Evaluation of daylighting in office buildings

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Abstract: - Harvesting daylighting can significantly cut energy use in office buildings. However it requires careful design to counterbalance heat gain or loss, glare and variations in daylight availability. Designers with proper planning can not only improve the visual environment and create a higher-quality space but also lower energy costs for buildings. Lighting control with photosensors can take full advantage of daylighting by dimming light output so that no more light is produced than necessary. As a result, occupants tend to be more productive, comfortable and efficient. This paper focus on the occupant satisfaction and acceptance in relation to the daylighting in offices with automated daylight control. 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 daylight was conducted.

Key-Words: - Daylight; Occupant preferences; Occupant satisfaction

1 Introduction

As the cost of energy has continued to rise, increasing effort has gone into minimizing the energy consumption of lighting installation. This effort has evolved along three major directions:

1. The development of new energy efficient lighting equipment
2. The utilization of improved daylighting design practice
3. The improvement in lighting control systems

Daylight design is a crucial and complex process from the early stage of the office building design. Especially in the perimeter zones of the building, thermal gains and daylighting are two critical domains that are inter-related. Daylight harvesting in buildings may result in significant savings in electricity consumption for lighting [1,2] using lighting controls such as photosensors [3-8]. Nevertheless, large fenestration areas often result in excessive solar gains and highly varying heating and cooling loads. In addition, intense daylight leads to glare problems, especially for south-facing facades of office buildings.

While saving energy is of a great importance, there are some other associated benefits, which should be considered. These are productivity and quality. The benefits in terms of higher productivity of office users in regard a more pleasant working environment are high [9]. However, it is quite difficult to quantify their influence. Consequently, there is a need for a comprehensive understanding of the occupants' needs, beliefs and preferences in daylit spaces with lighting controls [10].

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 [11, 12]. 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 [13-15] 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 [16] 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 [11].

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 [12]. The questionnaire

was modified to specifically focus on daylighting and 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 daylighting and lighting quality 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.

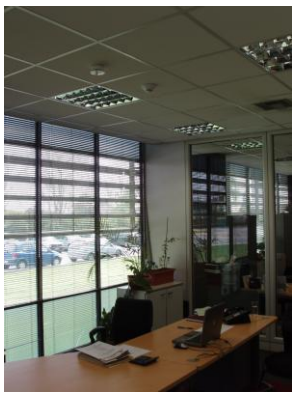

Fig. 1. Interior of Building A.

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.

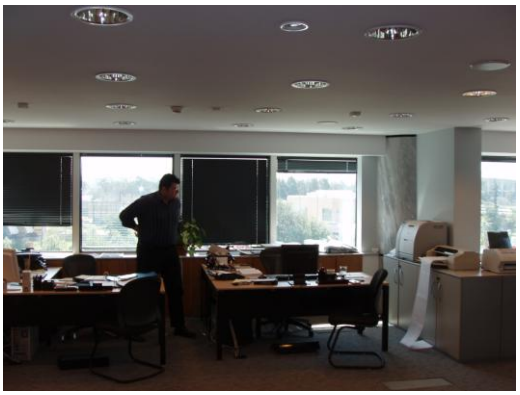

Fig. 2. Interior of Building B.

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.

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 [11]. The questionnaire was completed by a total of 122 occupants. Table 2 shows the number of participants in the different buildings.

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 bright' to `too dim' for the part of lighting quality and a 3 or 4-point scale for the part of daylighting.

Table 2. Number of participants in the different buildings

Building	Participants
A	29
B	64
C	28
Total	122

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 Daylighting

Figure 4 shows the occupants' preferences for the most important features of their workplace. The occupants ranked the three physical features that are most important in making a work place a pleasant one. The replies to this question were taken as indicators of what the occupants want and not necessarily what they have. Good light, comfortable temperature and good ventilation stand out as the most wanted features with average occupants' preferences 24.6%, 23.8% and 21.3% correspondingly.

