Pramod Bhusal, Eino Tetri, and Liisa Halonen. 2006. Quality and efficiency of office lighting. In: Proceedings of the 4th European Conference on Energy Performance and Indoor Climate in Buildings and the 27th International AIVC Conference (EPIC 2006 AIVC). Lyon, France. 20-22 November 2006, pages 535-540.

Quality and Efficiency of Office Lighting

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ABSTRACT

The use of artificial lighting in the office buildings has significant contribution on total energy consumption of the building. With the increase in the price of energy and public becoming more energy conscious, more attention has been given to the energy efficient lighting. On the other hand, with increased trend to go for efficient lighting systems, the quality of lighting has to be maintained. Efficient lighting and quality lighting are not contradictory to each other and the better understanding of these two terms would be helpful to promote the improvement of the energy efficiency.

The present paper first gives an overview of the different factors related to the quality of lighting in office environment. Different studies about the occupant's preference on light level, light distribution, colour, and other quality aspects have been summarized. The effect of efficiency measures on lighting quality is well discussed. Use of occupancy sensors, application of daylight and dimming according to daylight are some of the promising energy saving techniques. The result of the energy consumption measurement carried out in office rooms with different lighting control systems and their comparison shows that significant improvement in efficiency can be made without compromising on quality.

KEYWORDS

Office lighting, lighting quality, Lighting efficiency, Daylighting

INTRODUCTION

A substantial part of the populations of the industrialized world spend their working lives in offices. Lighting is the substantial energy consumer and a major component of the service costs in offices. The primary function of office lighting is to enable workers to see, in order to perform their tasks comfortably and safely. On the other hand, with the increase in the price of energy and with the public becoming more energy conscious, more attention is being given for the energy-efficient lighting. With the increased trend to go for efficient lighting systems, concentration should also be given to maintain the quality of lighting.

Modern lighting system today should meet the energy-efficient requirements for the conservation of the limited energy resources, while without compromising on the quality. Significant savings in energy consumption, and therefore cost, of providing lighting without affecting the visual comfort and task performance of occupant can be achieved by applying an energy-effective-design approach to lighting installations. This needs the better understanding of different quality and quantity aspects of lighting. Use of occupancy sensors, application of daylight and dimming according to daylight are some of the promising energy saving techniques. With advanced light sources and control technology combined with natural lighting source (daylight), we can achieve significant improvement in efficiency as well as visual comfort and task performance of occupants.

LIGHTING QUALITY AND OFFICE WORK

Lighting quality has different aspects and it involves much more than just visibility. Veitch &Newsham (1996) have proposed a behaviorally-based definition of lighting quality, in which it is defined as the degree to which the luminous environment supports the following requirements of the people who will use the space:

- visual performance;
- post-visual performance (task performance and behavioral effects);
- social interaction and communication;
- mood state (happiness, alertness, satisfaction, preference);
- health and safety;
- aesthetic judgments (assessments of the appearance of the space).

According to this definition, lighting quality is not directly measurable, but is an emergent state created by the interaction of the lit environment and the person in that environment. The quality of light is dependent not only on the properties of the light but also how that light is delivered to the space. The central quality issues that are getting the attention of lighting professionals are: glare, uniformity of luminance, colour temperature and colour rendition. Good lighting quality is characterized by uniform brightness, the absence of glare and ability to give pleasant colour appearance.

The effect of lighting conditions on office work has been investigated in various researches. Changing the luminous conditions in an office can affect office workers in three ways, by changing visual capability (Rea & Ouellette, 1991), by changing visual comfort (Wilbom and Carlsson, 1987), and, by changing the perception of the conditions (Flynn et al., 1979). Visual capability can influence task performance greatly (Eklund, Boyce and Simpson, 1999). Visual comfort has effect on mood that can influence feelings of health and well-being. These three aspects (visual capability, comfort and perception of condition) also affect the perception of competence to do the task and hence the motivation to do the task.

Lighting level is one of the main parameter, which influences the task performance and visual comfort. There have been many studies to investigate the acceptability of different light levels in offices. The results of the studies have the trend of increased satisfaction with higher light levels, followed by a decrease in satisfaction at highest light levels. Saunders (1969) noticed in his experiment that most of the observers were satisfied with the mean horizontal illumination of 1000 Lux for the office work and higher levels were not greatly appreciated by them. Rechard Katzev (1992) measured the subject’s behavior on variety of computer-presented tasks in four different lab conditions. Most of the subjects in his test preferred lighting levels between 45 ftc (450 Lux) and 55 ftc (550 Lux) range, showing their dissatisfaction when exposed to greater light level (100 ftc). A high illuminance level may allow a better visual performance, but in the same time creating a visual discomfort (Muck and Bodmann, 1961). The recommended illuminance levels for the offices in different countries are shown in the table 1.

