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Dr. Kasım ÇELİK

Çukurova Üniversitesi, Mimarlık Fakültesi, Mimarlık Bölümü
kcelik@cu.edu.tr

Prof. Dr. F. Rengin ÜNVER

Yıldız Teknik Üniversitesi, Mimarlık Fakültesi, Mimarlık Bölümü
runver@yildiz.edu.tr

VISUAL COMFORT IN SCHOOL BUILDINGS: A CASE STUDY¹

Abstract

The application of replacing components that can no longer function in the lighting system or cause excessive energy consumption with components that use energy more efficiently is defined as the retrofit. It is possible to increase the visual comfort with the actual lighting technologies to be used in retrofit applications and to reduce the electricity and maintenance expenses. Retrofit applications are carried out in two main steps as the define determination of the condition of the existing lighting system and the selection of appropriate lighting systems recommendations. There are various methods and tools to determine the condition of the lighting systems in existing buildings. In this study, "methods of determining lighting conditions", which is used to determine the defects in the lighting system of an existing school building, are introduced. A field study was conducted to determine the defects in the lighting system of a middle school building in Adana, Turkey by using the lighting control lists and questionnaires created within the scope of the study. It is aimed to contribute to the systematic, quick and easy determination of the condition of existing lighting systems of school buildings by the related professional groups by means of the methods and tools introduced in the study. Thus it is

¹ This study is developed over the paper that has been presented in "Balkan Light 2018 International Conference on Lighting" between 04-06 October 2018 in Sofia, Bulgaria.

thought that the success rate of retrofit applications may increase by using these methods and tools.

Keywords: Lighting, Schools, Post occupancy evaluation.

OKUL BİNALARINDA GÖRSEL KONFOR: ÖRNEK BİR ÇALIŞMA

Öz

Aydınlatma sistemindeki işlevini artık yerine getiremeyen ya da fazla enerji tüketimine neden olan bileşenleri, enerjiyi daha verimli kullanan bileşenlerle değiştirme uygulaması retrofit olarak tanımlanır. Retrofit uygulamalarında kullanılacak güncel aydınlatma teknolojileri ile görsel konforun artırılması, aydınlatmadan doğan elektrik ve bakım giderlerini azaltmak olanaklıdır. Retrofit uygulamaları mevcut aydınlatma sisteminin durumunun doğru bir şekilde belirlenmesi ve uygun aydınlatma önerilerinin sunulması olarak iki temel adımda gerçekleştirilir. Bu çalışmada retrofit uygulamasına başlanmadan önce bir yapının mevcut aydınlatma durumunun belirlenmesine yönelik olarak Adana’da bulunan bir ortaokul binasından seçilen dokuz farklı mekanın aydınlatma sistemlerinin kullanım sonrası değerlendirme (KSD) yöntemlerinden yararlanarak görsel performans açısından uzman ve kullanıcı gözlemleri ile değerlendirilmesine ilişkin sonuçlar sunulmuştur. Çalışmada kullanılan yöntemler okul yapılarının mevcut aydınlatma sistemlerinin durumunun ilgili meslek grupları tarafından sistematik olarak kolayca belirlenmesine katkı sağlaması hedeflenmiştir.

Anahtar kelimeler: Aydınlatma, Okullar, Kullanım sonrası değerlendirme.

1. Introduction

Human perceives the environment by physical stimulation of sense organs such as light, colour, acoustics, heat, humidity, odor. Seeing comprises the biggest rate in this perception. Consequently, visual perception has an important role in learning. Schools, having an effective role in learning, are the educational spaces where are needed to take care of providing visual comfort in lighting (Baskan, 2006:143) For this reason, the competence of an ambient lighting is assessed by how well it makes the environment more understandable visually as well as at what rate the performance of the rendering of the image in accordance with specific aesthetic and architectural rules is provided. Access to the required competence of the lighting scheme and realization of visual comfort, so visual perception in a complete manner, depending on the provision of "good vision conditions". Regarding lighting technique, good vision is defined as "to easily see the formal and three-dimensional features of all the objects and surfaces in the environment, colour and texture distinctions without disturbing and tiring." The natural lighting arrangements in which the daylight is used and the artificial lighting arrangements in which the lamp light is used are utilized in order that the aforementioned conditions are achieved. However, it is a well-known fact that the functions and properties of each building or each space are distinguished from each other (Ünver, 2016:114). Natural and artificial lighting schemes should be established and evaluated in view of the function and other characteristics of the space by taking into account the visual comfort criteria that play a part in ensuring good vision conditions. The design of an educational building cannot be considered as independent of the lighting issue.