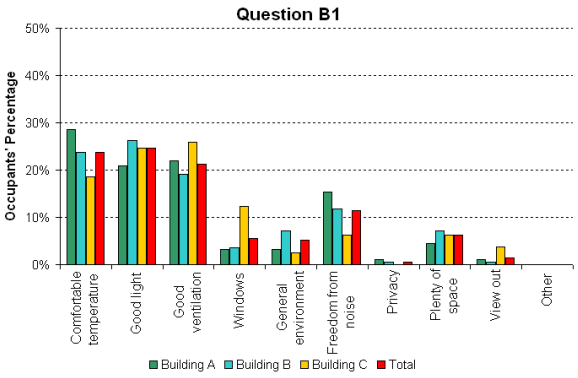

Fig. 4 Occupants' preferences of different aspects of the work place

Figure 5 shows the ratings of the indoor environment that occupants encounter in their own offices. Figures 6-8 show comparable values for the individual examined buildings. The features of Building B and C related to the most aspects came

out very well. On the other hand only lighting came out well for Building A because a new lighting system with photosensors and occupancy sensors was installed recently.

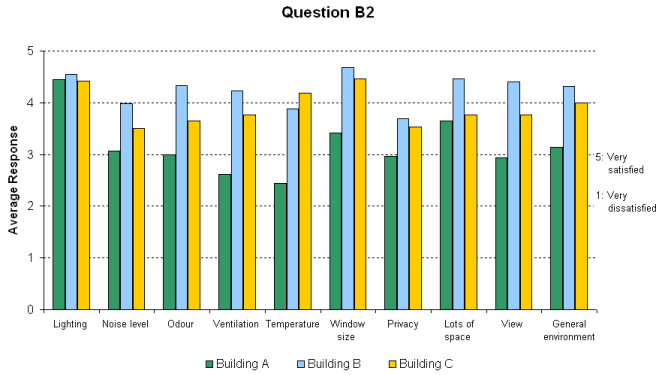

Fig. 5 Mean ratings of how satisfied are the occupants with the indoor environment of their work place, (Very satisfied: 5, Very dissatisfied: 1)

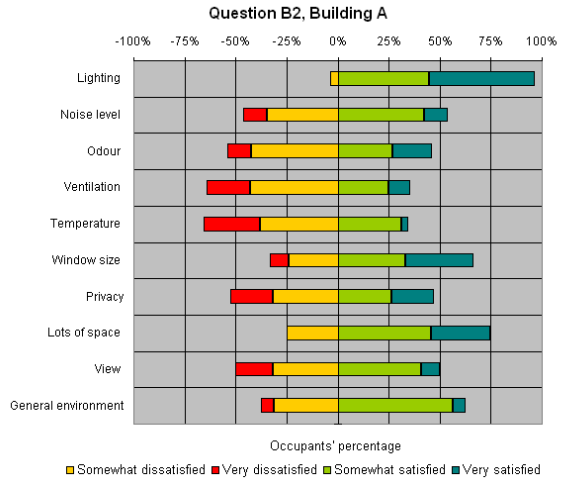

Fig. 6 Occupants' preferences of different aspects of the workplace in Building A

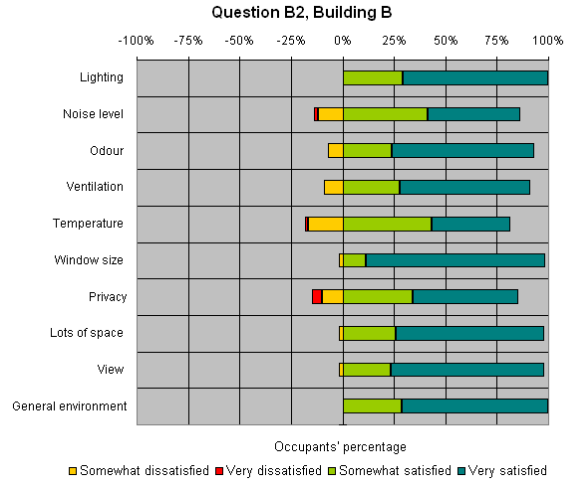

Fig. 7 Occupants' preferences of different aspects of the workplace in Building B

