2008-5435/14/63-131-136
INTERNATIONAL JOURNAL OF OCCUPATIONAL HYGIENE

IJOH 6: 131-136, 2014

ORIGINAL ARTICLE

Performance Indexes Assessment for Lighting Systems Based on the Normalized Power Density and Energy Losses Estimation in University Workrooms

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Received February 27, 2014; Revised May 13, 2014; Accepted June 8, 2014

This paper is available on-line at *http://ijoh.tums.ac.ir*

ABSTRACT

Well-designed lighting decreases accidents and diseases of eyes and can increase productivity and concentration. Increase of energy price and a high proportion of electric lighting energy consumption in buildings due to defects in designing and maintenance led to desirable lighting to be reduced. One of our challenges in providing health and quality of lighting is lack of economic justification of projects. Furthermore, evaluating the lighting systems is very important to improve these systems and maintaining lighting quality. In this study the performance of the various lighting systems has been evaluated. The health and quality conditions of lighting systems, energy loss and the difference between the lighting variables, based on room index and the designed required levels (normalized power density) in studied schools and education workrooms in Ahvaz Jundishapur University of Medical Sciences (south-west of Iran) have been evaluated. Results showed that the modern lighting systems had 58% more efficient than the traditional others. In other words, modern lighting systems increase illuminance to 58 percent without increasing the electrical energy power. The performance indices of lighting systems between workrooms that had modern systems and traditional was significant (p=0.000). In 77.4% of spaces of the school of Medicine, where that had new lighting systems, the satisfaction index of users was equal to one. Evaluation of lighting systems in order to decreasing the electrical energy power along with preserving the standards of illumination intensity is very important, and some appropriate solutions could be adopted by replacing the traditional systems with the new others.

Keywords: *Lighting, Energy savings, Power density, Lighting systems, Performance index*

INTRODUCTION

Light is able to affect physical, physiological and psychological behaviors. Well-designed lighting decreases accidents and diseases of eyes and can increase productivity and concentration [1-4]. The Interior Lighting Design is primarily determined by its application. The aim of the lighting design is to create suitable lighting conditions for a particular visual activity (e.g. reading, writing. etc) [5]. 83.5% of the

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workshops are in adverse lighting conditions in Iran [6]. On the other hand, artificial lighting is a very important issue to minimize the energy consumption [7].

Out of the total energy consumption, the lighting energy accounts for 25% [8]. In Finland, lighting energy consumption is 32% of the total primary energy consumption [9]. In general, the lighting energy consumption accounts for 25-40% of the total energy consumption in the commercial buildings and the offices in different countries [10-12]. With the rising cost of the energy [13], the control of lighting systems is considered as a priority in each country that is very important to control and reduce the energy consumption, while maintaining the standards of illumination intensity and the light quality; and different strategies such as the use of the artificial lighting systems and the efficient use of daylight have been recommended to reduce the amount of electricity used without compromising on the quality and health of lighting.

In this regard, it may control the artificial light energy using two general approaches, firstly reduces the density of the electrical power of the lighting system, and secondly, decreasing the time of the artificial light energy usage [6, 14]. Reducing the electrical power density should not compromise the illumination quality; and it should not lead to a decrease in the permissible illumination intensity on the work surface [15-16]. In order to reduce the electrical power density and to maintain the standards of the illumination intensity, the application of optimized lighting systems and improving in the lighting systems, including optimizing the technologies of the lamps and ballasts, the features of the lamps and their reflective surfaces, and the maintenance factors, are important issues [17-18].

Given these factors, it should be defined a criterion for evaluating the performance of lighting systems. For this purpose, there are different approaches for new buildings and the buildings that have already been made. In relation to already made buildings, the power consumption should be measured [14] and compared with a standard criterion [7, 9]. Normalized power density as a measure to evaluate the lighting systems regarding the factors of improving lighting systems is used and characterized by the unit $W/m^2.100$ Lx [7, 9]. To calculate the NPD, the measurement of the room index is used [9].

This study examines the performance of lighting systems, estimates the artificial light energy loss, and makes a comparison of different lighting systems at Ahvaz Jundishapur University of Medical Sciences; and the performance; ultimately the rate of energy loss and health and quality parameters at every school is estimated according to the various existing lighting systems.