The lighting design in the schools should become in the manner that the students and staff perform their actions in a comfortable and safe manner. When thinking about lighting design, it is necessary to consider possible flexibility and constraints. The replacement of components that can no longer function in the lighting system or cause excessive energy consumption, with the components that use energy more efficiently, can be described as the retrofit. It is possible to increase the visual comfort with the existing lighting technologies to be used in retrofit applications and to reduce the electricity and maintenance expenses arising from lighting. Retrofit applications are carried out in two basic steps as the correct determination of the condition of the existing lighting system and the presentation of appropriate lighting recommendations. Improvement of the lighting systems of the existing school buildings and the design of the new school buildings as sustainable design principles are necessary. Properly determination of the situation in terms of the lighting of the relevant premises before retrofit applications will prevent possible wrong designs, waste of time and materials. In this study, the first step of retrofit studies, the determination of the condition of the lighting systems, was dealt with, and it was aimed to present the visual comfort of the school buildings as an example of the existing lighting scheme. In this context, a field study on a middle school building in Adana, Turkey is presented to determine the existing lighting conditions by experts and users.

2. Determination of Conditions of Existing School Lighting Systems

The purpose of lighting in schools is to provide visual comfort conditions in the work areas, to create an attractive visual environment and to use energy efficiently. Both the design of the spaces and the selection of proper lighting methods play a role in achieving these goals. Disruptions in the lighting systems in the schools also negatively affect the health and performance of the students because of the visual comfort conditions of the place. For this reason, it is necessary to renovate systems that are damaged, outdated, unable to fulfil the lighting task, or that have low energy efficiency.

The process of replacing components that are no longer functioning in the lighting system or that cause excessive energy consumption, with components that use energy more efficiently, is called as the retrofit. In this context, it is aimed to increase the visual comfort by using up-to-date lighting technologies with retrofit applications and to reduce the energy requirement and maintenance costs arising from lighting. Retrofit work in many countries, in various fields and buildings, is increasing. The reasons for these numerous retrofit applications are below (IEA, 2000:35);

- Insufficient environments in terms of physical comfort conditions,
- High energy consumption,
- Failed applications,
- Providing a new function to space.

As the first step to retrofitting the lighting systems in schools within the context of retrofit studies, it is necessary to determine the condition of the existing lighting system. "Post-Occupancy Evaluation (POE)" methods can be used to determine the condition of the existing lighting system, in which the user is included in the process. In the literature, it is possible to find different definitions and interpretations of POE. In general, POE can be defined as a systematic processing of data about buildings in use and evaluation of building performance from the point of view of users (Hadjiri and Crozier, 2009:22). The primary objective of POE is that

the necessary information is provided to support the objective of continuous improvement (Zimmerman and Martin, 2001:170).

The fact that post-occupancy evaluation is successful (true) or unsuccessful (false) is usually determined by the methods of information gathering chosen and used by the researcher. Friedman, Zimring, and Zube (1978) summarize information gathering methods in three groups as direct observation, interview and simulation as described below:

• **Direct observation:** With this method, information is obtained from real life and natural behaviours. The observer records events without notice in a particular environment.

• **Interview:** This method is one of the most commonly used tools to assess people's reactions to the physical environment. In this method, interviews are made with the users and the user is asked questions during the field work.

• **Simulation:** In this method, the environments of the users are evaluated by being expressed or modelled.