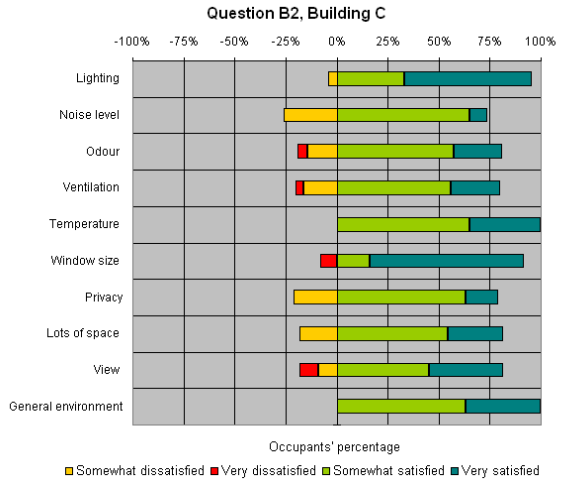

Fig. 8 Occupants' preferences of different aspects of the workplace in Building C

Most of the occupants prefer working with a combination of natural and artificial lighting (Figure 9). As a result a dimming lighting control is preferable than a simple on-off control. Furthermore for the most users is very important to have a window in their room or immediate work area (Figure 10).

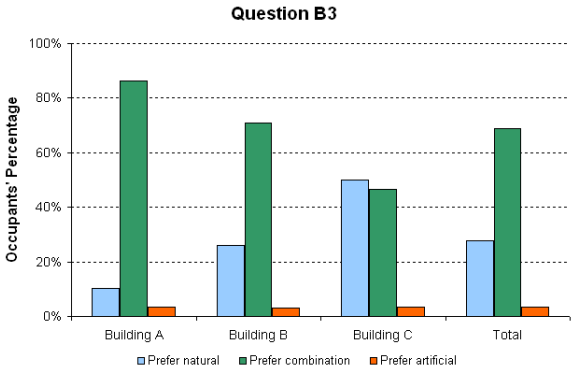

Fig. 9 Occupants' preferences for how they prefer their lighting conditions

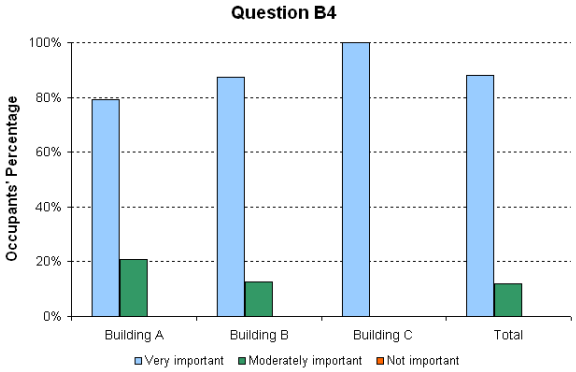

Fig. 10 Occupants' ratings for how important is for them to have a window in their room or immediate work area.

Only the occupants of Building C prefer working only with daylight, while the most users of Building A never use it (Figure 11). However most of the occupants believe that the size of their window is about right (Figure 12). In the case of the A Building, the size might have been rated as adequate if there had not been any blinds. Figure 13 shows that there is some dissatisfaction because there is more sunshine coming in through their windows than that is needed. Building A that has external shadings has the smallest dissatisfaction. In order to minimize dissatisfaction solar gain should therefore receive special attention in daylight design.

