

**INVESTIGATION OF EFFICIENT LIGHTING
SYSTEM DESIGN IN EDUCATIONAL BUILDINGS
AT THE EXAMPLE “MUNICIPAL SCHOOL OF LA
TOUR DE SALVAGNY**

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**EĞİTİM BİNALARINDA ETKİN AYDINLATMA
TASARIMININ İNCELENMESİ SALVAGNY
(FRANSA) ŞEHİR OKULU ÖRNEĞİ**

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ABBREVIATIONS

VDT	: Visual Display Terminal
EN 12464(E)	: Light and Lighting European Standard
UGR	: Unified Glare Rating
DSE	: Display Screen Equipment
HID	: High-Intensity Discharge
EIA	: Energy Information Administration
CIBSE	: The Chartered Institution of Building Services
GLS	: General Lighting Service
CRI	: Color Rendering Index

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SYMBOL LIST

E_m	: Maintained Illuminance
UGR_l	: Unified Glare Rating Limit
R_a	: Minimum Color Rendering
a_z	: Solar Elevation Azimuth
a_s	: Solar Azimuth
a_t	: Solar Altitude
a_p	: Solar Profile Angle
$L(\gamma)$	: luminance of sky element
θ	: angle from sun to sky point
γ	: sky point altitude
γ_s	: sun altitude
L_z	: zenith luminance

EĞİTİM BİNALARINDA ETKİN AYDINLATMA TASARIMININ İNCELENMESİ SALVAGNY (FRANSA) ŞEHİR OKULU ÖRNEĞİ

ÖZET

Bu çalışmada, eğitim binalarının enerji etkin aydınlatma tasarımının temel prensipleri incelenmiştir. Altı bölümden oluşan bu tezin birinci bölümünde tezin amaçları ve içeriği anlatılmıştır. İkinci bölümde ise eğitim binalarında aydınlatma sistemlerinin tasarım prensipleri incelenmiştir. Yine bu bölümde eğitim binaları için görsel gereklilikler, enerji yönetimi ve bakımı, aydınlatma sistemleri ve özel uygulamalar incelenmiştir. Bir sonraki bölümde enerji etkin aydınlatma sistemi tasarımında doğal ve yapay parametrelerin yanı sıra iklim koşullarının da etkisi incelenmiştir. Dördüncü bölümde, eğitim binalarında bütüncül aydınlatma stratejileri ele alınmış ve eğitim binalarında öncelikli olarak doğal ve yapay aydınlatma sistemleri ve uygulamaları genel olarak değerlendirilmiş daha sonra bütüncül aydınlatma yöntemleri ve uygulamaları incelenmiştir. Beşinci bölümde, Avrupa birliği 6. çerçeve programı kapsamındaki “Sürdürülebilir Mimarinin Kamu Kullanımındaki Binalarda Uygulamaları” (Sustainable Architecture Applied to Replicable Public-Access Buildings) projesi içinde yer alan Salvagny Şehir Okulu (Municipal School of La Tour De Salvagny) örnek çalışması incelenmiş, projenin amacı ve tasarım aşamasında değerlendirilmesi gereken tüm parametreler belirlenmiştir. Belirlenen bu parametreler ışığında var olan aydınlatma tasarımına alternatif bir aydınlatma sistemi önerilmiştir. Daha sonra, bu sistemlerin çeşitli bilgisayar yazılımları yardımı ile benzetimleri elde edilmiştir. Elde edilen benzetimlerle ışık dağılımı ve enerji harcamaları kapsamında karşılaştırmalar yapılmıştır. Bu bölümde önerilen aydınlatma sisteminin enerji tüketimi belirlenmiştir. Altıncı bölümde ise enerji etkin aydınlatma tasarımının eğitim binalarındaki önemi, bina harcamaları ve kullanıcılar üzerindeki fiziksel ve psikolojik etkileri değerlendirilmiştir. Sonuçlar tartışılmış ve bazı önerilerde bulunulmuştur.

INVESTIGATION OF EFFICIENT LIGHTING DESIGN IN EDUCATIONAL BUILDINGS AT THE EXAMPLE “MUNICIPAL SCHOOL OF LA TOUR DE SALVAGNY”

SUMMARY

In this study, the basic principles of efficient lighting design of educational buildings are investigated. The thesis consists of six chapters. In the first chapter the scope and the aim of the study is described. In the second chapter, the lighting system design principles for educational buildings are set out. Afterwards, regarding educational buildings the visual requirements, energy management, maintenance, lighting systems and special applications set out. The next chapter, besides the natural and built environmental parameters focuses on climate responsive design parameters researched in energy efficient system design. The fourth chapter deals with the integrated lighting strategies for educational buildings initially natural and artificial lighting systems and their applications are evaluated. Furthermore integrated lighting methods and their applications are investigated. In the fifth chapter, scope of EU 6th Framework Projects, Municipal School of La Tour De Salvagny as an example of Sustainable Architecture Applied to Replicable Public-Access Buildings Project is studied. The case study is put forward and in that manner, the range and aim of the project is specified. In light of the defined parameters, an alternative lighting system is suggested in stead of the existing one. Later, the systems are simulated with the use specific lighting design software. A comparison is made between original design and proposed design with in the scope of daylight distribution and energy consumption. At last, artificial lighting energy consumption is calculated for the proposed project. Finally, in the sixth chapter, the importance of energy efficient lighting design in educational buildings, building expenditure and physical and physiological impacts are evaluated, results are discussed and some solutions are suggested.

