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Analysis of Effective Lighting Systems for University Classrooms

Dr. Sam C. M. Hui* and Mr. Kenneth K. Y. Cheng

Department of Mechanical Engineering, The University of Hong Kong
Pokfulam Road, Hong Kong, China
* E-mail: cmhui@hku.hk, Tel: (852) 2859-2123, Fax: (852) 2858-5415

ABSTRACT

Lighting system is very important for university classrooms and other educational facilities because it affects the learning environment and energy management of the universities. With growing concerns on energy efficiency and increasing demands to enhance the physical environment of classrooms, there is an urgent need to improve the lighting systems in university classrooms.

This paper presents the key findings of a research project aiming to investigate effective lighting systems for university classrooms. The theory and requirements of classroom lighting design were studied. Technical measurements and computer modelling were carried out on several university classrooms in Hong Kong. It is found that the size of classroom, type of luminaire, lighting control methods and lighting operations modes are critical factors affecting the system performance. For new classrooms, it is necessary to coordinate the architectural and interior designs with daylighting and artificial lighting so that optimal performance can be achieved. For existing classrooms, there is a need to re-examine their lighting systems to identify energy saving measures and promote good practices in lighting control and operation. It is believed that better lighting can be obtained by considering the needs of end-users and development of teaching pedagogy.

Keywords: Lighting systems, university classrooms, Hong Kong.

分析大學課室的有效照明系統

許俊民，鄭啓業
(香港大學機械工程系)

摘要

照明系統對大學課室和其他教學設施非常重要。它不但影響學習環境，而且和大學能源管理有莫大關係。現今社會越來越關注課室的教學環境和能源效率，因此有迫切需要改善大學教室中的照明系統。本文介紹一個探討大學課室有效照明系統的研究結果。研究包括一些課室照明系統的理論和要求，並於香港兩所大學的教室進行一些技術測量和電腦模擬分析。結果發現教室的大小、燈具類型、控制方法和運作模式，是影響系統性能的重要因素。天然光和人工照明的互相協調有助優化照明系統的性能。現有教室有必要重新審查其照明系統，找出節能措施、良好的照明控制和運作方法。良好的照明系統一定要深入考慮用戶的需要及將來教學模式的發展。

關鍵詞: 照明系統，大學課室，香港。

1. INTRODUCTION

Lighting is a very important element in educational facilities especially in classrooms. Classroom lighting affects significantly the learning and teaching environments as well as the energy management of buildings (CIBSE, 1991; DiLouie, 1994; DUA, 2003). With increasing usage of media and technology in teaching spaces, the lighting systems in university classrooms should be flexible and efficient (Kirby, 2007; Niemeyer, 2003). Effective classroom lighting should meet the needs of educational purpose, and also be environmentally friendly with high energy-efficiency (NEEP, 2002; SCE, 2004).

This paper presents the key findings of a research project aiming to investigate effective lighting systems for university classrooms. The basic theory and requirements of classroom lighting design are studied. Some key factors of classroom lighting are identified by technical measurements and computer modelling carried out in several university classrooms in Hong Kong. The critical design factors for good classroom lighting are discussed and some suggestions are provided for enhancing the performance of the lighting systems in both new and existing classrooms.

2. CLASSROOM DESIGN AND LIGHTING SYSTEMS

In recent years, the teaching-learning concepts are evolving very fast because new teaching methods, instructional technology and educational facilities have been brought into classrooms (NJSCC, 2007; Stevenson, 2007). Nowadays, 'smart' classrooms contain not only blackboards, seats and tables, but also audio-visual (AV) equipment, video projector and screens, computer system, control systems, etc (Kirby, 2007; Niemeyer, 2003). The needs of the users are changing and this will affect classroom planning and design (Allen, *et al.*, 1996; DUA, 2003; CCWG, 2007). Since classroom design and layout influence significantly the lighting system, it is necessary to study the key design issues and future trends of university classrooms.