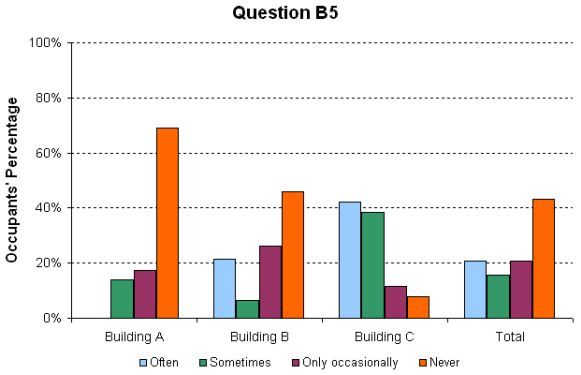

Fig. 11 Occupants' preference for working using only daylight from the windows

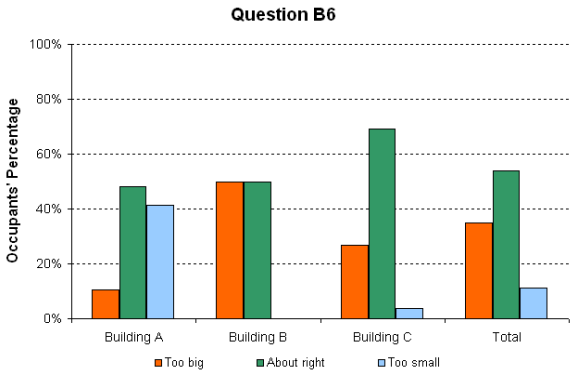

Fig. 12 Occupants' preference for the size of their window

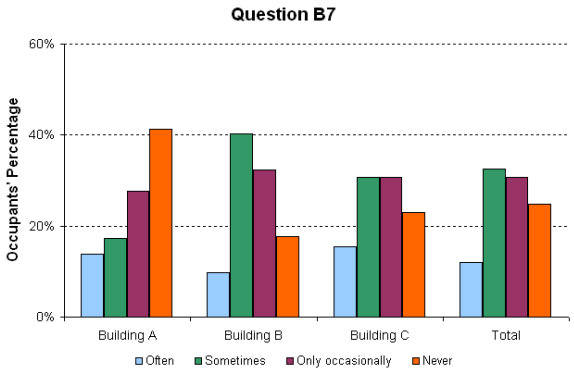

Fig. 13 Occupants' ratings for thermal gains because of the sunshine coming in through their windows

4.2 Lighting quality

Most of the users like their visual environment with the slight exception of the A Building (Figure 14). The use of the external blinds in Building A may dissatisfy some occupants because the blinds cut back the view. Responses to the brightness questions show a general tendency to report surfaces as being on the bright, rather than the dim side (Figures 15 to 18).

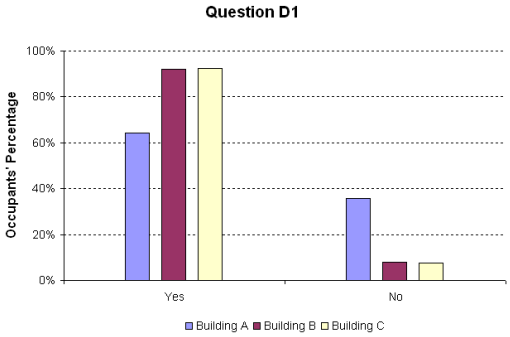

Fig. 14 Occupants' preference for their visual environment

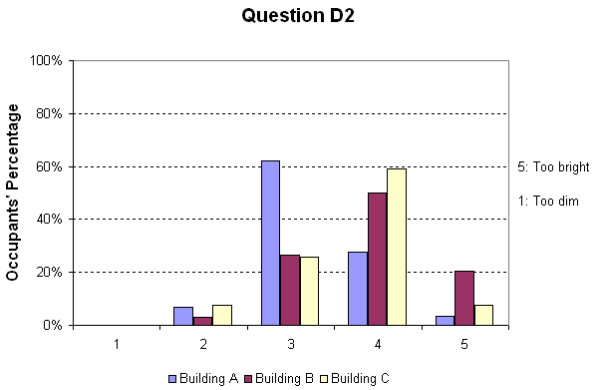

Fig. 15 Occupants' preference for how dim or bright is the scene in front of them