TABLE 1
Some recommended illuminance levels for offices worldwide (in Lux) [CIBSE (1997), CIE (2001), EN 12464 (2002), IESNA (2004), Mills (1998), Zhao (2005)]

Country	Year	General Area	Task Area	Reading
Australia	1990	160	320	320
Brazil	1990	750-1000	------	200-500
China	2004	200-300	300–500	300-500
Japan	1989	300-750	300-750	300-750
USA/Canada (IESNA)	2004	100-500	300-500	300-500
European standard	2002	200-500	500	500
CIE/ISO standard	2002	200-500	500	500
CIBSE code	1997	300	500	500

To ensure visual comfort and promote visual performance, it is important not only to provide the right level of light but also to ensure that light is evenly distributed across the task area. Our eye does not see absolute levels of illuminance; rather it sees differences in luminance. Eyestrain and fatigue are caused when the eye is forced to adapt continually to different luminances. Saunders (1969) found that illuminance ratios lower than 0.7 caused sharp increase in dissatisfaction, although the drop in satisfaction from 1.0 to 0.7 was small. Luminance ratios of no more than 3:1 (i.e., task brighter than surround) for close objects and 10:1 for distant objects and outdoor applications are acceptable in IESNA recommendation (Rea, 2000). Uniformity greater than 0,7 around task areas and greater than 0,5 for immediate surrounding areas is recommended by European standard (EN 12464).

Another concern about office lighting for good performance is glare. The brighter a task is, the easier it is to see and the lower the amount of light that is required. Too little brightness decreases contrast and calls for a higher light level. But if not properly controlled, high brightness can produce levels of glare that either impair or prevent a desired task being performed. European standard (EN 12464) recommends that the CIE Unified Glare Rating (UGR-) value should be less than 19 for general offices. CIBSE code for interior lighting also recommends the UGR value should not exceed 19 in general offices.

The colour qualities of a light source are described by two attributes: colour rendering and colour temperature. Basically, colour temperature describes the colour appearance of a light source. The choice of colour appearance is a matter of psychology, aesthetics and of what is considered to be natural (EN 12464, 2002). There is no consensus on the psychological effects of colour temperature in previous studies (Tiller, 1992). In warm climates generally a cooler light colour appearance is preferred, whereas in cold climates a warmer light colour appearance is preferred. The ability of a light source to accurately reveal the true colours of objects is measured by its colour-rendering index (CRI), which ranges between 0 and 100 where daylight have 100. Lamps with a higher CRI make people and objects appear more natural and bright. Lower illuminances are required from lamps with good colour rendering properties to achieve judgements of equivalent brightness (Kanaya, 1979). Lamps with a colour-rendering index lower than 80 should not be used in interiors where people work or stay for longer periods (EN 12464, 2002).

EFFECT OF EFFICIENCY MEASURES ON QUALITY

Energy efficiency improvements means the reduction in the energy used for a given energy service while keeping the service same or even better. Being more energy efficient does not mean sacrificing quality lighting. On the contrary, with advanced light sources and control technology, we can actually improve the quantity of light and the quality of life while saving energy. This makes the energy efficiency different from energy conservation. Conservation implies sacrifice, giving something up to achieve energy savings. Veitch and Newsham (1997) examined the relationship between lighting quality and lighting energy-efficiency and found that energy-efficient lighting and good-quality lighting can be compatible. Participants in their test preferred the low energy lighting designs, even designs with lighting power densities below energy code levels. They also found a clear pattern of evidence that supports the adoption of energy-efficient electronic ballasts because of their effects on people.

Energy saving measures for lighting involves either reducing electricity consumed by the lighting equipments or reducing the length of time the light source is on. The main strategy that can be applied for the energy efficient lighting is the use of efficient source to provide right amount of light where it is needed and when it is needed. Fluorescent lighting has been shown to be the most efficient and cost-effective lighting to provide the high quality of illumination suitable for offices. Tri-phosphor fluorescent lamps (T5) provide more light using less energy while offering improved colour rendering, and the linear distribution of light is uniform for more effective illumination of the task area. The consumption of energy reduces further if these lamps are used with electronic ballasts. Employee health benefits can be realized from electronic ballasts, which have less flicker and noise, reducing risks of lost time from headaches and stress.

Reducing the wattage of lighting system represents only one part of the energy saving opportunity; other part is to minimize the use of those loads using right control system. This involves the application of occupancy sensing, automatic switching and dimming according to the availability of daylight. Study of seven different open-plan office buildings equipped with modern lighting equipments and controls suggested that energy savings associated with user control are not at the expense of comfort. Occupants on those buildings with efficient lighting installations had positive perceptions of the lighting quality (Moore, Carter and Slater, 2003).

