminating Engineering Society 26 (2) (1997) 150-160.

[10] A.S. Choi, R.G. Mistrick, Analysis of daylight responsive dimming system performance, Building and Environment 34 (1999) 231-243.

[11] NLPIP. Specifier Report: Photosensors, 6 (1) 1998.

[12] F. Rubinstein, D. Avery, J. Jennings, On the calibration and commissioning of lighting controls, in: Proceedings of Right Light 4, Copenhagen, Denmark, 1997, pp. 225-230.

[13] R. Mistrick, C. Chen, A. Bierman, D. Felts, A comparison of photosensor-controlled electronic dimming systems in a small office, Journal of the Illuminating Engineering Society 29 (1) (2000) 66-80.

[14] A.S. Choi, M.K. Sung, Development of a daylight responsive dimming system and preliminary evaluation of system performance, Building and Environment, 35 (2000) 663-676.

[15] S. Ranasinghe, R. Mistrick, A study of photosensor configuration and performance in a daylighted classroom space, Journal of the Illuminating Engineering Society 32 (2) (2003) 3-20.

[16] R. Mistrick, A. Sarkar, A study of daylight-responsive photosensor control in five daylighted classrooms, Leukos, 3 (1) (2005) 51-74.

[17] L. Heschong, Daylighting and human performance, ASHRAE Journal 44 (8), 2002, 65–67.

[18] International Energy Agency (IEA) Solar and Heating Cooling Program, Task 31 – Daylighting Buildings in the 21stCentury, http://www.iea-shc.org/task31/.

[19] IEA, Post occupancy evaluation of daylight in buildings, IEA SHC TASK 21 / ECBCS ANNEX 29, December 1999

[20] T. Moore, DJ Carter, AI Slater, A study of opinion in offices with and without user controlled lighting, Lighting Res. Technol. 36,2 (2004) pp. 131-146

[21] Collins, B. et al., Post-occupancy evaluation of several U.S. Government buildings, U.S. Department of Commerce, National Bureau of Standards, NISTIR 89-4175, Gaithersburg, USA, (1989).

[22] Elder, J., Turner, G. E., & Rubin, A. I., Post-occupancy evaluation: A case study of the evaluation process. Center for Building Technology, National Engineering Laboratory, National Bureau of Standards (NBSIR 79-1780), Gaithersburg, USA, (1979).

[23] Energy Edge, Energy Edge - Post-occupancy evaluation project, Final report, University of Washington, Seattle, USA, (1991).

[24] Fontoynont, M. (Ed.), Daylight performance of Buildings. European Commission Directorate General XII for Science, Research & Development, Hong Kong: James & James, (1999).

Appendix A

Questionnaire

This is part of the questionnaire in regard lighting quantity and installed lighting controls.

C. Lighting level

C.1 Would you say that the amount of light on your office is:
Too much 5( ) 4( ) 3( ) 2( ) 1( ) Too little

C.2 Would you say that the amount of light on your desk is:
Too much 5( ) 4( ) 3( ) 2( ) 1( ) Too little

C.3 Would you say the amount of light on your monitor is:
Too much 5( ) 4( ) 3( ) 2( ) 1( ) Too little

C.4 Think about the amount of daylight that reaches your desk is:
Too much 5( ) 4( ) 3( ) 2( ) 1( ) Too little

E. Lighting control

E.1 Does exist system of automated lighting control in your office or in your general working place?
Yes ( ) No ( )
If yes, is it annoying? Yes ( ) No ( )
If yes, for what reason?

- O Lighting levels are too low
- O Lighting levels are too high
- O Flickering of the lamps
- O Dimming is too fast
- O Noise
- O Other reason (Please specify) :

E.2 How important to you is that you are able to control the level of electric lighting over your desk:
Important 5( ) 4( ) 3( ) 2( ) 1( ) Unimportant

E.3 What degree of control do you have over the electric lighting above your workstation:
Full control 5( ) 4( ) 3( ) 2( ) 1( ) No control

E.4 How satisfied are you with this level of control:
Satisfied 5( ) 4( ) 3( ) 2( ) 1( ) Unsatisfied

E.5 Do you think that it is important to be able to control the lighting of your desk separately from that of adjacent desks:
Important 5( ) 4( ) 3( ) 2( ) 1( ) Unimportant

E.6 Do you have any control on the amount of daylight that falls on your workstation (e.g. control over blinds):
Full control 5( ) 4( ) 3( ) 2( ) 1( ) No control