In all three methods, users are included in the evaluation process, either directly or indirectly (Sanoff, 2001). In order to evaluate the lighting systems of the existing schools, the information given in Table 1 has been drawn up by taking into account the above-mentioned methods of collecting information, stakeholders and the transactions to be carried out. In short, it is possible that one or more of the methods mentioned in Table 1 can be applied by stakeholders in the relevant occupational groups to determine the condition of an existing school's lighting system.

Table 1. Lighting system condition determination methods and properties

Methods	Stakeholders	Actions
Observation	Expert (Architect, engineer, lighting designer), User (Administration staff, teacher)	On-site observation (Determining the lighting conditions by observing the spaces) Checklist (Determining the characteristics of the existing lighting system with the aid of a checklist) Measuring (Determining lighting conditions with measuring devices)
Interview	User (Student, teacher, administration staff)	Face to face interview (Identify problems with lighting conditions by face-to-face with users) Questionnaire (Determining the lighting conditions by applying questionnaire to the users)
Simulation	Expert (Architect, engineer, lighting designer)	Model (Determining the performance of the existing lighting system by modelling)

3. Method of Study

In order to renew the lighting system of a building within the context of retrofit works, the processes that will be made are to determine the existing situation and present the lighting proposals accordingly. Accurate determination of defects in the lighting system before the improvement of the lighting will increase the success of the retrofit. The steps of the method applied in this study aiming at sampling the issue of determining the existing state of lighting systems, which is the first step of retrofit studies, are listed below, and field work has been carried out by using the mentioned steps:

- Selection of the example space/building to be used for lighting renewal and determining the space properties,
- Selection of the most appropriate method from the "Lighting system condition determination methods (Table 1)",
- Determination of minimum required lighting conditions for different space and actions,
- Determination of stakeholders and appropriate procedures for the selected method,
- Establishment of tools related to the operations to be performed (checklist, questionnaire, interview questions etc.)
- Implementation of the transactions to be performed by the relevant stakeholders,
- Evaluation of the obtained data.

4. Field of Study

A middle school building (Ramazanoğlu Middle School) located in the province of Adana was selected as an example within the scope of the field study for determining the condition of existing lighting system. The various spaces of the chosen school building are investigated, and the lighting situation determination methods are applied to a total of 140 students, 6 teachers, and 2 administrative staffs. There are 19 classrooms, 5 offices, 1 multipurpose hall, 1 computer laboratory, 1 science laboratory, 1 teacher room, wet spaces and other places used for service in the middle school building. General information about the school, the plan and the views of the school and plan are presented in Figure 1.-2.

Figure 1. General view of the school

Figure 2. Plan of the school

Two of the above methods, observation and interview, were used to determine the condition of the existing lighting system in the middle school. The stakeholders that will be involved in the evaluation methods are grouped into two categories: **expert** (architect) and **user** (administrative staff, teacher and student). In this context;

- **For the evaluation of expert observations;** "Expert-lighting observation list" was prepared to collect and evaluate information about the lighting system. The checklists were filled by the expert and measurements of the illumination levels were carried out. Thus, information on the natural and artificial lighting conditions of the classes has been obtained.
- **For the evaluation of user observations;**
 - Six teachers in different locations in the school were asked to complete the "User-lighting observation list" prepared for the study. In addition, two administrative staff members of the school were interviewed about the school's lighting system.
 - "Student lighting observation questionnaire" was prepared in order to get opinions of about the lighting conditions in learning places. The questionnaires were conducted to a total of 140 students in the 10-14 age group.

Illuminance required for different activities in educational buildings may vary depending on the functions. In the standard in force in Turkey "TS EN 12464-1: Light and Lighting – Lighting of Work Places – Part 1: Indoor work places", listed are the minimum values required for lighting of different functions in educational buildings (Table 2). By this standard, one can reach useful information quantity (illuminance) and quality (glare, light colour, light distribution etc.) of the lighting in classrooms.