In the present study the purpose of lighting system was ballasts, lamps and bulbs, and the physical characteristics of the environment; so, two distinct lighting systems are examined, A) A system in which 36-Watt FPL energy-efficient fluorescent lamps, the stainless steel reflectors and electronic ballasts are used, and in this paper, it is called as "New System" from now on. B) A system in which T8, T10fluorescent lamps, with typical painted metal reflectors (cream color) and conventional magnetic ballasts, which from now on they are called as the "Traditional System".

Table 1. Determination of measurement points

Room index	Minimum number of measurement points
Below 1	9
1 and below 2	18
2 and below 3	25
3 and above	36

The aim of this study was to evaluate the performance of lighting systems and estimating the rate of energy loss at the schools of, 1– Health, 2–Medicine, 3- Nursing and Midwifery, 4- Rehabilitation Sciences, 5–the old building of Paramedical Sciences, and 6–the new building of Paramedical Sciences at Ahvaz Jundishapur University of Medical Sciences, and to perform a comparison between the performance of different lighting systems and the amounts of energy dissipation at these schools.

MATERIALS AND METHODS

Each area (room) with the administrative and clerical applications, such as classrooms and faculty offices, etc. were identified at first, and then in a grid method, minimum points in which the illumination intensity was to measured, were determined considering the room index(Table1). The room index was calculated based on Eq. 1 [18-20].

$$RI = (L.W) / [h_m(L + W)] \qquad \text{Eq. 1}$$

W and *L* are the measured width and length of the room and h_m is the height of the light opening from the work surface.

The sample rooms were divided into equal squares, based on the minimum measured points, and in each square center the illumination intensity was measured in both on and off situations, using a Lxmeter TES (model 1339), at the height of 80 cm from the floor. The measurements were carried out in December, 2012 and March, 2013 under intermediate sky. When the lighting system was turned on, the natural and the artificial lights were measured simultaneously, and when the lighting system was turned off, the natural light was measured alone. Therefore, the artificial illuminance was measured by subtracting these two digits .Then the power of each lamp and ballast was written from its catalog, and it was multiplied by the number of room

Table 2. Performance indicator based on the numbers obtained from the Installed Load Efficiency Ratio (ILER)

The performance of lighting system		
Satisfaction level	**ILER**	**Evaluation**
1	0.85 and above	Good and satisfying
2	0.61 to 0.84	Reevaluation of lighting system and corrective actions if possible
3	0.6 and less	Emergent corrective actions as soon as possible and preparation of more efficient sources

Table 3. Installed load efficiency ratio (ILER)

Place of measurement	Type of Lighting System	Installed load efficiency ratio of lighting systems (ILER)	Energy wastage of lighting lystems (kWh/yr. m^2)	Installed power density (W/m^{2}per 100 Lx)	Room index
Health School	Traditional system	0.46	20.9	9.06	1.2
Nursing and Midwifery School		0.4	38.48	8.87	1.41
Rehabilitation School		0.53	30.81	7.27	1.1
Old Paramedical- School		0.46	20.78	9.30	1.09
Medical School	New system	1.04	- 0.4	4.16	0.98
New Paramedical- School		1.05	1.41	4.23	1.11

luminaries', so the total circuit power was obtained in Watt. If the total circuit power were divided by the room area, the illumination intensity and the number of 100, the result would be considered as Installed power density, which its unit is Watt per square meters multiplied by 100 Lx (W/m^2.100 Lx). Dividing the normalized power density (NPD) obtained from the Eq. 2 [3] by Installed power density a quantity named as the Installed Load Efficiency Ratio would be obtained that showed in following [9, 21]:

NPD = [2.25 + (1.5 /RI)] Eq. 2
ILER = NPD / IPD Eq. 3

Where NPD is Normalized Power Density, RI is Room Index, IPD is Installed power density and ILER is Installed Load Efficiency Ratio. Based on the results from the ILER, the performance lighting system indexes are showed in Table 2.

