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Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: a literature review

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Abstract

This paper presents an overview of peer-reviewed investigations of subjective issues linked to the use of daylighting in office buildings, particularly studies of preferred physical and luminous conditions in daylit office environments, and studies of occupant satisfaction and acceptance of electric lighting and window shading controls. The literature shows a consistent strong preference for daylight and a wide distribution between individuals in relation to the preferred illuminance levels in daylit offices. Existing knowledge about how people respond to daylight-linked lighting and shading controls in the workplace is very limited; therefore, this paper presents a summary of knowledge gaps in the field of daylighting and its interaction with the occupants. The resulting key directions for future research highlight issues for which a better understanding is required for the development of lighting and window shading control systems that are both energy efficient and suitable for the office occupants.

Keywords: Daylight; Daylighting; Occupant preferences; Occupant satisfaction; Lighting control; Shading control

1. Introduction

As part of the effort to reduce greenhouse gas production and preserve the natural environment, office buildings ought to consume less energy. The commercial buildings share of U.S. electricity consumption was reported in 2002 to be 35% [1]. In Canada, offices and other institutional buildings also use about 30% of the energy consumed by the commercial sector [2]. Lighting represents a major energy-user in these buildings (around 15%), and large amounts of energy can be saved by using well designed lighting controls that can take advantage of the natural light available. To take full advantage of their savings potential, however, lighting control systems also need to be integrated effectively with the window shading systems. Moreover, lighting and shading systems must provide luminous conditions that are suitable to the building occupants as well as reducing energy use. Consequently, there is a need for a comprehensive understanding of the occupants' needs and preferences in daylit spaces, as has been recognized by the building research community, for example, in the creation of Subtask A: User perspectives and requirements, under the IEA Task 31, ‘‘Daylighting Buildings in the 21st Century’’ [3].

Recent developments in automated control systems and novel materials and technologies will require new investigative directions, but these should be based upon the foundation of notable work that exists in the scientific literature. This paper summarizes over 60 research studies on daylighting covering the period from 1965 to 2004.[1] The review is structured around two themes:

- studies that examined the preferred physical and luminous conditions in daylit office environments; and
- studies that investigated the occupant satisfaction and acceptance in relation to the control of electric lighting and window shading in daylit offices.

2. Preferred luminous conditions in daylit environments

2.1. Beliefs about lighting

Several surveys have documented that people believe that daylight is superior to electric light in its effects on people. Cuttle [6] administered questionnaires in England and New Zealand to investigate the perceived attributes of windows.

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[1] The second author has previously reviewed the literature with a greater emphasis on electric lighting [4,5], which complements the present review.

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The sample of participants consisted of 471 office workers who were asked whether they considered windows to be an important feature of a workplace and, if so, how important that was to them and why. Almost all respondents (99%) thought that offices should have windows, and 86% considered daylighting to be their preferred source of lighting. The preference for daylighting was attributed to the belief that working by daylight results in less stress and discomfort than working by electric light, but as the author noted, this belief was not so much that daylight was beneficial but that electric light was harmful to health.

Heerwagen and Heerwagen [7] surveyed occupants of an office building in Seattle, USA, in winter and summer. More than half of the occupants reported that they believed that daylight is better for psychological comfort, for office appearance and pleasantness, for general health, for visual health, and for colour appearance of people and furnishings. People whose offices had windows held these beliefs less strongly than those without windows. The overall bias in favour of daylight was less pronounced for questions concerning work performance and jobs requiring fine observation, and on these questions people with and without windows did not differ. Despite holding strong beliefs about daylight, these participants rated it 19 out of 20 in importance among features essential to a comfortable work environment.

University students surveyed in Canada by Veitch et al. [8] about their knowledge, beliefs, and preferences for lighting provided similar data. Those who endorsed beliefs about lighting effects on health also endorsed beliefs about the superiority of natural light over other types. Between 65 and 78% of the sample endorsed statements about the superiority of natural light, such as ‘‘natural daylight is better for working under than artificial light’’. When Veitch and Gifford [9] refined their questionnaire and examined the question again across a mixed sample of office workers and university students, they again observed that people believe that daylight is superior to other light sources. The average score over several such questions was 2.94 on a scale from 0–4, where higher numbers indicate a stronger belief. Looking at individual questions, 52% of the sample reported believing that they did their best work when in places lit by natural light. The averaged daylight beliefs correlated moderately with beliefs about the importance of lighting, the beneficial qualities of bright light, beliefs about mild harmful effects of fluorescent lighting (e.g., headache, eyestrain), and lighting effects in creating social settings.

2.2. *Estimates of daylight availability*

Wells [10] interviewed office workers on two floors of an open, deep-plan office building with glass-curtain walls located in the UK, to identify the relationship between the actual physical conditions and the beliefs and attitudes of people towards windows, daylighting and artificial lighting. Previous research conducted by the same author and including 2500 employees showed a strong preference for daylighting and an outdoor view: Eighty-nine percent of the subjects felt that a view out was very important, and 69% felt that it was better for their eyes to work by daylight than by electric light. However, this second study, which took place during two similar overcast mornings in August, showed that occupants’ assessment of daylight levels were far from accurate. People tended to overestimate the proportion of daylight that they worked under proportionally with their distance from the windows. The subjects were asked to estimate the amounts of daylight and electric light that they thought they had at their desks, while measurements of the total illuminance were taken. The illuminance from daylight was then calculated by subtracting the illuminance measured at night from the total illuminance measured during the day. The results showed that the subjects perceived that they still had considerable levels of daylight at their desks, even when there was very little daylight available and most of the illumination was supplied by the electric lighting. The author concluded that people’s estimates about what they think they need in terms of daylight and view out are independent of the actual physical environment and the presence of daylight as an illuminant. In Wells’ study, the estimates about daylight levels depended rather on psychological considerations such as the judgment of apparent brightness distribution and the preference for a view out, which were not related to the distance from the nearest window.

2.3. *Preferred window type*

Various researchers have investigated people’s preferences for the size, number, position in the walls, and degree of transparency of windows. Ne’eman and Hopkinson [11] conducted an experiment with participation from 318 occupants of three buildings in the UK to determine whether there was a subjective minimum window size that influences people’s preference and satisfaction. The experiments were conducted from January to July under various sky conditions using a 1:12 room model fitted with mirrors that permitted the variation of the room width and the window width, height and number. While looking through the model at various outside views incorporating given configurations of these variables, the subjects were asked to select the minimum acceptable window width after which they would lose satisfactory view of the outside landscape.

The results showed that for a room 7.3 m long × 5.5 m wide × 3 m high and a fixed window height of either 1.5 or 2.1 m (window sill at 0.9 m above the floor), the minimum acceptable window width was between 2.2–3.2 m, and the window width was directly proportional with the distance between the participant and the window (window width over distance from the window was constant for any viewing point) [11]. When the length of the window-wall was less than half of the room depth (viewing angles below 30°), the subjects seemed to base their choice on the need to obtain sufficient visual information from the outdoors. When the window-wall was between 0.5–1.2 times the depth of the room (viewing angles between 30° and 60°), the subjects appeared to be influenced in their choice by the dimensional relationship between the width of the window and the lengths of the window-wall. However, in rooms with window-walls longer than 1.2 of the room depth (viewing angles over 60°), no further increase in the selected window width was observed.