Table 3. Minimum lighting conditions suggested to provide in classrooms (TS EN 12464-1/2011)

Function	E_m (lux)	UGR	U_0 (E_{min}/E_m)	R_a
Classrooms	300	<19	0,6	80
Blackboard (Vertical illumination)	500	<19	0,7	80
Office	300	<19	0,6	80
Corridor (floor)	100	<25	0,4	80
Stairs (floor)	150	<25	0,4	80

All evaluations were performed according to the required lighting conditions specified in the standard.

4.1 Lighting Observation Results of Expert and Users

Expert lighting observation results: In the field study, firstly, nine different spaces (including four classrooms, computer laboratory, office, circulation areas, hall) were investigated. Later on, basic features of the natural and artificial lighting systems were determined by on-site observation and measurement methods in the selected spaces.

In the classroom, natural and artificial lighting systems and properties of interior surfaces were determined, and illumination levels were measured. Information on the characteristics of the existing artificial and natural lighting schemes of the classes is given in Table 3 and 4.

Table 3. Artificial lighting features of spaces

Name	Lamp type	Number of lamps/working lamps	Condition	Control equipment
SW classroom	36W-765 Linear fluorescent	12/12	Dirty	Manuel
SE classroom	36W-765 Linear fluorescent	12/10	Dirty	Manuel
NW classroom	36W-765 Linear fluorescent	12/10	Dirty	Manuel
NE classroom	36W-765 Linear fluorescent	12/10	Dirty	Manuel
SE Comp.Lab.	36W-765 Linear fluorescent	12/9	Dirty	Manuel
NW Office	23W-Compact fluorescent	4/4	Dirty	Manuel
Hall	36W-765 Linear fluorescent	24/15	Dirty	Manuel
Corridor	36W-765 Linear fluorescent	4/3	Dirty	Manuel
Stairs	36W-765 Linear fluorescent	2/2	Dirty	Manuel

Table 4. Natural lighting features of spaces

Name	Direction	Window units / size	Condition
SW classroom	Southwest	3/ 1,40x1,50 m	Dirty
SE classroom	Southeast	3/ 1,40x1,50 m	Clean
NW classroom	Northwest	3/ 1,40x1,50 m	Dirty
NE classroom	Northeast	3/ 1,40x1,50 m	Dirty
SE Computer Lab.	Southwest	3/ 1,40x1,50 m	Dirty
NW Office	Northwest	2/ 1,40x1,50 m	Dirty
Hall	Southeast	6/ 1,40x1,50 m	
Corridor	-	-	-
Stairs	-	1/ 0,60x3,00 m	Dirty

The illumination levels of the spaces were measured under clear sky conditions on December 15, 2016, and December 12, 2017, at 12:20, 12:50, 13:30, 14:00, 14:40, and 15:00. The illumination level measuring points have been determined in accordance with the EN 12464-1 standard. The illumination level measurements were made at the 16 points with 0.72 m high on the horizontal working plane and a total of 9 points with 1, 1.50 and 2 m height on the black-board in the vertical plane. In other places, the measurements were performed by taking into consideration the standard intervals. Extech HD450 lux meter is used for illuminance measurements. Measurement points in the classrooms are given in Figure 3. and the results of measurement of natural and integrated (natural and artificial) lighting are given in Table 5.

Figure 2. Illuminance measurement points and luminaire locations for a sample classrooms

Table 5. Illumination level measurement results

Name	Natural lighting				Integrated lighting			
	E _h (lux)	E _v (lux)	U _h	U _v	E _h (lux)	E _v (lux)	U _h	U _v
TS EN 12464-1	300	150	0,6	0,7	300	150	0,6	0,7
SW classroom	1089	712	0,29	0,60	1208	813	0,33	0,68
SE classroom	497	286	0,29	0,72	605	354	0,38	0,85
NW classroom	274	274	0,39	0,48	348	410	0,40	0,63
NE classroom	242	121	0,24	0,52	298	196	0,36	0,67
SE Comp.Lab.	672	513	0,26	0,64	786	584	0,43	0,81
Hall	258	86	0,25	0,47	374	135	0,26	0,59
Office	219	-	0,43	-	258	-	0,55	-
TS EN 12464-1	100	-	0,4	-	100	-	0,4	-
Corridor (floor)	35	-	0,12	-	62	-	0,19	-
TS EN 12464-1	150	-	0,4	-	150	-	0,4	-
Stairs (floor)	140	-	0,25	-	173	-	0,31	-