The ILER and the performance index were calculated at each school, and then regarding the various applied lighting systems (new and traditional), the level of satisfaction was determined. In order to estimate the annual energy consumption of the artificial lighting system and also the energy loss resulting from the inefficiency of lighting system the equations four and five were used, and the energy loss was evaluated respecting either the overload or the inefficiency of the lighting systems. Other indexes showed in following:

AEC= [Total load×2500]/1000 Eq. 4
AEW= [(1.0 - ILER) × Total load × 2500]/1000 Eq. 5

Where AEG is Annual Energy Consumption (kWh/m². yr), Total load (W/m^2), 2500 hours per year, AEW is Annual Energy Wastage (kWh/yr. m^2) and ILER is Installed Load Efficiency Ratio.

In these equations, the mean official and clerical work times were considered 2500 hours [17]. The usual criterion to evaluate the illuminance distribution as one of lighting quality factors is in terms of uniformity which is the ratio of minimum to average illuminance $U = (E_{\min} / E_{ave})$ and should not be less than 0.7 over any task area [22]. To perform the statistical analysis we used the SPSS software version 16.0 by the t-test, analysis of variances and the Chi square test with the significance level of 5%. The one-way ANOVA test was used to compare the lighting system efficiency, the energy loss and the room index between different schools. The t-test was also used to compare the mentioned variables between new and traditional lighting systems. The Chi square test was used to compare the performance indices in various lighting systems.

RESULTS

The ILERs in studied schools by separation of types of artificial lighting system (modern or traditional) are presented in Table 3. Based on the artificial lighting system (new or traditional), it shows that the Medical and new Paramedical schools which possess new lighting systems have the highest efficiency and performance values. Moreover, the Installed Power

Table 4. Annual lighting energy consumptions and the energy wastes in artificial lighting systems

Place of measurement	Type of lighting system	Annual electricity consumption power (kWh /yr. m^2)	Energy wastage (kWh /yr. m^2)	Average illuminance (Lx)
Health School	Traditional system	38.17	20.9	189
Nursing and Midwifery School		64.44	38.48	303
Rehabilitation School		67	30.81	395
Old Paramedical School		36.27	20.78	195
Medical School	New system	63.7	- 0.4	620
New Paramedical School		35.63	1.41	354

Table 5. Parameters of measured dayligh in the various schools of Ahvaz Jundishapur University, Khuzestan , Iran

Place of measurement	E_{ave} (daylight)	E_{ave} (day and artificial light)	Measuring time (hour)	Average Uniformity
Health School	175	368	12.23	0.57
Nursing and Midwifery School	288	573	12.03	0.64
Rehabilitation School	233	601	12.1	0.64
Old Paramedical School Building	267	411	11.53	0.49
Medical School	405	967	12.3	0.67
New Paramedical School Building	493	848	11.17	0.45

Density due to artificial lighting systems in terms of (W/m^2.100 Lx) is presented; showing that each consumed Watt per area unit can supply 100 Lx illuminations, which shows the lowest power density at Medical and Paramedical schools with the new lighting systems. The annual lighting energy consumption and the annual energy wastage resulting from the artificial lighting systems are presented in Table 4. In addition, Table 5 shows the parameters of measured dayligh in the studied schools.

Results showed the significant relationship between the performance index and the type of lighting system (new and traditional) (p=0.000), in such a way that 72.7% of new lighting systems have a performance index with the satisfaction level of one. To 25% of them the satisfaction level is two; however, 85.5% of traditional lighting systems have a performance index with the satisfaction level of three, and in 7%, the satisfaction level is two.

77.4% of measured spaces at Medical School have the satisfaction level of one, representing a good and satisfying performance index, which is the best performance among the all schools of the university. Only 22.6% of these spaces have the satisfaction level of two, and need a corrective action, if possible. In addition, the satisfaction levels of three at the school of Nursing and Midwifery and the old Paramedical School building were 96.6% and 87.5%, which were the worst among the measured ranges. 84.8% of the area of the School of Health and 83.3% of the area of the Rehabilitation School has been at the satisfaction level of three. At the new Paramedical School building, 61.5% of performance index has been at the satisfaction level of one and 30.8% at the level of two.

The average artificial lighting in Health School and Old Paramedical School building were lower than recommended ranges (300-500) and in Medical School was higher than recommended range. in three schools illumination levels was standard. Average uniformity was lower than standard (0.7) in all the schools according to Table 5.

DISCUSSION

In this study, we assessed the lighting systems in 140 university workrooms in six schools based on the Normalized Power Density and Energy Losses Estimation. Results showed the significant difference between the performance indexes of the lighting systems in studied schools of Ahvaz University of Medical Sciences.