2.1 Classroom Design Issues

In general, university classrooms can be divided into three categories: lecture theatres, lecture rooms and teaching rooms (CIBSE, 1991). Some special purpose rooms such as laboratories, computer rooms and art rooms are not included in the present study.

(a) Lecture Theatres (Large rooms, 80-240 persons)
Lecture theatres are large rooms that are used for formal lectures. Usually, they have ranked floors and/or balconies or galleries with fixed seating. The audience size presents the main difference between lecture rooms and lecture theatres. There is no point to provide ranked seats for less than 60 audiences in a room, whereas, ranked seating is necessary if there are more than 80 audiences unless the lecturer is raised on a stage or podium.

(b) Lecture Rooms (Medium-size rooms, 60-140 persons)
Similarly, lecture rooms are also used for delivery of formal lectures. However, lecture rooms usually have flat floor and fixed seating. This category includes rooms with a raised step or podium for the lecturer, and rooms with one or two raised steps towards the rear of the seating.

(c) Teaching Rooms (Small Classrooms, < 60 persons)
Teaching rooms are used for class teaching and tutorial purposes. They usually have a capacity less than 60 and are equipped with simple AV system. They have no raised step or podium and no fixed furniture except chalkboards and projection screens.

In principle, the classrooms are places of social and personal interaction, where learning takes place and where creative thinking is encouraged (OCP, 2000). The primary objective of classroom design is to achieve the best possible arrangement of architectural elements and teaching facilities so that both teaching and learning is maximized. Design of classroom spaces requires a balanced relationship between architectural/construction skills and teaching/AV disciplines. Major elements commonly found in university classrooms include moveable or fixed chairs, boards and AV facilities like instructor lectern, projection screens, computers, overhead, slide and data projectors (CCWG, 2007).

2.2 Trends of Classroom Design

Our society and educational system have changed radically in recent decades (Kirby, 2007). Classroom design must reflect changes in educational styles and support new ways of learning and new models of pedagogy (Jensen, *et al.*, 2003). For example, learning modes have expanded beyond the formal lectures to include group learning, seminar discussions, independent work, and informal learning. To encourage the interactive learning, classrooms should be more flexible and more diverse in shape and format.

Traditional classrooms are being replaced by some learning rooms and exploratory centres (Stevenson, 2007). The ideas of “learning commons” have been suggested as a good direction for collaborative environment on campus. The learning commons brings together services that support students in their learning, writing, research, numeracy and use of technology. This trend would present different requirements for classrooms and their lighting systems.

In addition, classroom design is trying to adapt to the advancement of information technology. As many reference materials are now available in electronic form or through the Internet, paper-based learning materials are reduced. Technology supplements texts; laptops are ubiquitous. As a result, increased use of electronic resources will affect the visual needs of classrooms. For example, electronic whiteboards or other e-learning tools may be introduced into university classrooms. Glare control becomes a critical issue for the viewing of computer screens. Therefore, the lighting systems should be designed to accommodate the e-instruction and digital learning of tomorrow.

2.3 The Role of Lighting Systems

The role of the physical environment in enhancing teaching and research has been studied in Clark (2002). The overarching goal of education is to provide a good visual environment for all the users, including students and instructors, in the classrooms to support the learning and teaching process. This can be achieved only if the occupants can see their visual tasks accurately, quickly, and comfortably. A well-designed lighting system can help to make classroom environment attractive and pleasant, reinforce feelings of spaciousness, delineate areas of different functions, simulate learning, and improve behaviour (IESNA, 2000a; Karlen and Benya, 2004).

The lighting in a lecture space must reveal the lecturer to the audience and the audience to the lecturer and also provide for the other visual tasks involved. The visual tasks include observing demonstration, reading words on chalkboard and the notes taking. Notes-taking has to go on when slides, films or video are used at the same time (CIBSE, 1991).

DUA (2003) pointed out that lighting and electrical power systems in the classrooms shall be energy-efficient, easy to maintain and modify, and provide appropriate lighting levels for all room activities that are easy to control. Figure 1 shows an example of lighting zones for a typical small classroom.