When the light level measurement results of the spaces discussed in the field study are compared with the values in TS EN 12464-1 standard, the following results are obtained:

- Southeast, Southwest classrooms of the secondary school building and Southwest computer laboratory provided the horizontal illumination level values required for the working plane (300 lux for the desk plane) separately for natural lighting and integrated lighting situations.
- For the vertical natural and artificial illumination on the board level, other classrooms could not reach the desired values except Southwest classrooms and Southwest computer labs.
- It is seen that the required values in the standards for the distribution of luminance are provided only in the floor hall, whereas in other places there is no uniform luminous distribution.

User lighting observation results: "Teacher observation list" was prepared so that teachers could determine the lighting conditions of the class through observation and it was requested that these lists should be filled. For this purpose, teacher observation lists were filled by a total of eight users, including six teachers in the classrooms and two teachers in the administration office. Apart from the observation lists, general information about the school lighting system was obtained by interviewing face to face with the administrative staff. All the situations determined by the teachers are presented in Table 6.

Table 6. Teacher - Lighting observation list results

Questions for teachers	Spaces					
	SW class-room	SE class-room	NW classroom	NE class-room	SE Comp. Lab.	NW office
When the lamps are off, is the daylight illumination level on student desks sufficient?	Yes	Yes	No	No	Yes	No

When the lamps are turned on, is the illumination level on student desks sufficient?	Yes	Yes	No	No	Yes	Yes
Does the sunlight coming from the windows cause glare?	Yes	No	No	No	Yes	No
Does the light coming from the lamps cause glare?	No	No	No	No	Yes	No
Are the windows clean?	No	No	No	No	Yes	Yes
Is there a building around the school that blocks daylight?	No	No	No	No	No	No
Are there trees, plants, etc. that block daylight around the school?	No	No	No	No	No	No
Are interior surfaces (wall and ceiling colours) light?	Yes	Yes	Yes	Yes	Yes	Yes
Do all the lamps in the classroom work properly?	Yes	No	No	No	No	Yes
Are the lamps in the classroom clean?	Yes	No	No	No	No	Yes
Are the lamps and luminaries cleaned regularly?	Yes	No	No	No	No	Yes

For the students, "student lighting observation questionnaire" consisting of 19 questions was prepared by using a 5 point Likert scale, and a total of 140 students in different classrooms were conducted. In the questionnaire, students were asked about the level of perception of lighting conditions as well as the issues they were uncomfortable with regard to the surrounding environment.

In the questionnaires, students are asked to evaluate visual comfort, glare and shadow conditions in the classroom. The evaluation criteria corresponding to the range of points in the question are given in Table 7. The range of points was calculated according to the Likert scale of 5 (score range 0.80).

Table 7. Score ranges used in the evaluation of questionnaires

Likert scale	Questions (scales)		Score ranges
	E, U ₀	Glare	
1	Poor	None	1,00-1,79
2	Fair	Little	1,80-2,59
3	Neutral	Neutral	2,60-3,39
4	Good	Much	3,40-4,19
5	Very good	Too much	4,20-5,00

In this context, results of students' responses to the questionnaire are given in Table 8-10.