The authors concluded that the amount of indoor and outdoor light levels, as well as the sun position and the sky luminance were not the main factors that influenced the selected minimum acceptable window size [11]. The type of outside view and the view content were more significant factors, with closer views triggering the selection of wider windows than the more distant views. The authors also speculated that within a 60° field of view, satisfaction would not be lost if the minimum acceptable window width was to be divided into a number of windows whose summed widths equalled the width of the single window.

Keighley [12,13] carried out experiments in a similar 1:12 office model incorporating, however, windows with variable geometry to examine various window design options and to investigate which of them provided the greatest degree of occupant satisfaction. The model represented a room 17.7 m long and 3.1 m high, with variable width created with mirrored side-walls. Based on these experiments, which included the participation of 70 subjects, Keighley developed a calculation method to estimate satisfaction based on the number of apertures, window height, window area, mullion width, and type of view. Ne'eman's study used real views through the model [11], but Keighley's study projected pictures of cityscape views (ranging from distant views to views of a nearby building) through various window arrangements. These were presented in sequence to the participants, who rated the views in terms of visual satisfaction and acceptability.

The results showed that subjects' satisfaction was proportionally affected by the window area, and was inversely proportional with the number and width of the window mullions. For an aperture of a constant area of 20% of a 6 m × 3.1 m wall, the optimum window width ranged between 2.8–3.4 m, the optimum window head height varied between 1.8–2.4 m, and the optimum sill height varied between 0.7–1.1 m. All three variables were related to the type of outside view presented, being at the lower margin for distant and ground floor views and higher for close views and views from an upper floor. Outside of these ranges a decrease in occupant satisfaction was recorded for all types of views. Most subjects preferred to see a wide lateral view of both the skyline and the horizon. Large horizontal windows that were 25% or more of the wall area were the most appreciated, while windows below 10% of the wall area were rated as unsatisfactory. Similarly, Cuttle [6] found that "the larger the windows are, the more desirable they are perceived to be" (p. 206).

A different conclusion was reached, however, by Wotton and Barkow [14], who after examining the relationship between windows, lighting, work performance, workers' mental and physical well-being, and subjective perceptions in six Canadian office buildings concluded that while the access to windows was important to 56% of the respondents, "having a *large* window or a *good* view out seems to be unimportant" to 86% of the workers (pp. 408). This study involved the participation of 235 office workers surveyed in high-rise buildings with glazed areas ranging from 11 to 68% of the office wall area. Seventy-nine percent of the respondents worked in open-plan areas, while the rest worked in private offices. In each building, half of the respondents worked near a window, while half were located further than 10 m away from the closest window.

Few of the measurements of well-being clearly related to daylighting conditions. The researchers found that the time spent on non-productive activities did not vary with the distance from the window and no relation was found between the ratings of job satisfaction, the perceived physical and mental comfort, and the office lighting [14]. In general, half of the respondents suffered from either headaches or eyestrain, but no relation was found between this aspect and the access to daylight, and only 14% of the workers considered daylight to be too bright. The workers in the buildings with 68% glazing reported more eyestrain than those in the buildings with only 11% glazing, and absenteeism was twice as high in these buildings. Nevertheless, the workers in the buildings with 11% glazing suffered more from headaches than the average worker, or than the workers in the buildings with 68% glazing. The researchers speculated that both "*too much daylight*" as well as "*too little daylight*" may affect the occupants' physical well-being. The mental well being of the occupants and their appreciation of the offices was not affected by the office lighting or the available glazing area, and only 20% of the respondents mentioned "*good lighting*" to be an important factor in their work place.

Butler and Biner [15] found in their survey conducted in Indiana, USA, that the preference for windows and their size varied according to the type of space. Contrary to previous research which showed a general preference for large windows, this study provided evidence that large windows were not the preferred choice for the majority of spaces. Fifty-nine university students were asked to specify their preferred window option for 14 spaces including offices, residential spaces, libraries, lecture halls, classrooms and so forth and to indicate the factors on which they based their preference. The results showed that large windows were rated by only 43% of the respondents to be their choice of window for an office environment, of which 32% preferred clear windows and 11% preferred translucent windows. Medium sized windows were selected by 46% of the subjects as their preferred choice, of which 35% preferred them to be clear. Access to an outside view, mood, sunlight and task performance were cited by over 65% of the respondents to be the main factors associated with these selections. Small sized windows were indicated by 16% of the respondents as their choice for an office environment. The survey, however, provided no indication of the physical size that participants would rate as "*small*" or "*large*".

Boubekri et al. [16] also attempted to investigate the effects of window size and amount of direct sunlight on occupant emotional response and satisfaction. However, in this case the question the researchers tried to answer was whether small sunlight patches were preferred by people over large sun patches and what was the acceptable limit. The study took place in a private windowed office located in Canada on sunny and partly cloudy days during the month of August, with the participation of 40 office workers (38 females and 2 males) who regularly worked in windowless offices. Four window sizes were tested (10%, 20%, 40% and 60% of the exterior wall area), and two seating positions were considered: facing the window and sideways to the window. For each window size the amount of sunlight penetration was measured and expressed as the percentage of the floor sunpatch area to the total floor area. Although the authors acknowledged the limitations of their study, particularly the gender bias and the difference from the participants' usual windowless work areas, they noted that regardless of the seating position, neither the window size nor the size of the sunlight patch have affected the occupant degree of satisfaction, feeling of excitement or emotional state. The size of sunlight patch, however, was found to have affected the feeling of relaxation described as ''calm, relaxed and peaceful'' when the subjects were seated sideways to the window. The optimal size of a sun patch in a room was found to be between 15–25% of the total floor area, and 40% was considered to be the maximum acceptable limit. The authors concluded that ''if the occupant's emotional well-being is the primary concern, then sunlight sparkles are preferred to large floods'' (pp. 491–492).

Windows offer a view of outdoors, as well as a way of admitting daylight. A team of UK researchers investigated both view and the amount of direct sunlight provided by the windows in a southern European wine-producing organization [17]. Unusually, the settings occupied included warehouses, the factory floor, and laboratories in addition to offices. Participants self-reported the percentage of floor area that was covered in direct sunlight when the sun was at its maximum penetration in the room. They also completed a set of questionnaires concerning job strain, job satisfaction, and well-being. People who reported larger areas of sunlight penetration reported higher job satisfaction and better well-being, and lower intention to quit their jobs. Small effects suggested that a more rural view improved well-being.

A post-occupancy evaluation conducted by Christoffersen et al. [18] during spring and fall in 20 Danish buildings with perimeter offices and workstations positioned at a maximum distance of 7 m from the windows also showed a strong preference for workplaces located near windows. ''A view out'' was rated to be the most positive aspect of a window, followed by the ability to ''see the weather outside'' and the ability to ''open the window'' for increased ventilation. The study involved the participation of 1823 office workers who expressed their opinions about windows, daylight, and electric light in their working environment. Over 70% of the respondents said that they were never bothered by sunlight and were ''highly satisfied'' or ''satisfied'' with the daylighting conditions in their offices, and 80% were never bothered by glare. However, in spite of a high preference and satisfaction with daylight and the proximity of the workstations to windows, the authors also noted that many respondents had their electric lights turned on even when there was sufficient daylight. This prevalence increased with the number of people occupying an office. Regardless of orientation, the number of office workers who found the windows to be either too small or too large increased with glazing areas of less than 20–25%, or over 30-35% of the building façade.