Considering that the system performance is related to various items, including the type of the lamps and ballasts, the reflective surfaces of the room (walls, ceiling and floor), and the room dimensions. On this basis, a criterion named as the normalized power density has been calculated according to the Eq.2, and the study carried out by Hansaler et al. [9]. The mean calculated NPD in different spaces with the new systems was 3.92 W/m^2.100 Lx, and it was 3.6 W/m^2.100 Lx in spaces where the traditional systems were installed. There were no significant difference was in Installed Power Density (W/m^2. 100 Lx), and the installed load efficiency ratio between different schools in the new lighting system. However, a significant difference existed between the variables of installed power density and efficiency in the different lighting systems (new and traditional) (p= 0.000) [14, 18, 21].

It should be noted that among the schools with traditional lighting systems, the lighting system performance of the Rehabilitation School had a significant difference with the Nursing and Midwifery School (p=0.000). Moreover, a significant difference in the room index and surfaces reflection coefficient exists between the Rehabilitation School and the Nursing and Midwifery School with the traditional lighting systems, showing an increase in the lighting system efficiency with increasing the room index and surface reflection coefficient [9].

The present study shows that the new lighting systems have a priority of 58% on average compared with the traditional systems [17]. A significant difference was seen between the performance index and the type of lighting system, as well (p=0.000). Annual Consumption Power is a very important parameter, and the existing standards should be used, according to the quality standards. The mean electrical lighting at the administrative environments in Sweden is 23 KWh/m^2.yrbased on the Borg standard [23], while with installation the advanced lighting system in these spaces; it may be reduced to 11 KWh/m^2.yr. More declines are possible using the light sensors and the presence to even 5 KWh/m^2.yr. (Preserving the illumination up to 300-500 Lx). Furthermore, the European standard EN-15193 offers a Lighting Energy Numerical Index (LENI) equal to 20-25 Kwh/m^2.yr considered as the optimized amount of energy consumption for private and large rooms [24].

In the present study, considering that in the school of Medicine, the efficiency of the artificial lighting system has been assessed as proper, and on the one hand, the energy wastage resulting from the defect in this system is approximately-0.4 Kwh/m^2.yr, but because of the overload (the excess power), artificial lighting has been 620 Lx that 120 Lx is more than permitted limit (the illumination standard is 300- 500 Lx) and it has caused that the annual consumption power is equal to 63.7 KWh/m^2 yearly, which this value is several times more than the European countries and standards. This standard, in terms of 2500 hours of work of employees in the year, is estimated equal to 28 kWh/m^2.yr [9]. The combined light (daylight and artificial in the middle of the day, i.e. 12.3 hours averagely) has been measured 967 Lx averagely, and by using the daylight, additional power of artificial light can be controlled and reached up to the standard level (28KWh/m^2.yr) [27, 26, 25]. At the old Paramedical school building the energy power consumption is approximately in the permissible limit, which is about 36.27 Kwh/m^2.yr, but the artificial illumination intensity is about 195 Lx, and the minimum artificial light has not been kept.

Therefore, a balance should be established between the power consumption and the illumination intensity standard. As it could be seen in tables, the new Paramedical School building has a more suitable situation comparing with the other schools, because it is both better in efficiency and the lighting system performance, and is closer to power consumption standards, while requiring corrective actions. So, a well daylight illumination enables to reduce the artificial lighting along with preserving the standards of illumination intensity and decreasing the Annual Electricity Consumption Power (kWh/m^2.yr) [12, 17].

CONCLUSION

Auditing and evaluating lighting systems as an approach for estimating the efficiency of the in workrooms. In this study, necessary decisions could be adopted to improve the systems. As well as, using the new system and improving the lighting equipment and sources it may reduce the power consumption, while preserving of user needs by preservation of the recommended illumination levels and the excess power demand in the system could be evaluated.

ACKNOWLEDGMENTS

This paper is extracted from the results of a registration No. U-91143 , 2012 in research project financially supported by Vice Chancellor for Research and Technology of Ahvaz Jundishapur University of Medical Science, The authors appreciate and thank the Research Consultation Center (RCC) for methodological supports. The authors declare that there is no conflict of interests.

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