Table 8. Student observation questionnaire illumination level and distribution of illuminance results

Name	Daylight		Integrated lighting		U ₀
	E _h (desk)	E _v (blackboard)	E _h (desk)	E _v (blackboard)	
SW classroom	Very good	Good	Very good	Very good	Good
SE classroom	Very good	Neutral	Very good	Neutral	Bad
NW classroom	Neutral	Bad	Good	Neutral	Good
NE classroom	Bad	Neutral	Neutral	Good	Good
SE Comp. Lab.	Good	Good	Very good	Good	Bad

Table 9. Student observation questionnaire glare results

Name	Daylight		Integrated lighting			
	Glare from window	Glare on the blackboard	Glare on the blackboard	Glare on the desk	Glare from lamps	Shadow on the desk
SW classroom	Neutral	Little	Little	Little	Much	Little
SE classroom	Much	Too much	Too much	Much	Little	Much
NW classroom	None	Neutral	Much	Neutral	Little	Much
NE classroom	Little	Much	Much	Little	Little	Neutral
SE Comp. Lab.	Too much	Neutral	Much	Little	Much	Neutral

Table 10. Student observation questionnaire discomfort situations

Name	The first three situations that are most disturbing to students		
	1.	2.	3.
SW classroom	The light from the lamp causes glare (%81)	When the lamps are lit, the blackboard is glowing (%61)	The light from the lamp causes glare (%45)
SE classroom	The light from the window is shining on the blackboard (%88)	When the lamps are lit, the blackboard is glowing (%83)	The light from the window is glowing on the desk (%50)
NW classroom	When the lamps are lit, the blackboard is glowing (%96)	The light from the lamp causes glare (%68)	The light from the window is shining on the blackboard (%52)
NE classroom	The light from the window is shining on the blackboard (%75)	When the lamps are lit, the blackboard is glowing (%72)	The light from the window causes glare (%50)
SE Comp. Lab.	When the lamps are lit, the blackboard is glowing (%89)	The light from the window is shining on the blackboard (%87)	The light from the window causes glare (%75)

5. Evaluation and Conclusion

Obtained measurement, observation list and survey results to determine the expert and user observations in the school can be summarized as follows.

Expert - Measurement results: The illumination levels of the spaces considered in the field study were evaluated by taking into account the numerical values in the standard entitled TS EN 12464-1. Southeast, Southwest classrooms and the Southwest computer laboratory separately provided the horizontal illumination level values for the working plane (on the desk: 300 lx). For the vertical natural and artificial illuminances on the blackboard, other classrooms outside the Southwestern classroom and the Southwest computer laboratory did not achieve the required values (on the desk: 500 lx). For uniform distribution of the light, there is no uniform light distribution in places.

Teacher - Lighting observation list results: According to the control list information, the teachers indicated that the natural lighting on the desks is sufficient when the lamps are turned off in the Southwestern, Southeast classrooms and the Southwestern computer laboratory classrooms and the natural lighting in the Northeast and Northwest classrooms and the Northwest office is insufficient. When the lamps were turned on, all the teachers stated that the integrated (natural and artificial) lighting on the desks was sufficient, except Northeast classroom. In addition, most teachers said that the lamps did not cause glare, but that they were neglected and that no maintenance was done on a regular basis.

Student - Lighting observation questionnaire results: According to the survey results, the students in the south classes generally were satisfied with the illumination level on the desk. Most of the students stated that the illuminance on the blackboard was insufficient. In addition, an average of 80% of the students complained about the glare on the blackboard. The reason for

this is that the blackboard consists of a bright surface material. Also, illuminance uniformity is inadequate in terms of required values.

The findings obtained by using the lighting observation lists, questionnaires and measurement methods used to determine the lighting conditions of the school have been investigated and it has been observed that these methods result in parallel with each other. In this study, problems in lighting system were identified with different methods as the first step of retrofit application.

In the scope of the study, it is aimed to make it easy to determine the characteristics of lighting systems of existing schools in general and to introduce a method by which people from different professions such as school administrations, teachers, students, lighting designers, architects, engineers and energy managers can be utilized. After the evaluation process, with the information obtained with the participation of users and experts, the most accurate solution proposal can be presented in lighting design. In this way, it will be possible to prevent the wrong solutions and the waste of time.

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