2.4. *Preferred configurations for window shading*

Window shading is a key element in controlling glare and overheating, both of which affect the occupants' well-being and the building energy consumption. A number of researchers have attempted to investigate whether occupants of office buildings use the shading devices according to predictable patterns and if so, if these patterns are dependent on factors such as window orientation, time of day, sky condition, season, latitude, and workstation position.

Rubin et al. [19] found that most occupants of perimeter offices equipped with venetian blinds preferred blind configurations that had little to do with the sun position or the daily and seasonal climatic conditions. Photographs of 6 office buildings located in Maryland, USA, were examined to see whether approximately 700 venetian blinds purposely set by the researchers in either an open or a closed position after the occupants left for a weekend had changed position on the following Monday, when the subjects arrived back to work. The experiment took place over three 10-day periods in October, February and July, and each building façade was photographed at least four times in the morning and in the afternoon before and after the change occurred. The various blind configurations selected by the occupants were analysed based on the percentage of window coverage and slat angles described as ''*open*'' and ''*closed*'' but whether the blind slat angle was tilted upward or downward was not identified. The results showed that blind occlusion was higher on the southern façade (about 80%) than on the northern façade (about 50%), which suggests that occupants used their blinds to avoid sunlight penetration and overheating of their offices. However, most blinds were set with the slats open rather than closed, which suggests a preference for a view out. The researchers also found that occupants did not change the blind position daily, and their preference for a certain blind configuration seemed to be mostly based on perceptions formed over long periods of time ranging from weeks to months.

Following on Rubin's work, Rea [20] reported the results of a pilot study conducted in Ottawa, Canada, in a 16-storey building to investigate whether the window orientation, the time of day and the weather conditions had any effect on the use of the blinds. Photographs of the building's southern, eastern and western façades were taken in the morning, at midday and in the afternoon on a cloudy day in April and a clear day in May, and the variation in blind occlusion was compared. The results showed that on the clear day about 60% of each façade was occluded by blinds, while on the cloudy day only the eastern façade was different from the rest, being 40% occluded by blinds, whilst the two other façades had similar occlusion to the clear day. The position of the blinds did not change throughout the day and photographs of the same building dating 10 years earlier showed almost identical values of window blind occlusion under a clear sky in March and September. Similarly to Rubin et al. [19], Rea also concluded that blind positions change irregularly and that an occupant most likely changes the position of the blind when direct sunlight reaches the work area, but seldom changes the setting for view or daylight.

Rea et al. [21] surveyed 58 US offices over seven weeks, obtaining results confirming the earlier conclusion. In the offices surveyed, the blinds were usually pulled down as soon as the sun created glare and thermal discomfort, and they were kept down for long periods of time even after these conditions ended. The occupants adjusted the blinds more frequently on the western and southern sides of the building (about 3–5 times/week) than on the northern and eastern sides (about twice a week). The authors noted that the sky condition and the sun position, as well as the task and the desk location influenced the blind position and the slat angle chosen by the occupants.

Inoue et al. [22] found that for a solar radiation of over 60 W/m^2, the percentage of blind occlusion on the façades of four high-rise buildings located in Japan was directly proportional with the depth of the sunlight penetration into the room. The study included the monitoring of over 1000 windows oriented in the east, west, south-west and south-east directions during winter, summer and fall, as well as two questionnaires of roughly 800 building occupants. The results showed no correlation between the amount of solar radiation (solar heat gain through the windows) and the rate of blind operation. However, blind operation varied with façade orientation and sky conditions. Photographs of the façades taken at regular time intervals by an automatic camera revealed that on clear sky days on the eastern façades, the blinds that were closed in the morning gradually opened in the afternoon, while the opposite occurred on the western façades. Blinds were not operated under overcast sky. This suggests that blind operation was mainly a factor of the depth of the sunlight patch from the window. On average about 60% of the monitored blinds were not operated at all throughout the day, which confirms previous findings that most people operate the blinds based on perceptions formed over long periods of time, rather than primarily in response to current conditions.

When asked about their preferred seating location, 50% of the participants said that they would prefer to be seated near a window, while less than 8% preferred work locations further away from the windows [22]. When asked about how they manually control their blinds, 70% responded that they usually like to keep the blind open for as long as possible unless it was too bright or too hot, which suggests that glare and heat were the main reason for blind manipulation. In Inoue's study, the highest blind occlusion was observed on the buildings' façades when the measured sunlight penetration into the offices was over 2 m, and when the direct solar radiation falling on the occupants was about 250 W/m^2. Once closed, the blind remained closed the entire day.

Farber Associates [23] found that 300 W/m^2 was the level of solar radiation that would trigger a change in blind position by occupants of buildings in the UK. They also noted that while it was very probable that the blind would be closed by the occupants based on the perceived solar intensity and altitude, it was quite unlikely that the blind would be raised again before any "*dramatic changes*" occurred. A similar conclusion was reached by Escuyer and Fontoynont [24] in France. They also found that people tended to forget to raise their blinds, or raised them only partially when sunlight was no more a source of glare. However, these authors also found that the majority of the 41 participants surveyed in their study left the blinds in the horizontal position regardless of the variations in sky condition, although some people preferred to let the blinds down and switch the lights on rather than handle the blinds, and others preferred to leave the blinds fully retracted to enjoy the daylight.

Lindsay and Littlefair [25] confirmed previous findings and found a strong correlation between the amount of sunshine, the sun position and the venetian blind use. This conclusion was reached based on a field study involving photographic surveys of five office buildings in the UK over the course of four years, which included records of blind positions on over 300 windows facing mostly south, south-east and south-west, and one building with a curtain wall façade. The results showed that:

- blinds were moved more frequently on the south façade than on any other façade;
- there was a large variation in the amount of blind usage, some blinds hardly being changed, while some others were used over 70% of the days studied;
- the typical daily blind operating rate of 35–40% on south façades reported by Inoue et al. [22] for Japanese workers was similar to the rate exhibited by British office workers;
- blinds were mostly operated in response to the sun position, a horizontal angle of incidence between 25–70° triggering closing;
- people mostly put up their blinds either early in the morning or at the end of the day;
- short periods of sunshine had little effect on the blind movement; however, long periods of sunshine of over 1 h generally triggered the blinds to be lowered;
- fear of overheating caused some occupants to keep their blinds lowered at all times (even though there was no conclusive evidence to suggest that blind movement was influenced more by either thermal or visual considerations, the authors speculated that it was more likely that glare caused the blinds to be changed);
- people with poor outdoor views were less likely to manipulate their blinds;
- in the buildings where desks were located further from the window there was less blind manipulation.

Foster and Oreszczyn [26] examined the assumptions in the occupants' use of blinds presented above. Using a video camera to record the blind positions, the researchers compared the assumed use with the actual use from monitored data of blind usage in both summer and winter in three buildings located in the UK, and examined the effects of façade orientation, sunshine, and electric lighting on blind usage. Results confirmed previous findings that on average about 40% of all four façades of an office building are usually occluded by blinds, which results in a reduction in daylight equivalent to an unobstructed glazed area of about 70% of the building's façade, assuming that 20% light penetrates into the interior when blinds are fully drawn. The authors concluded that the way the occupants used their blinds did not seem to be primarily affected by the solar availability as often modelled, and the relation they found between orientation and window blind occlusion was not significant. In the three buildings studied, the majority of the blinds were kept down most of the time.