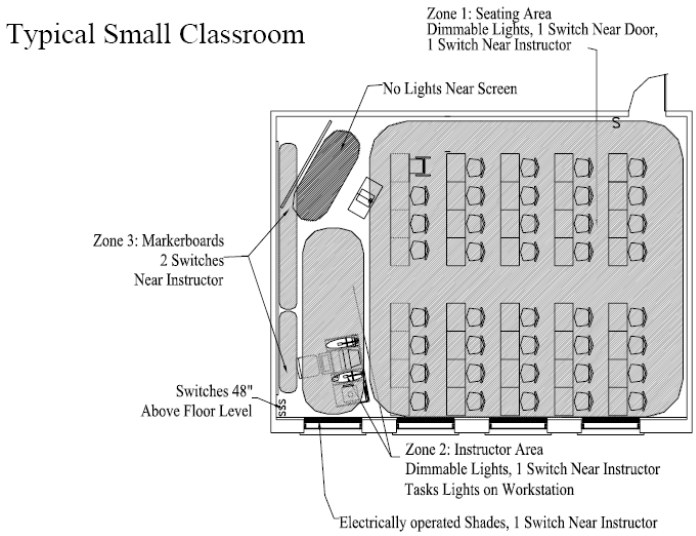


Figure 1. Lighting zones for a typical small classroom (DUA, 2003)

2.4 The Use of Natural Daylight

Daylight is a good quality source of light and can help to achieve energy saving in electric lights. Some studies show that students inside a classroom with natural daylight access can perform better than those without access to daylight (Benya, 2001; NEEP, 2002). Natural daylight can enhance colour and appearance of objects. It can also vary the light levels, stimulating visual interest. It is a healthy and sustainable light source. Although natural light is often preferred by students, it is hard to control in practice and may cause problems such as secondary glare and other distractions (CIBSE, 1991). Therefore, some classroom design guides suggest not to include daylight in lecture halls (Allen, *et al.*, 1996; OCP, 2000). Light levels and types in windowless rooms must be varied as well to eliminate gloom.

In fact, daylight could be introduced into university classrooms by controlling the access of natural light through skylights, roof or windows. When designing the illumination and views, both natural and artificial light sources should be considered to ensure the clarity and nature of the view afforded to the student. It is believed that a balance of natural and artificial light is most likely to achieve the optimum learning environment. Other design factors such as solar heat gain, positioning and control of electric lights should also be evaluated.

3. ANALYSIS OF CLASSROOM LIGHTING IN HONG KONG

In order to evaluate the lighting systems in local universities, assessment and analysis were carried out in 5 university classrooms in Hong Kong.

3.1 Technical Measurements

Technical measurements were carried out in two universities, namely, The University of Hong Kong (HKU) and City University of Hong Kong (CityU). The illuminance levels on the task performing surfaces such as tabletop of the audience area and the surface of writing boards were measured. Also, the luminance levels at some potential glare locations were assessed and the correlated colour temperature of the light sources was evaluated. Figure 2 shows the pictures of the 5 university classrooms being studied. Table 1 gives a summary of the classroom capacity and type.