Richard Katzev (1992) measured the subject’s behaviour on a variety of computer-presented tasks to investigate the productivity, preferences, and affective impact of energy-efficient lighting systems. Participants were exposed to four different lighting strategies for a normal work day, spending over hour and a half in each lighting scheme. At the end of task in each lighting strategy, they were asked to adjust the lighting level to their most preferred and acceptable settings. The findings indicate that it is possible to introduce more energy-efficient lighting systems to contemporary office environments that will be both appealing to office employees and maintain the quality and accuracy of their performance. On the other hand, the results also indicated that the most energy-efficient lighting systems may not always be well liked.

MEASUREMENTS IN THE OFFICE ROOMS

Measurement of the power used by the office rooms of Lighting Laboratory was done during all four seasons of the year and the annual energy consumption was calculated based on the measured values. The Lighting Laboratory building was built as a demonstration building for lighting research. The rooms of the building are equipped with the variety of lighting control systems including both old manual system and newest technologies for the integration of artificial and natural lighting.

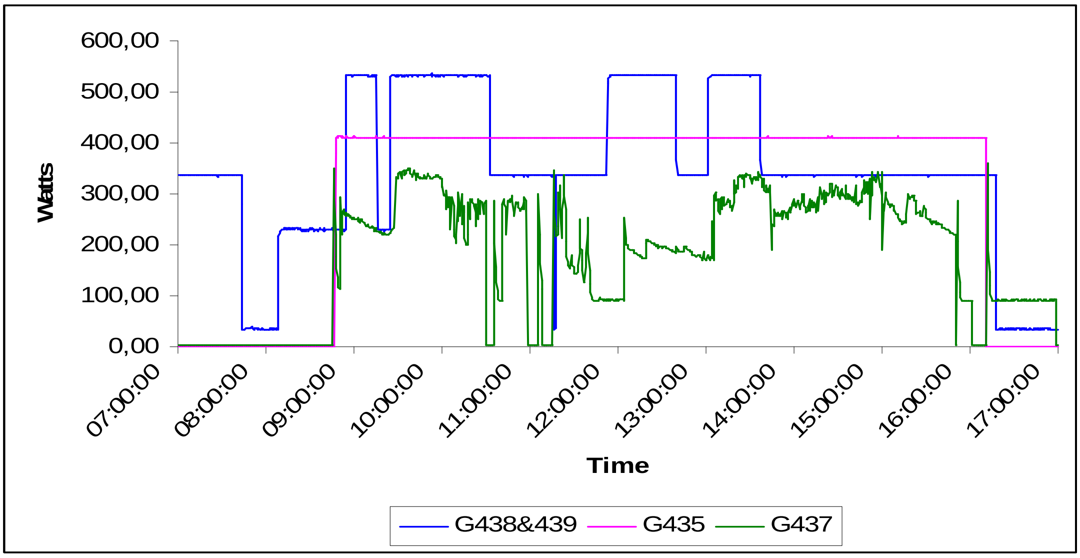

Figure 1: Power consumption curve for rooms G435, G437, and G438&439

Three set of rooms (G435, G437, and G438&439) each with different lighting control system was chosen for the measurement and assessment. All the rooms were equipped with T5 (35 W and 28W) fluorescent lamps (CCT = 3000, and CRI>80). Room G435 has only manual up/down lighting control system whereas room G437 has a constant light control with a photosensor, rotary control switch and occupancy sensor. Only occupancy sensor control was used in the rooms G438&439. As seen in the power curve (Figure 1), the room G435 uses full installed power all the time. Rooms G438&439 also use full installed power but only when the rooms are occupied. Due to the combination of dimming according to daylight and occupancy control, the power curve of room G437 can be seen changing over short intervals. It uses full installed power only when the daylight is completely unavailable.

TABLE 2

Measured values of illuminance, glare rating, installed power, and energy consumption

Rooms	Average Illuminance in Lux		UGR	W/m²	kWh/m²
	Working plane	Floor			
G435	575	380	11	14,1	33
G437	665	390	16,4	16,9	20
G438&439	704	501	11,5	16,3	24

UGR = Unified Glare rating
W/m^2 = Installed power for lighting per square metre of room, in W/m^2
kWh/m^2 = Annual energy consumption per square metre of the room, in kWh/m^2

Room G437 has highest (16,9 kW/m^2) and the room G435 has lowest (14,1 kW/m^2) installed power for lighting but due to daylight based dimming and occupancy control in room G437, it consumes the least energy (20kWh/m^2 per annum) compared to 24 kWh/m^2 of rooms G438&439 (only occupancy control) and 33kWh/m^2 of room G435 (manual control). On the other hand, as seen in the table 2, the working plane illuminance on the room with high energy consumption is less compared to the other rooms. The energy consumption for rooms except the one with manual control is well below the average annual energy use for lighting in Finnish offices, which is 31kWh/m^2 (korhonen et al., 2002). The average working plane illuminance levels of all these rooms (Table 2) are higher than the current recommendation level (Table 1), so there is still space to reduce the annual energy consumption level below 20kWh/m^2 without compromising on the quality. Detailed study of the quality aspects of lighting in all rooms will be done in future.

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