Reinhart and Voss [27] monitored ten German south-west facing offices with no air-conditioning from March to December. The private and semi-private offices were equipped with a closed-loop dimming lighting control system with on/off manual switching, and an external two-component photocontrolled blind system with a manual override option which, when used, disabled the automatic system for 2 h. The automatic blinds, which were monitored with the help of a video camera on an adjacent building, were set to fully lower or retract when the illuminance on the building façade was above or below 28 klux. When lowered, the slats of the bottom blinds were fully closed, while the slats of the top blinds were kept horizontal for daylight admission.

The results showed that the fourteen participants in the study very rarely used the manual override option to close the blinds when they were automatically retracted [27]. Quite the reverse, however, was their reaction when the blinds lowered automatically, which prompted them to retract back the blinds on 88% of these occasions (the manual override was considered to be a correction of the control algorithm of the automatic system if it occurred within 15 min after an automatic blind adjustment). The occupants used the manual override if the direct solar radiation on the workplane was below 50 W/m^2 after the automatic lowering, a threshold which confirms the previous finding of Inoue et al. [22]. Reinhart and Voss [27] found that blinds were usually manually closed when the illuminance on the façade of the building was above 50 klux (~450 W/m^2), and retracted at 25 klux (these were manual adjustments that occurred unrelated to an automatic blind adjustment and were not considered to be a correction of the automatic blind system). The authors concluded that the occupants selected the position of their blinds consciously and consistently, and that individuals were more likely to accept the opening rather than the closing of the blinds. The automatic blind system prompted the users to manipulate the blinds, but it is not known if the same users would have manipulated their blinds with the same frequency if the blinds had been only manual.

Rather than examining new data on blind use, Sutter et al. [28] developed a predictive model to determine recommended blind positions to achieve visual conditions for comfort derived from other research. They estimated that when the illuminance on the window plane exceeds 8000 lux and there is no direct sun entering the room, the blind needs to be closed to satisfy the performance criteria set by three previously developed visual performance evaluation methods (Blackwell chart [29], Cornell formula [30], and Moon & Spencer [31]). The authors also concluded that when direct sun penetrates into the room, the blind should be tilted downward (view of the ground from the interior) rather than upward (view of the sky from the interior) because visual comfort decreases for the latter configuration. The 8000 lux criterion was developed based on a total of 22 photographs of a daylit office located in France, which were taken under both sunny and overcast sky conditions with various window blind arrangements. Each scene was analysed based on screen luminance values and measured illuminance on the window pane to identify the optimum blind position that would satisfy all the three above-mentioned formula.

As part of the same study, the authors also predicted the probability that a certain blind configuration would occur throughout the year at five different locations in Europe [28]. These predictions, based on their model, showed that latitude should play a significant role in the probability of blind utilization, with a lower rate for the northern latitudes, where the probability that the blind would be left in a horizontal position was about 65% compared to only 40% for the southern latitudes. More research by the same authors is in progress to identify whether the 8000 lux criterion is related to the users' behaviour when confronted with similar glare and visual discomfort situations. As the authors noted, "if such a simple parameter was linked to discomfort glare evaluation, it could be useful for those who elaborate automated blinds" (pp. 254).

2.5. Preferred light levels in daylit offices

Escuyer and Fontoynont [32] adopted a semi-directed interview method to survey French participants' preferences toward their working environment, office lighting control system, lighting remote control, and office blinds. Desktop illuminance measurements and photographs of the offices were taken after the interview. Forty-four percent of the respondents said that "*having plenty of daylight*" was one very important characteristic of an office. The results showed that for people working on computers, the preferred light levels were between 100–300 lux, while for people working less time on computers, preferred light levels were higher, 300–600 lux. When people chose to dim the electric lights, it was either because they preferred to take advantage of the daylight, or they wanted to save energy, or their eyes hurt because of the high illuminance levels. Many occupants chose low electric light levels when daylight was available, in order to benefit from daylight. Given the choice, people added on average between 150–400 lux of electric light to the daylight available on their desk, and many of them added no more than 280 lux, even when daylight levels were below 100 lux.

For 12 participants whose north-east private offices included both daylight- and occupancy-linked on/off lighting and manually controlled task lighting (the subjects could adjust the light level and the time delay according to their preference), Escuyer and Fontoynont [32] examined the balance chosen between daylight and electric light during winter. Sixty per cent of the participants were satisfied with the general on/off lighting providing 270 lux, and the desk lamp providing between 230 to 730 lux. Three levels of illuminance from general lighting were preferred: less than 250 lux, around 300 lux, and over 500 lux. Forty-two percent of the subjects found the combined system (on/off lighting plus task lighting) to be more comfortable compared to only general lighting, mainly because this way they felt that they had partial control over the lighting. Thirty-three percent of the subjects found the combined system to be less comfortable than having only general lighting, mainly because they disliked the type of task light that was provided (the authors noted that control over the colour temperature of the task light might have improved the subjects' overall impression about the combined system). Twenty-five percent of the respondents neither liked nor disliked the combined system.

The illuminance levels reported by Escuyer and Fontoynont are significantly lower than the levels reported in an earlier study by Begemann et al. [33] who found that in four north-facing offices in the Netherlands people added between 300 and 1200 lux of artificial lux to all daylight levels throughout the year. A total of 170 subjects participated in full-day sessions of normal office routines. All subjects had the possibility to adjust the workplane illuminance, wall illuminance and colour temperature over a very wide range (200–2000 lux, and 2800–5000 K) at any time throughout the day according to their need and preferences, however, they were required to set their preference every hour when the electric lights were automatically switched off. Results showed that individual settings differed greatly from one person to another, which the authors believed to depend on the individual's sensitivity to light, quality of sleep, biological clock, and degree of well-being and comfort. Preferred artificial lighting levels were dependent on daylight levels and weather type, and independent of age and gender. Under overcast sky the participants added on average about 1000 lux of electric lighting, while on clear sky days the increase was between 500–1200 lux, with decreasing daylight levels from 2000 to 0 lux. The high addition of artificial light in Begemann's study showed a morning, midday and afternoon effect, which the authors speculated to be a result of the need of people for biological stimulation from indoor lighting to regulate their circadian rhythm according to the daylight cycle.

Begemann et al. also found a relationship between the desktop daylight illuminance and the preferred colour temperature [33], which suggests that at low daylight levels (500 lux) the average preferred colour temperature was around 3300 K, while at higher daylight levels (1500 lux), the preferred colour temperature increased to 4300 K. They also found that vertical planes and illuminance ratios were "important to create the optimum luminous environment" and that keeping a constant working plane illuminance would not meet occupants' needs and preferences.

Halonen and Lehtovaara [34] reached a similar conclusion after observing how 20 subjects working in an east facing office in Finland adjusted their dimmable lighting system at 15-min intervals over a 3 h period. They found that the difference in light levels set by the participants were extremely large, varying between 230 and 1000 lux, and that most subjects had not tried to maintain a constant level of illuminance at their desks. Some subjects even increased the level of the electric lighting with increasing daylight levels, behaviour which was attributed to the high ratio between the vertical illuminance available at the back of the room and the vertical illuminance near the windows, and a high vertical to horizontal illuminance ratio.