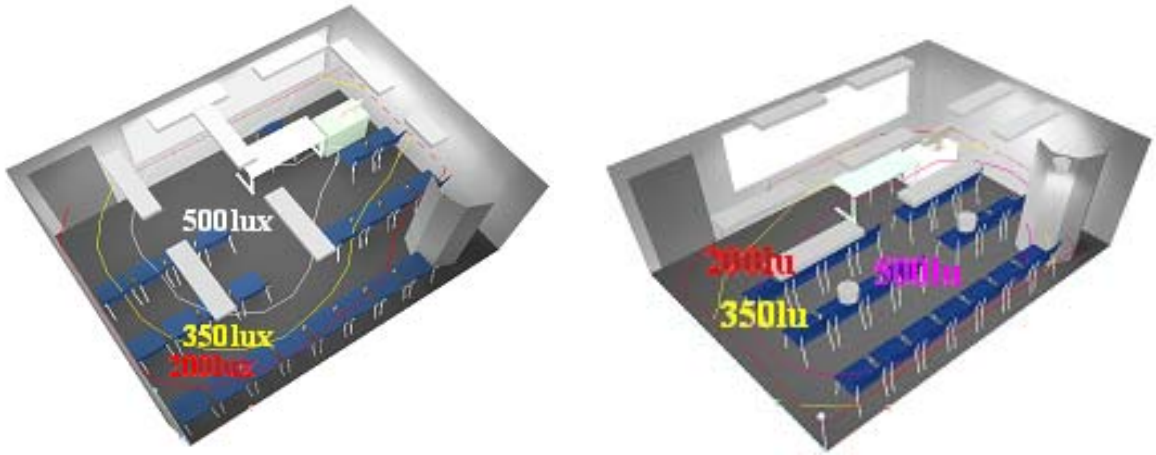
Figure 2. University classrooms in Hong Kong being studied

Table 1. Classrooms chosen for technical measurements

Classroom Code	Location	Capacity (persons)	Description
CYC-A	HKU	117	Lecture theatre
LE6	HKU	137	Medium-size classroom
S702	HKU	25	Small classroom
G5-317	CityU	60	Medium-size classroom
G5-128	CityU	20	Small classroom

3.2 Computer Modelling

To study the details of the classroom lighting situation, computer simulation models were set up using DIALux 4.4 lighting analysis software (www.dialux.com). The simulation results were compared with the measurements and some lighting improvement measures were evaluated by modifying the simulation models. Figure 3 shows a comparison of simulation results between a base case (existing situation) and an alternative case.



(a) Base case (existing situation) (b) Alternative case

Figure 3. DIALux simulation results of a university classroom

3.3 Summary of the Evaluation

The results of technical measurements and modelling are used to evaluate the lighting performance of the 5 classrooms. Two operation modes (full mode and projection mode) were assessed. In the projection mode, the lighting at the front near the screen is turned off. Table 2 gives a summary of the evaluation.

Table 2. Summary of the evaluation for the 5 classrooms

Classroom	**Lighting system**	**Lighting Performance (full mode)**	**Lighting Performance (projection mode)**	**Control methods**
CYC-A	T8 lamps with incandescent downlights	Some positions have very low lighting levels	Very low lighting levels on front rows and sides of the room	Two switches next to two entrances and one preset control panels
LE6	T8 lamps with incandescent downlights	Some positions have very low lighting levels	Quite a lot of positions have very low lighting levels	One switch next to the board and one next to the entrance
S702	T8 lamps	Over lighted and glare problems exist	Some positions do not have sufficient lighting levels	Only one switch that is far from lecturer's position
G5-317	T8 lamps	Not enough brightness	Not enough brightness	One switch next to the board and one next to the entrance
G5-128	T8 lamps	Not enough brightness	Not enough brightness	One switch next to the board and one next to the entrance

It is found that the projection mode is often a weak point for the lighting systems because when some lights are switched off to ensure a better projection image, the lighting level at the students' area might not be sufficient for normal reading and studying. This is obvious when the lighting zones are not well designed. The situation will also be worsened when slide or video presentation is made in the classroom because it requires a much lower level of background illumination.

Another common problem is that the lighting levels for seats closed to the walls and corners are not adequate. This issue of uniformity is often created when many seats are placed to achieve the maximum capacity of the room. If the lighting layout and wall reflectance have not been adjusted to reduce those dim positions, students will suffer when they do not get to the best seats in the classroom.

From the energy management's viewpoint, the lighting systems in the 5 classrooms could be enhanced by adopting luminaires with better energy efficiency. For example, T-5 fluorescent lamps and compact fluorescent downlights might be used to replace the existing light fittings. The lighting controls could also be enhanced to enable better zoning, uniformity and convenience.