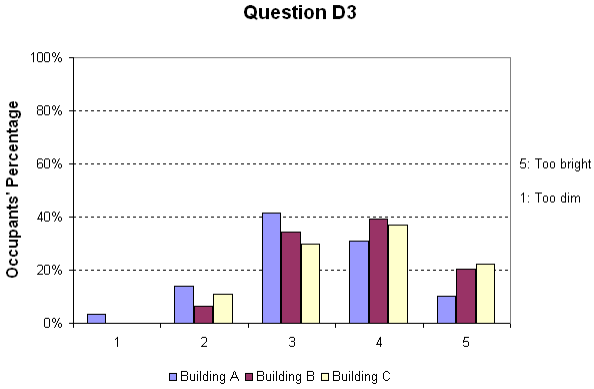

Fig. 16 Occupants' preference for how dim or bright is the scene on their left

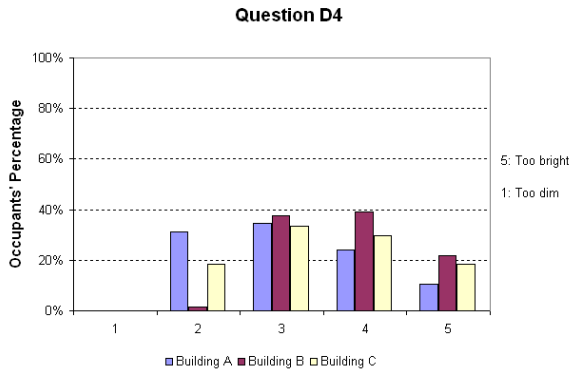

Fig. 17 Occupants' preference for how dim or bright is the scene on their right

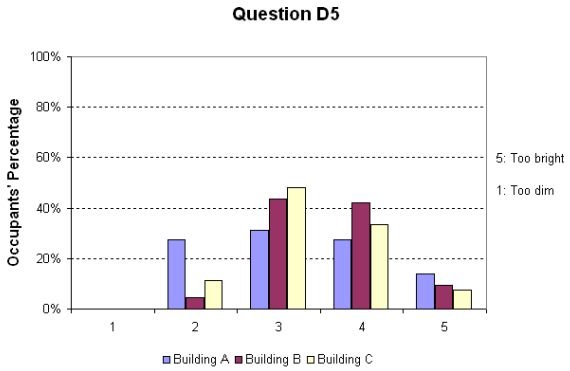

Fig. 18 Occupants' preference for how dim or bright is the ceiling

The two main sources of glare are artificial light and daylight (sun) as reported in figure 20. Most of the values in question 'Does glare ever disturb or annoy you?' are from the region of occasionally (3) to never (1). None of the ratings in A Building come close to frequently (5) (Figure 19). In the case there are disturbing reflections they occur mostly on the monitors (Figure 21). In addition more than the half occupants consider themselves that aren't sensitive to the glare (Figure 22).