Laurentin et al. [35] looked over two months in the spring (March and April) at how people control artificial lighting and daylighting in response to different amounts of natural lighting. The 30 French subjects, who were tested on computer tasks for three periods of 30 min, each chose different levels of illuminance based on their distance from the window. During the experiments, which took place in two east-facing side-by-side offices from 3 to 5 PM in the afternoon to avoid direct solar penetration, a set of two participants were successively seated at three workstations located at various distances from the office window. At the end of each test, the participants also had to respond to a series of questions assessing their perception of the visual environment.

Results showed that when seated near the window, 57% of the participants did not add any electric light, while the rest added between 20 and 450 lux [35]. In the middle of the room, 40% of the participants did not add any electric light, while the rest added between 30 and 580 lux. Far from the window, where the daylight levels were quite low (120 lux), 30% of the participants chose not to add any electric light, while the rest added between 20 and 350 lux. This showed that the levels of illuminance on the workplane depended greatly on the position of the occupant relative to the window, which suggests that people accept to work under very different lighting conditions in relation to their position. The workstation located near the window was the location the most appreciated by the occupants, even though the maximum light level recorded here was very high (1200 lux) compared to 500 lux, the maximum recorded at the location furthest from the window. Overall, a maximum of 500 lux was added by the participants to the available daylight even when the daylight illuminance was below 100 lux, despite the fact that the maximum level that could have been added from electric lighting was 1200 lux.

Light source type also appears to influence judgements of visual preference and attractiveness of the lighting environment [36]. Twenty French office workers evaluated the visual comfort perceived while reading the same text under three light source types: daylight, electric light and combined lighting for the same constant illuminance of 300 lux maintained throughout the tests. The experiments were conducted during both summer and winter and included a 1 h adjustment period to the lighting and thermal conditions of the office environment, followed by a 45-min session of text reading during which each light source illuminated the text for 15 min. At the end of each session, participants were asked to choose their preferred lighting conditions by adjusting either the blinds, the electric lighting or both. The participants perceived the 300 lux illuminance level as pleasant under daylight and unpleasant under electric light, but in general the preference evaluations showed that they preferred a lower illuminance level under electric light alone than under daylight or mixed lighting. The authors speculated that this preference was most likely linked to the way the light was distributed in the space under the three light source types, with a high difference in contrast between the area close to the window and the back of the room when illuminated by daylight only, and the participants perceiving lower light levels on their desktop when illuminated at a lower angle from their left-hand side by daylight alone, than when illuminated by direct electric lighting only. Nonetheless, when the participants were allowed to choose their own visual environment, under daylight only the average illuminance level on the desk chosen was about 300 lux; for electric light only the average illuminance was about 500 lux; and for mixed light the average illuminance was 560 lux.

The authors also noted that when thermal conditions are not pleasant and accepted, lighting conditions were also very likely to be viewed as unpleasant [36]. In addition, the sky condition and the daylight correlated colour temperature influenced the visual and thermal perception and a gender difference related to the visual and thermal comfort was also found. Overall, women were more sensitive to thermal conditions, while men were more sensitive to sky conditions.

Roche et al. [37] reported on the findings of a survey conducted in the UK in 16 daylit buildings with the participation of 270 office workers. The surveys included questionnaires administered to the facility managers and about 20 occupants in each building in the winter and summer. For each building they calculated the design average daylight factor (ADF). The ADF is used to define the overall amount of daylight in a space, and is calculated as a function of the angle of sky visible from the centre of the window, the glazing area and transmittance, and the area of all room surfaces (ceiling, walls, floor, and windows) and their average reflectance.

The results showed that the ADF index is a useful predictor of the general daylight level in a space, as well as of the general level of combined daylight and electric lighting [37]. People were more likely to be dissatisfied with daylight when the design average daylight factor (ADF) was over 5%. High daylight levels, with ADFs above 5%, generated complaints of sun and glare. ADFs between 2% and 5% resulted in the highest mean levels of satisfaction. The respondents indicated a stronger preference for combined lighting (daylight and electric light) in the winter than in the summer. The preference for combined lighting decreased with the distance from the windows. High levels of daylighting were generally viewed as more unpleasant than lower levels, which suggested a strong psychological link to glare and overheating.

2.6. Visual comfort and glare

Despite several efforts, successful prediction of discomfort glare from daylighting has not yet been achieved in a form useful for widespread practical application. Two reasons for this are a lack of attention to the wide individual variability in discomfort glare response [38,39], and the importance of the view outside the window [40].

Hopkinson [41] developed a Daylighting Glare Index by modifying the formula for the Glare Index for small glare sources to large glare sources such as windows. To validate his calculation method, he asked groups of participants to make judgments of the level of discomfort present in a daylit space due to glare. He found that people tolerated daylighting glare better than glare originating from other light sources. Generally, participants did not complain about glare from windows, which suggests that people have a high tolerance for mild glare in real daylight situations. Hopkinson speculated that this may be either because people are used to daylight glare and do not consider it to be stressful, or they value the view out much more than they are likely to complain about glare. One of the most common comments received from the participants was related to the view outside the window, which they said had affected their judgment about the degree of glare in the space. Hopkinson speculated that when a pleasant view is seen from the window, the tolerance for higher glare levels increases.

Iwata et al. [42] investigated, through subjective evaluations of glare in real rooms, the applicability of the daylight glare index (DGI) and unified glare rating (UGR) to actual windows. The experiments were conducted in December and January in two identical rooms on the 11th floor of a building in Tokyo, Japan, one facing north, the other facing south, and included the participation of 46 students who evaluated perceived glare from three positions relative to the window. The subjects assessed the glare while reading on a desk illuminated by fluorescent lighting at 500 and 1000 lux, looking at the window and responding to a questionnaire providing a glare acceptability scale. Whenever direct sun reached the location where the occupant was seated data was excluded from the analysis.

Both the DGI and UGR were found to be insufficient to predict perceived glare under all conditions [42]. The weight of the background luminance used in both calculation methods was found to be too large and ‘‘the effect of the total amount of light coming into the eyes’’ was shown to be a significant variable in the case of large light sources such as windows. The distribution of luminance on the window surface, as well as the line of sight when looking toward the window were also identified to have a significant effect on the glare sensation vote (GSV). The authors also found that the relation between the glare sensation vote and glare acceptability was not dependant on room orientation, task illuminance, or position of the subject in the room. The percentage of people dissatisfied (PPD – people who judged the glare not to be acceptable) was directly proportional to the glare sensation vote (GSV).

Identifying the building and workplace factors associated with the assessment of visual comfort in daylit offices was the objective of a survey of 83 subjects in nine daylit office buildings in USA and Germany [39]. The results of the survey, which took place over two periods of three weeks during summer and fall, showed that 75% of the workers preferred daylighting over electric lighting, and 94% of them considered the windows to be very important. Glare was less of an issue or was even ignored in the west- and east-facing offices when pleasant views from the windows were available. The survey results also indicated that the level or presence of glare experienced by the subjects was not correlated with the window orientation, and the east and west-facing windows showed no higher perceived glare levels than the south-facing windows. The presence of shading devices, computer screen contrast and orientation relative to the window (52% had the screen perpendicular to the window), and people's age were also not correlated with the assessment of the glare in the daylit work environment. The authors speculated that having access to windows that provide attractive views may be far more important than any perceived discomfort glare associated with them; indeed, ‘‘. . .view content and the experience of a connection to the outside world appear to increase occupant tolerance towards glare from windows'' (pp. 454).