3.4 Suggestions for Improvement

The 5 classrooms being studied represent the typical situation in Hong Kong. The land is so valuable and the space is limited in the local universities. Therefore, the classroom seating is quite fully packed and some classrooms are created by refurbishing the offices or other spaces in the university. This gives rise to some limitations and constraints in the design of the classrooms and their lighting systems. For example, some student seats are put near the

walls, corners or columns; the shape and configuration of the classroom make lighting zones and controls more difficult.

In order to achieve effective lighting in the classrooms, some suggestions are developed by studying the recommendations of relevant design guides (Allen, *et al.*, 1996; Benya, et al, 2003; CIBSE, 1991; DUA, 2003; CCWG, 2007; IESNA, 2000b; IESNA, 1988; NJSCC, 2007; OCP, 2000). A summary of the key suggestions is given below.

- Avoid light that creates glare or reflections on computer screens:
    - Use indirect natural and artificial lighting
    - Use indirect or parabolic fluorescent lights that can reduce the risk of glare
    - Avoid placing lights behind instructor workstations
- Enhance the ability to see projected images and read lecture notes:
    - Lighting configuration and control optimised to suit presentation and projection needs
    - Light levels at the front of the room require special attention to avoid washing out projected images.
    - Task light for instructor workstations that avoid light spillover to screens/monitors
    - Lights focused on markerboards that do not wash out screen images
- Increase energy efficiency by using:
    - Lighting controls that automatically turn off lights in vacant rooms
    - Energy-efficient dimmable lighting for seating areas
    - Lighting zones and levels appropriate for the classroom
    - Daylighting strategies as far as possible
- Provide lighting and audio-visual system controls that are easy to use:
    - Pre-set light levels on the audio-visual control system menu
    - Suitable locations for installing wall-mounted switches
- Ensure proper maintenance and cleaning for the light fittings and room surfaces

4. DISCUSSIONS

Lecture facilities has a significant impact on student learning experience (Fleming and Storr, 1999). Classroom lighting is a fundamental issue that must be considered when planning, designing and refurbishing university teaching spaces. For new classrooms, there are usually less constraints and it is possible to satisfy all the goals for ideal lighting. For existing and refurbished classrooms, the scope of optimising the environment will vary and some key factors should be assessed and evaluated during the design process.

4.1 Critical Factors Affecting Lighting Performance

The critical factors affecting lighting system design in the three different types of university classrooms are explained.

(a) Small Classrooms

They usually have a simple lighting system with movable seats and tables oriented so that students and instructors can easily interact with each other. They do not have special-purpose equipment and power socket points for student use that would make the room unsuitable for

multiple disciplines. Because the room size is small, lighting zoning may not be ideal. But the projection image and light switches can be managed quite easily.

(b) Medium-size Lecture Rooms

These rooms typically have a multi-media AV system, with movable seats oriented towards the front of the room, and writing surfaces for each student. They do not have special-purpose equipment for student use. Because they are larger in size, it is easier to define the zoning for the lighting system. These rooms require a good design in lighting control and viewing positions since there would be a few door entrances and the back of the classroom may be quite far away from the board or projection screen.

(c) Large Lecture Theatres

They usually have fixed seatings, work surfaces and titled floor, with seats normally arranged in a gentle arc to enhance the viewing angles. A lecture theatre or auditorium is often equipped with sophisticated multi-media AV system (such as the room CYC-A in our study). Because of the size and shape, the lighting zones and controls will be more complicated. Lighting controls is often located to the instructor station and have a few options: full-on, 2 or 3 projection settings, and full-off. Dimmable directional downlights are used to allow adjustment of the lighting level for the work surface.

4.2 Important Issues for New Classrooms

Stevenson (2007) has highlighted that in future classrooms, papers would be replaced by computers and education would require a flexible multi-purpose classroom. Such changes would bring a new challenge to lighting designers. Two important issues are discussed.