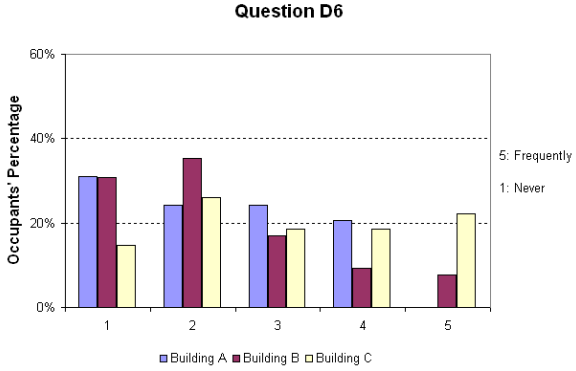

Fig. 19 Occupants' ratings for dissatisfaction from glare

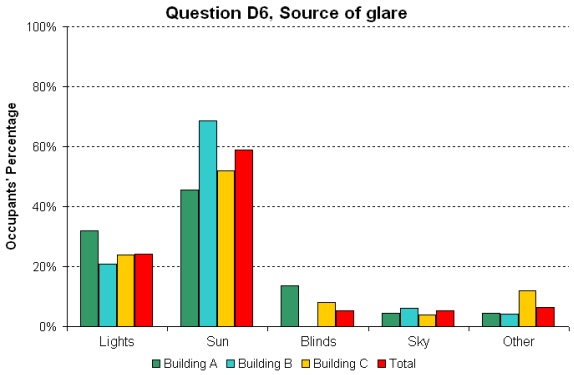

Fig. 20 Occupants' ratings for the source of glare

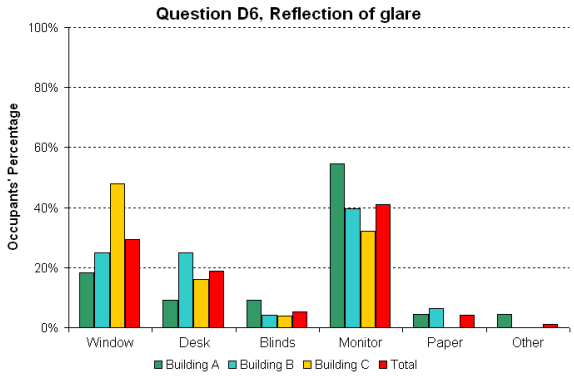

Fig. 21 Occupants' ratings for the reflection of glare

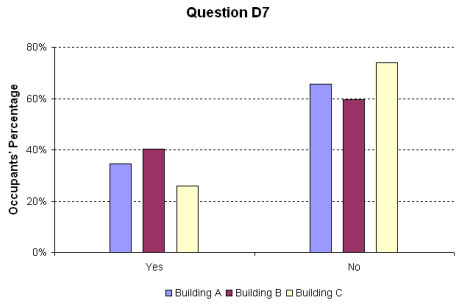

Fig. 22 Occupants' ratings for sensitivity to glare

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 daylight in buildings with installed lighting control system with photosensors.

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.

The preference for daylighting has attributed to the belief that working by daylight results in less stress and discomfort than working by electric light. The most wanted indoor features in an office are good light, good temperature conditions and ventilation. 'Freedom from noise' and 'plenty of space' received high, but not the highest satisfaction ratings of the indoor environment from all the characteristics that studied. Dissatisfaction with daylight in buildings is mainly caused by glare, in particular at the monitors. Glare should therefore receive special attention in daylight design.

Responses to the brightness in the offices and at the workplace were on the brighter side in most buildings, and a proper commissioning of the installed photosensors could result in to greater amounts of energy savings.

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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Appendix A

Questionnaire

This is part of the questionnaire in regard daylighting and lighting quality.

B. Daylight

B.1 Mark the three physical features that are most important to you in making a work place a pleasant one for you to work in. Mark from 1 to 3, with 1 = the most important.

O Comfortable temperature
O Good light
O Good ventilation
O Window(s)
O General environment (colours, carpet, decoration)
O Freedom from noise
O Privacy
O Plenty of space
O View out
O Other (please specify) .....

B.2 How satisfied are you with the following aspects of your work place?
Very satisfied 5( ) 4( ) 3( ) 2( ) 1( ) Very dissatisfied

a. lighting
b. noise level
c. odour
d. ventilation
e. temperature
f. window size
g. privacy
h. lots of space
i. view
j. general environment (colours, carpet, decoration)

B.3 Do you prefer working in natural light, artificial light or a combination of natural and artificial?

O Prefer natural
O Prefer artificial
O Prefer combination

B.4 How important is it to you to have a window in your room or immediate work area?

O Very important
O Moderately important
O Not important

B.5 Do you ever work using only the light from the windows?

O Often
O Sometimes
O Only occasionally
O Never

B.6 How about the size of your window, is it:

O Too big
O About right
O Too small

B.7 Does it ever become too hot because of the sunshine coming in through the windows?

O Often
O Sometimes
O Only occasionally
O Never

D. Lighting quality

D.1 Do you like your visual environment?

O Yes
O No

D.2 When you look up from your desk does the scene that your see in front of you seem:

Too bright 5( ) 4( ) 3( ) 2( ) 1( ) Too dim

D.3 When you look to your left does the scene that you see seem:

Too bright 5( ) 4( ) 3( ) 2( ) 1( ) Too dim

D.4 When you look to your right does the scene that you see seem:

Too bright 5( ) 4( ) 3( ) 2( ) 1( ) Too dim

D.5 Do you find the ceiling:

Too bright 5( ) 4( ) 3( ) 2( ) 1( ) Too dim

D.6 Does glare (glare is unwanted brightness viewed either directly or via reflection) ever disturb or annoy you?

Frequently 5( ) 4( ) 3( ) 2( ) 1( ) Never

What is the source of the glare (if any)?

I. Does it come directly from any of the following?

O Lights
O Desk Lamps
O Sun
O Sky
O Blinds
O other
If other please state…….

II. And/or are any of the above reflected in any of the following?

O Window
O Monitor
O Desk
O Paper
O Blinds
O other
If other please state…….

D.7 Do you consider yourself as very sensitive to glare?

O Yes
O No