Nazzal [43] proposed a new method for the calculation of a daylight glare index (DGI_N) applicable to non-uniform light sources, which takes into account the direct sunlight component along with the diffuse daylight. This new index was introduced as an improvement of previous glare evaluation methods developed by Chauvel [44,45] and Hopkinson [41], which were developed based either on experiments with uniform light sources, or assuming no direct sunlight in the space. To test the applicability of his new method, Nazzal [46] conducted measurements in a south facing test room in Helsinki, Finland, in April and June, every hour from 11 AM to 1 PM when peaks of vertical illuminances occurred. He then used Radiance simulations to model the experimental conditions and provide the luminance values under clear sky conditions including direct sunlight needed for the DGI_N calculation, and compared the newly calculated index with Chauvel's glare index provided by the Radiance glare calculation program. The DGI_N values did not increase with window size to the extent predicted because of the adaptation luminance which counteracted the effect of the window size. However, as expected, the DGI_N-predicted glare sensation increased with the vertical illuminance on the window and the increase in solar angle, contrary to the predictions from Chauvel's daylight glare index, which behaved the opposite. Nazzal explained that, contrary to Chauvel's evaluation method which depends mostly on ''the existence of the sun down close to the horizon and thereby to the sunrays entering the room'', the new method is mostly dependant on the vertical illuminance of the daylight source itself, the vertical window. However, this evaluation of the new method did not test the DGI_N in relation to occupant ratings of discomfort.

In her study on lighting quality in office rooms incorporating daylighting systems, Velds [47] developed procedures for overall lighting quality assessments, including visual performance and visual comfort. Three user-acceptance studies including a total of 84 subjects were conducted in the Netherlands and Germany in 1:5 scale models of existing rooms under artificial sky, and full-scale rooms under real intermediate and overcast sky, to validate these procedures. Twenty-one subjects were asked to evaluate the perceived degree of discomfort glare and the acceptability of the perceived glare under various lighting conditions generated by various daylighting designs, including regular window openings as well as windows incorporating various daylighting systems installed in the upper part of the window (e.g. holographic optical elements, laser-cut panels) while the lower part of the window was covered by a blind. One important difference between this work and the studies above is that participants were directed to evaluate discomfort glare, while view was held constant. This permitted examination of discomfort glare independent of view. Twenty-three subjects participated in an experiment which identified problems associated with the use of automatic lighting control systems and exterior blinds, and 40 subjects participated in a glare assessment experiment conducted under real sky conditions to validate glare assessment results obtained under artificial sky.

Velds reached the following conclusions and recommendations [47]:

- discomfort glare was less acceptable for subjects working on computer tasks than for those working on horizontal reading and writing tasks;
- perceived degree of discomfort glare near the façade of the building was higher than that at the back of the room;
- glare indexes developed by previous research to predict discomfort glare from large uniform glare sources positioned on the line of sight [41,42] were found not to be applicable to windows with daylighting systems (such as light shelves, louvers, controlled blinds) because these light sources cause more glare than uniform light sources due to their non-uniform luminance distribution;
- lighting and blind control systems might be more acceptable if they would include a user interface;
- the main complaint of the users assessed in Velds' studies was their inability to personally overrule the systems;
- simple blind systems realized an equal or higher lighting quality than innovative daylighting systems in the predominantly cloudy climate studied and had the advantage of being easy to use and install.

Velds also recommended that daylighting systems be applied for visual comfort reasons rather than visual performance reasons and suggested that they should preferably be located in the upper part of the window to reduce perceived discomfort glare at the back of the room [47].

3. Lighting and shading control systems

The satisfaction of occupants is a necessary condition for acceptance of technical solutions combining daylight and electric light. The following summaries outline several research studies of occupants' acceptance of user- and photocontrolled lighting and blind control systems.

3.1. Lighting control systems

Based on field studies of electric lighting switching behaviour, Hunt [48] developed a switch-on probability equation for daylit multi-occupant spaces and found that on arrival this probability is strongly correlated with the minimum workplane illuminance, and the outdoor and indoor daylight levels. In most continuously occupied spaces investigated, lights were either on or off for the entire day, which led the author to conclude that generally, once the electric lights are turned on, they will remain on until the space is vacated. The data that generated this conclusion originated from 6-month monitoring through time-lapse photography of three multi-person offices, two school classrooms, and two open-space teaching spaces. No season-related switch-on dependency was found and the location of the light fixtures within the room (in control groups or relative to the window) was not a factor. Generally, light fixtures were switched on or off together.

Following on Hunt's work, Love [49] investigated electric lighting switching patterns in south and north oriented offices and found that switching patterns depended on the occupant as much as on the indoor daylight availability. The author noticed that while some people used the electric lights only when the indoor daylight illuminance decreased below a threshold, others kept their lights on throughout the whole the day regardless of the daylight levels, and switched the lights off only when leaving the office for a longer period of time (mostly when leaving work for the day). The results of this study, which was carried out in six south-facing and two north-facing offices in Calgary, Canada, in April, May, October and November also showed that office occupants may be satisfied with lower levels of daylight than the light levels usually required from electric lighting. In this study, in 80% of the cases the daylight illuminance before a switch-on event occurred was between 210 and 380 lux, and in 50% of the cases even lower daylight levels that ranged between 150–260 lux were accepted.

Reinhart and Voss [27] also reported that in their field study 86% of the total switch-on events occurred upon arrival to work, however, the indoor daylight illuminance level that triggered this switch-on varied widely between individuals, ranging from 38 to 410 lux. The authors also noted that sometimes occupants did not switch off the electric lighting even when the indoor daylight illuminance was rather high because "they failed to notice that it was on" (pp. 253). The average switch-on probability function from 10 private offices monitored in this study was consistent with Hunt's function, however, individual behaviour showed clear evidence of considerable spread between individual preferences.

A field study conducted from December to March by Maniccia et al. [50] in 43 US daylit offices with various orientations also examined user-controlled lighting systems. In this case, however, the authors investigated the impact of manual switching and manual dimming controls on occupant behaviour and attitudes, as well as on window blind usage and energy consumption. Electric lighting in each office was controlled via a centralized building system which turned the lights off automatically after a 30-min absence from the space. Upon re-entering the office, if wished, the occupants could restore the lights back on via either a wall-mounted dimmer located at the door or a portable desk-dimmer.

The results revealed that overall, 74% of the occupants used their dimmers to adjust their lights; however, in the offices with a north- or east-orientation lights were more often turned off than in the offices facing south or west [50]. Occupants appreciated having dimmers located on their desks, and removing the desk-dimmers resulted in fewer dimming adjustments. A questionnaire revealed that people did not use their light dimmers to save energy (despite working for an organization concerned with environmental issues), but rather to accommodate for the tasks being performed. However, data showed that light levels did not vary with the type of task. Few respondents stated daylight as being a secondary reason for their electric lighting dimming action. Generally, 18% of the respondents did not describe accurately their own actions (some claimed to have adjusted the lights when in fact they never did, while some others claimed the reverse). Occupants generally selected vertical blind configurations that avoided direct sunlight, but admitted daylight. Blinds were adjusted more often on the west façade followed by the south façade, and the blind slats were adjusted more frequently than the blind position (from fully open to fully closed across the face of the window). Most of the times when blinds were closed, the lights were fully on. Overall, people adjusted the position of the window blinds three times more often than the electric lights.