(a) Review of Lighting Requirements

As E-instructions become more and more popular in education purpose, computers are often installed in classrooms. Students can read the notes directly from the monitors or even from their personal digital assistant (PDA) or similar types of handheld computers. As such devices emit lights themselves, the lighting levels required would be largely reduced. That means, the lighting levels required in classrooms would no longer be 500 lux. In future classrooms, lighting design's main mission is no longer providing sufficient lights for reading handouts. The mission would change to avoid reflected glare inside classrooms which would affect the viewing of monitors.

Diffused lighting makes spaces more inviting (Kirby, 2007). Indirect lighting may outweigh direct lighting in future classrooms. Lights emitted upwards to light up the ceiling and are reflected back to the task area. Indirect lighting would feature more balanced brightness and visual comfortable, reduced glare.

(b) Flexible Lighting Controls

Classrooms should be multi-purpose in order to meet the trends of education with more interactive and students-based teaching methods. To satisfy this requirement, flexible lighting controls are required. Kirby (2007) pointed out that lighting control is as important as the brightness or quality of the light. To be effective, teachers should be able to adjust the lighting quickly to respond to changing educational needs. Also, it is necessary to vary the

light to match the needs of various educational scenarios. For example, a group discussion requires brighter light than a presentation. Video conferencing and broadcasting will require specific lighting and audio concerns.

A common approach is to preset several teaching scenarios on the control system, making it easy for instructors to adjust lighting to the right level for lecture, discussion, video, oral presentation, etc. In some situations, classrooms could be provided a stage with spotlights in order to meet the needs of drama or performance arts. At the minimum, it is best to provide three zones in each room – one for seating, one for the lecturer area and a third for the teaching wall. When possible, each of these zones should themselves be variable for different teaching modes, sets of instructors or teaching media.

4.3 Good Practices for Existing Classrooms

For existing classrooms, there is a need to re-examine their lighting systems in order to identify energy saving measures and promote good practices in lighting control and operation (DiLouie, 1994). Lighting surveys and audits might be carried out to evaluate the lighting system and current visual environment (Fetters, 1998). When renovating existing classrooms, which is very common in Hong Kong nowadays, it is important to consider how to leverage technology in the way that best supports learning. It should be noted that one classroom cannot accommodate all possible uses. It is necessary to know the development of teaching pedagogies, identify the most important potential uses of each specific classroom and design to reinforce those needs.

After assessing the 5 existing classrooms in Hong Kong, some common problems have been identified. A summary of the recommendations to resolve them is given below.

- Lighting level at seats close to the walls is not sufficient:
  - Luminaires should be added or placed close to the walls.
- Lighting level at the front student area is not sufficient (during projection mode):
  - Luminaries above that student area should be put into a separate zone.
  - Additional luminaires such as downlights might be added in order to increase the lighting level.
- Lighting for the writing board is not satisfactory:
  - Luminaires for the board lighting should be selected and designed with good uniformity and little or no reflected glares.
- Lighting level for the student area is not uniform:
  - Luminaires should be uniformly placed above the seats in the student area.
- It is not convenient to control the lighting system:
  - Control systems should be added in lecturer's area and entrances of the room.
- Current lighting system is not energy efficient:
  - Replace inefficient lighting unit like incandescent lamps by more efficient one.
  - Regular cleaning and maintenance works should be done on the light fittings and room surfaces.
  - Assess and consider the possibilities of using daylight.
  - Bear in mind the orientation and the layout of classrooms to get the best use of natural daylight.
  - Other new technologies like LEDs or light pipes should be considered.

5. CONCLUSIONS

Lighting system is very important for university classrooms because it affects the learning environment and energy management of the universities. With growing concerns on energy efficiency and increasing demands to enhance the physical environment of classrooms, there is an urgent need to improve the lighting systems. It is found out from our study that effective lighting systems in the local universities in Hong Kong might not be easily achieved as there are certain limitations and constraints such as the lack of teaching spaces.

The success of the classroom as a teaching space could be measured by its ability to support and enhance teaching. Technical measurements and computer modelling were carried out on 5 typical university classrooms in Hong Kong. It is found that the size of classroom, type of luminaire, lighting control methods and lighting operations modes are critical factors affecting the system performance. Some suggestions to improve the current situations are developed by studying the recommendations of relevant design guides and considering the practical conditions of the classrooms.

For new classrooms, it is necessary to coordinate the architectural and interior designs with daylighting and artificial lighting so that optimal performance can be achieved. For existing classrooms, there is a need to re-examine their lighting systems to identify energy saving measures and promote good practices in lighting control and operation. It is believed that better lighting can be obtained by considering the needs of end-users and development of teaching pedagogy.

REFERENCES

Allen, R. L., *et al.*, 1996. *Classroom Design Manual*, third edition, Academic Information Technology Services, University of Maryland, College Park, MD.

Benya, J. R., 2001, *Lighting for Schools*, National Clearing house for Educational Facilities, obtained from Benya Lighting Design, www.benyalighting.com

Benya, J., *et al.*, 2003. *Advanced Lighting Guidelines*, 2003 ed., New Buildings Institute, White Salmon, Washington.

CCWG, 2007. *Emory College Classroom Design Guide*, College Classroom Working Group (CCWG), Emory University, Atlanta, GA.

CIBSE, 1991. *The Visual Environment in Lecture, Teaching and Conference Rooms*, LG5:1991, Chartered Institution of Building Services Engineers (CIBSE), London.

Clark, H., 2002. *Building Education: The Role of the Physical Environment in Enhancing Teaching and Research*, Institute of Education, University of London, London.

DiLouie, C., 1994. *The Lighting Management Handbook*, Fairmont Press, Lilburn, GA.

DUA, 2003. *Design Guidance: Learning Environments*, Division of the University Architect (DUA), University of Cincinnati, Cincinnati, OH.

Fleming, D. and Storr, J., 1999. The impact of lecture theatre design on learning experience, *Facilities*, 17 (7/8): 231-236.

Fetters, J. L., 1998, *The Handbook of Lighting Surveys and Audits*, CRC Press, Boca Raton, FL.

IESNA, 2000a. *The IESNA Lighting Handbook: Reference & Application*, 9th ed., Illuminating Engineering Society of North America (IESNA), New York.

IESNA, 2000b. *Recommended Practice on Lighting for Educational Facilities*, IESNA School and College Lighting Committee, Illuminating Engineering Society of North America (IESNA), New York.

IESNA, 1988, *American National Standard: Guide for Educational Facilities Lighting*, Illuminating Engineering Society of North America (IESNA), New York.

Jensen, E., *et al.*, 2003, *Environments for Learning*, The Brain Store, San Diego, CA.

Karlen, M. and Benya, J. R., 2004. *Lighting Design Basics*, John Wiley & Sons, Hoboken, NJ.

Kirby, C. J., 2007. *Trends in Classroom Design: Smart classrooms are more than a place to plug in a laptop*, Einhorn Yaffee Prescott Architecture & Engineering, P.C., Albany, NY. Available at www.eypaedesign.com.

NEEP, 2002. *Classroom Lighting Knowhow*, Northeast Energy Efficiency Partnerships, Inc. (NEEP), Lexington, MA.

Niemeyer, D., 2003, *Hard Facts on Smart Classroom Design: Ideas, Guidelines, and Layouts*, Scarecrow Press, Lanham, MD.

NJSCC, 2007, *21st Century Schools Design Manual*, New Jersey Schools Construction Corporation (NJSCC), NJ.

OCP, 2000. *General Lecture Hall Design Guidelines*, Office of Capital Planning (OCP), University of Maryland, Baltimore County, Baltimore, MD.

SCE, 2004. *Classroom Lighting Guide*, Southern California Edison (SCE), Irwindale, CA.

Stevenson, K. R. 2007, *Educational Trends Shaping School Planning and Design*, Department of Educational Leadership and Policies, College of Education, University of South Carolina, SC.