Escuyer and Fontoynont's [24] interviews included questions about the acceptability of the lighting systems in offices. Each building incorporated a different type of lighting control system as follows: Manual control fixed on the wall, which allowed storage of lighting levels and lighting scenarios; semi-manual control combined with automatic daylight-linked dimming with manual choice of reference illuminance level and occupancy sensors; automatic dimmable lighting control (photocell controlled continuous dimming with a 15% light base load and 550 lux target illuminance). 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. However, where the occupants had remote controls, none stored personal lighting scenarios or knew this was possible. They used only pre-set lighting scenarios, which were easy to select on the control. Twenty-nine percent of all subjects considered manual dimming to be their system of choice; 22% preferred automatic dimming with manual choice of illuminance reference level; few subjects preferred a fully automatic system (not to have to think about the lighting). In the building with the photocell control, 69% of the subjects had not noticed any change in light levels during the day. Among these, half did not even know that an automatic lighting system was in place. In the other two buildings, 48% of the subjects changed the electric lighting levels according to daylight levels, 12% changed the levels according to the nature of their activity, and fewer reported changing the lighting in response to mood or eyestrain.

Ease of use of lighting controls and the occupant awareness and training related to these controls are essential factors in obtaining the most comfortable lighting conditions along with reduced energy consumption. Following a study which included half-day visits to 25 open-plan office buildings equipped with either local control, time control, occupancy detection, photocell control or lighting energy management systems, Slater [51,52] reported that where controls were difficult to use, occupants chose lighting levels that reduced the need for using the controls and increased the energy consumption. When the occupants perceived that a particular set of environmental conditions was imposed upon them, the control systems were deactivated. Daylight-linked switching was accepted without complaints in circulation areas and atria, spaces that were considered not to be owned by anyone. At 4 out of 6 sites that had photocontrolled lighting in the office areas, the systems had been deactivated to reduce occupants' complaints. Generally, the buildings with complex lighting control systems were not successful in achieving energy savings and satisfying the occupants, and the ones that had simpler controls were viewed as superior from both points of view.

Following on the above study, Slater et al. [53,54] and Carter et al. [55] reported on a survey conducted during 1-day-visits in April and May, and one subsequent winter visit in January, in 11 deep- and shallow-plan office buildings in the UK to investigate how automatic lighting controls are being used. In 10 out of the 11 buildings, electric lighting was managed via a central computer operating groups of two to nine light fixtures controlled either by local hand-held or wall-mounted controls, which enabled on/off switching or dimming. In the remaining building, individual controls were installed in each workstation. The one-day surveys included measurements of the luminous environment collected in up to 30 workstations in each building and interviews with the facility managers as well as a few employees in each surveyed area to assess the occupants' awareness, knowledge and satisfaction with the lighting control system.

Measurements showed a high preference for daylighting and electric light levels below the current standards [55]. While the British Office Lighting Guide recommends 500 lux for general office lighting, between 300–500 lux for computer workstations, and 750 lux for deep-and open-plan offices, in over half of the shallow- plan offices the occupants chose average levels of task illuminance below 300 lux, while the average illuminance in the deep-plan buildings was below 750 lux. The light levels throughout the space varied with the distance from the windows, but in all buildings the electric light load was below 100% of full lamp output. The average electrical load was 53% in January and 43% in April and May, much of the electric lighting being turned off during work hours. However, half of the lighting installations had hardware problems (ballast, lamp or control unit failures), blinds were not adjusted to maximize daylight admittance and were used only to prevent glare, and there was great dissatisfaction among occupants regarding the light levels in the areas where a large number of light fixtures were grouped together. No such complaints were encountered in the building with individual controls. Some facility managers found the automatic control systems to be too difficult to use, which often resulted in features of the systems being deactivated.

The above study was followed by a third investigation two years later, from January to March, which included a questionnaire administered to the occupants to investigate luminous conditions and user attitudes toward the lighting control systems [56–58]. Seven of the 14 UK office buildings visited incorporated user-controlled lighting (191 respondents), whereas seven had no user control (161 respondents). Overall, including the January visit 2 years earlier, the total number of questionnaires completed by the occupants in the various buildings investigated was 410. The results showed that the installations that had no user control accomplished better workplane illuminance and luminance ratios according to current recommendations. However, users viewed the installations that they could control more positively, even when the lighting conditions did not meet current lighting practice guidance. 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.

The installations that permitted user control operated at 50% of maximum output, which suggests a great potential for energy savings without affecting negatively the occupants' perceived lighting quality. However, the authors also noted that there is reason to believe that the presence of controls and the people's inability to use them due to negative perceptions of the degree of control that they have over them (i.e., controls being too difficult to use; not sure which luminaires they could control; fear of conflict in shared spaces) may make them more likely to respond negatively to an unwanted daylighting condition than when no controls are present. The satisfaction with the amount of daylight reaching the workstation was strongly correlated with the perceived level of control over it.

Similarly, Bordass et al. [59] emphasized the importance of providing the users with the control of daylight-linked lighting and blind control systems by giving them easy access to them and by designing simple and easy to use interfaces. They have found that automatic lighting installations that did not allow individual control for each workstation generated conflict situations between the occupants, which triggered the systems' deactivation. Moreover, whereas in individual offices occupants have the option to operate the blinds according to preference, in the open-plan offices surveyed this was not the case; therefore, the blinds-closed/lights-on scenario was very common. Especially in the buildings with tall windows, this was done intentionally by the occupants in order to keep the photocontrolled lights on, because of complaints from people seated further from the windows and not in direct control of the blinds, who often complained about glare from the upper sky. As the authors noted "while not energy-efficient, blinds closed-lights on was the easiest and most common way of obtaining harmony" (pp. 253). Among other problems associated with the use of photocontrolled lighting, the authors also noted the furniture layout (which generally did not allow the occupants to change the position of the VDT terminals to avoid glare), and the tinted window glass, which prompted occupants to keep the lights on in order to "cheer the place up" (pp. 256).

Although having control over the work environment is often reported as being important to employees [60], control over lighting is not always the highest priority. Ne'eman et al. [61] surveyed the 162 office workers in the USA about their satisfaction with the controls of lighting and window shading and other environmental conditions, such as temperature, ventilation, privacy, ability to control sound from the outside the building, view form the window et cetera. These occupants rated the window views and the control of window shading and lighting among the least important features of the work environment. The control over these systems was thought to be "of very little importance" by at least 20% of the respondents. The ability to control the temperature, however, was ranked among the most important features by most subjects. The authors noted also that people were typically inclined to consider very important the features that they were mostly dissatisfied with, while the ones that they were satisfied with seemed to be perceived as less important. The satisfaction with the workplace also seemed to depend on the location of the occupant in the building, the window orientation, the amount of time spent at the workplace, the gender and the age of the respondents.

3.2. Shading control systems

Very few investigations have looked specifically at the issue of occupants' acceptance, preferences or satisfaction with photocontrolled shading systems. Most of the previous work has mainly focused on the trends and patterns of use of manually controlled blinds as presented above, or on their thermal transfer and impact on the building heating and cooling loads [62–65].

In the study by Inoue et al. [22] discussed above, which included a questionnaire of about 800 building occupants in two high-rise buildings located in Japan, the windows were provided with time-controlled automatic blinds based on orientation and season, which could also be adjusted manually by the occupants. The researchers reported that about 60% of the occupants thought that the automatic blinds were a valuable addition to the office environment, while only 10% were against it. When asked about what they liked or disliked about the automatic blinds, the most common responses were that: "the blinds operate even when it is not required", followed by "the blinds do the work themselves", and by "the blinds do not operate when it is required". The last response, as the authors noted, is an important factor to take into consideration especially because the blinds were set to react at only 60 W/m^2, which is a very small value of solar radiation. Bordass et al. [59], working in the UK, also found that in the buildings incorporating automatic photocontrolled blinds a large majority of people were annoyed mainly because the blinds were perceived to operate at the wrong time. The need for controls to override the automatic settings was seen as essential by most occupants.

This aspect was also indirectly confirmed by Reinhart and Voss [27], in which out of a total of 3005 automatic blind manipulations which occurred from March to December in a German building, 45% were re-adjustments done manually by the fourteen participants in the study, who chose to override the control algorithm of the automatic blind system. In 88% of these cases, the occupants retracted back the blinds when the blinds lowered automatically based on their set-point of 28 klux illuminance on the building façade. The occupants mostly accepted the automatic lowering of the blinds only when the illuminance on the façade of the building raised above 50 klux.

3.3. Integrated lighting and shading control systems

In a mock office, Vine et al. [66] evaluated workers' response to a prototype integrated photocontrolled venetian blind/dimmable lighting system designed to optimise daylight admission in an office building. Fourteen workers aged between 40–49 were tested for 3 h over a 2-week period in July under mostly sunny conditions during which the blind/lighting system was activated to operate for 1 h in three modes of operation: Manual on/off operation of lighting and blinds during which users were allowed to adjust the blinds and lights according to their preference; Automatic operation of the integrated system with a design illuminance 540–700 lux, 11% base dimming load with turn-off capability after a 10-min delay with sufficient daylight, and non-retractable blinds designed to block direct sun; and semi-automatic operation with user-preference setting of blinds and lights via a remote control, which allowed users to set the indoor illuminance level between 240–1650 lux.

The results suggested that occupant satisfaction increased with the semi-automatic and manual modes of operation [66]. Eighty-five percent of the participants judged the overall lighting to be comfortable in the manual mode, while 78% felt similarly about the semi-automatic mode, and 57% about the automatic mode. However, in the manual mode, in contrast to the other modes of operation, relatively more people were dissatisfied with specific sources of brightness and glare (although the frequency of complaints was still low): 14% found the lighting fixtures to be too bright; 7% complained about glare from the electric lights; and 15% complained about glare from the windows. A large number of people were satisfied with having control over the blinds and the lighting (78%), and 90% of the occupants found the manual control mode to be "just right". Overall, the results of this study showed a trend for high preferred illuminance levels with 57% of the subjects being comfortable with about 570–700 lux in the automatic mode, while 71% preferred 680 lux in the semi-automatic mode. These illuminance levels contrast significantly with the illuminance chosen by the occupants in the manual mode of operation, which on average ranged between 850 and 2200 lux in the morning and between 800 and 1300 lux in the afternoon. However, while between the automatic and manual modes of operation the preference for high illuminance levels was evident, in the semi-automatic mode, out of the 60% of the subjects who stated that they would prefer more light, none set the system to provide it.

4. Conclusions and suggestions for future research

The literature review reveals the limitations of current knowledge about how people respond to daylight, and particularly how they respond to automated photocontrolled lighting and shading controls. Current knowledge may be succinctly expressed as follows:

- there is a strong preference for daylight in workplaces, associated particularly with the belief that daylight supports better health;
- when both daylight and electric light are used, people overestimate the contribution of daylight to the overall illumination, and the degree of overestimation increases with the distance from the windows;
- preferred window size probably varies for different settings, but in general larger windows are preferred. Optimal window size for offices appears to be in the range 1.8–2.4 m in height

and somewhat wider than taller, to provide a wide lateral view;
- when manually operated shading devices are available, people tend to set them and then rarely to change them;
- preferred illuminance levels in offices with daylight are very variable from one person to another. In addition, desired quantities of additional electric light vary with the type of task and the distance from the window;
- discomfort glare from windows is less problematic than daylighting glare index models would predict, although it too is very variable from one person to another. The degree of discomfort reported depends in part on the quality of the view outside the window, as well as on the distance from the window and on the task;
- photocontrolled lighting systems have best acceptance when there is individual override control provided to users. Fully automated systems have low occupant acceptance, and are sometimes too complex for facility managers to maintain;
- photocontrolled shading devices also need overriding occupant controls if they are to be accepted;
- integrated controls for both lighting and shading can be acceptable, but are most accepted when a degree of manual control is provided;
- control systems are more acceptable to both occupants and facility managers when they are simple and easy to use.

Improving the energy-efficiency of commercial building lighting should include better use of daylight, but that will require the development of control systems that result in luminous conditions that are suitable to occupants. The summary above provides guidance to researchers and policy makers concerning the gaps in our knowledge about what constitutes a suitable control system. Such a general summary reveals in particular that we do not yet know what control system features would be most acceptable, nor what range of luminous conditions the system should permit.

Specific research gaps that should be investigated include the following:

- Systematically study the luminous conditions that individuals create using manual lighting and shading control systems, to determine whether automated control algorithms based on actual use can create acceptable conditions. Laboratory experiments would be the most efficacious starting point.
- Conduct systematic comparisons to establish the generality of recommendations for various orientations, weather conditions, times of day, latitudes, seasons, building and window types, cultures, and individuals. The studies cited here preclude confident generalizations because they are predominantly from northern, industrialized countries. This will probably require co-ordinated field studies with multiple sites.
- Expand the range of luminous conditions studied beyond simple horizontal illuminance. The absence of reporting of other metrics precludes confident conclusions about preferred vertical luminances, luminance ratios, or other metrics.
- Study the relationship between discomfort glare reports, use of the window view, satisfaction with overall luminous conditions, and chosen luminous conditions in relation to outdoor conditions, to assess the trade-off between access to view, glare control, and lighting control for energy efficiency. Automated controls based on maintained illuminance alone are unlikely to achieve a balance between these considerations.
- Compare automated systems using behaviourally-derived algorithms, to semi-automated systems (i.e., add manual over-ride controls) to determine the incremental benefit of allowing individuals to modify the conditions. This work should begin in the laboratory, but should be replicated in the field.
- Compare the luminous conditions chosen by individuals to the conditions that they report that they want. Discrepancies might indicate areas to target in training people to use controls.
- Analyse the use of various control interfaces and interface locations (wall-mounted; remote control; computer screen). This is most effectively done in a laboratory setting.
- Analyse the energy use resulting from the choices made by individuals using manual controls, in contrast to automated or no controls. Both laboratory and field data may be used for this purpose.
- Study the potential for conflict in open-plan spaces having manual or semi-automatic lighting and shading controls, to identify system designs that minimize conflict while maintaining energy savings and widely acceptable lighting conditions. Field studies, possibly including interventions, are likely to be most effective in addressing this question.

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