1. INTRODUCTION

In the world newly concerned about carbon emissions, global warming, and sustainable design, the planned use of natural light in non-residential buildings has become an important strategy to improve energy efficiency by minimizing lighting, heating, and cooling loads. The introduction of innovative, advanced daylighting strategies and system can considerably reduce a building's electricity consumption and also significantly improve the quality of light in an indoor environment.

Before the 1940s, daylight was the primary light source in buildings. An artificial light informs of oil, gas lamps or candles completely supplemented the natural light. In the short span of 20 years, electric lighting had transformed the workplace by meeting most or all of the occupants' lighting requirements. Recently, energy, economical and environmental concerns have made daylighting a rediscovered aspect of building lighting design. The physics of daylighting has not changed since its original use, but the building design to use it has. Daylighting is often integrated into a building as an architectural statement and for energy savings. However, benefits from daylighting extend beyond architecture and energy. The psychological and physiological aspects of natural light also have to be considered. The comforting space and connection to the environment provided to building occupants provide benefits beyond the energy savings to building owners and managers [1].

The most important subject in the design of educational buildings is to provide comfort conditions, particularly thermal, acoustical and visual. The visual conditions in classrooms, where the pupils spend most of their time are not only important for the visual tasks, but also play an important role on the performance of their intellectual activities. Therefore, fulfilling the physiological and psychological needs in classroom is one of the designers' responsibilities [2].

A well-integrated daylight design has a greater positive impact on a school than any other sustainable design strategy.

The aim of this study is to set principles of energy efficient lighting system design for educational buildings and to apply these principles to minimize the artificial lighting energy consumption of a Case Study building. Information on general lighting system design principles in educational buildings, visual requirements, energy management and maintenance are given and comparison of two design alternatives for a classroom in Municipal School of La Tour De Salvagny in terms of the lighting energy consumption is carried out.

2. LIGHTING DESIGN PRINCIPLES IN EDUCATIONAL BUILDINGS

There are continuing challenges and opportunities for the lighting designer of educational facilities. New educational buildings reflect new philosophies of education and new technologies for instruction. Many existing educational buildings need retrofitting to improve the new visual environment and to reduce energy usage. In general, it is not sufficient simply to replace old lighting equipment. Innovative lighting designs are often required to meet new visual needs and to reduce energy consumption [3]. When building or renovating a school, put up for consistent improved appearance lighting systems are crucial for two reasons. At the first because of the inordinate amount of energy especially if calculated as primary energy that electric lighting can consume compared to the rest of a facility and the second because of the effect that light (both electric light and daylight) can have on the behavior and performance of the building occupants. Lighting systems must be selected carefully to ensure that both the facilities and people using them can operate effectively and efficiently [4]. The overarching goal of educational facility lighting is to provide a visual environment for both students and instructors that are supportive of the learning processes. This can be achieved only if the occupants can see their visual tasks accurately, with required speed and comfortably. Uniform horizontal illuminance provided for an educational facility does not necessarily ensure high levels of visual performance because of the great variety of visual tasks, including visual display terminal (VDT) tasks, found in a school. The visual tasks become more varied as the student moves from the elementary school the high school to university.

Lighting also must be response to psychological and emotional needs of learners. Lighting can make a school pleasant and attractive, reinforce feelings of spaciousness, delineate areas of different functions, stimulate learning, and improve behavior.

2.1 Visual Requirements in Educational Facilities

Providing suitable lighting for the tasks and activities of a school is crucial for visual comfort. For providing visual comfort, it is necessary to balance and compose light and shade. For better understanding certain definitions have to be made further explanations.

In EN 12464-1:2002 (E) European Standard gives the terms and definitions following:

- Visual task: visual elements of the work being done. The main visual elements are the size of the structure, its luminance, its contrast against the background and its duration.
- Task area: Partial area in the work place in which the visual tasks are carried out. For places where the size and/or location of the task area are unknown, the area where the task may occur shall be taken as the task area.
- Illuminance uniformity: Ratio of minimum illuminance to average illuminance on a surface [5].

As guidance of these definitions, it should be noted that lighting not only affects visual performance but also performance of non visual tasks. Investigation on the effect of lighting upon intellectual performance, for instance, have shown significant improvements in memorizing, logical thinking, concentration and intelligence level the quality of lighting was improved. Quality factors that are important in this respect are the illuminance and the luminance distribution in the room [6].

The visual task of pupils in classrooms consists of reading and writing in books, reading of cursive writing at the board, reading from maps and wall charts, prolonged looking at the teacher, looking at the television, slide or film-projection, etc. Apart from this multitude of different visual tasks it is a characteristic of visual demands imposed in classrooms, that different tasks must be performed repeatedly in succession. For instance there may be a need to change repeatedly between reading at long distance and reading or writing at short distance. This involves changes in accommodation and convergence and may also entail changes in adaptation when slide projection must be viewed and

notes made in dimmed lighting. The main visual task of teachers are observing the students and reading his/her notes, or looking involved in performing demonstrations at demonstration benches [7].

Quality and quantity of illumination are interdependent. A lighting system may provide the appropriate illuminance level for a task, but reflected glare, veiling reflections, and excessive luminance in the field of view can compromise visibility and therefore encourage the perception that the system provides low lighting quality [8]. For general teaching spaces a level of light is required which makes it easy to carry out small and difficult tasks. Reading and writing, typical school activities require a minimum level of illuminance with relatively high illuminance uniformity over the task area. Higher levels should be used for more detailed work and for particularly demanding visual tasks, such as using a machine in the workshop or studying fine details in the art room. The higher levels can be provided by using adjustable task lights, which supplement the general illuminance of the particular area provide localized lighting to complement ambient lighting [9].

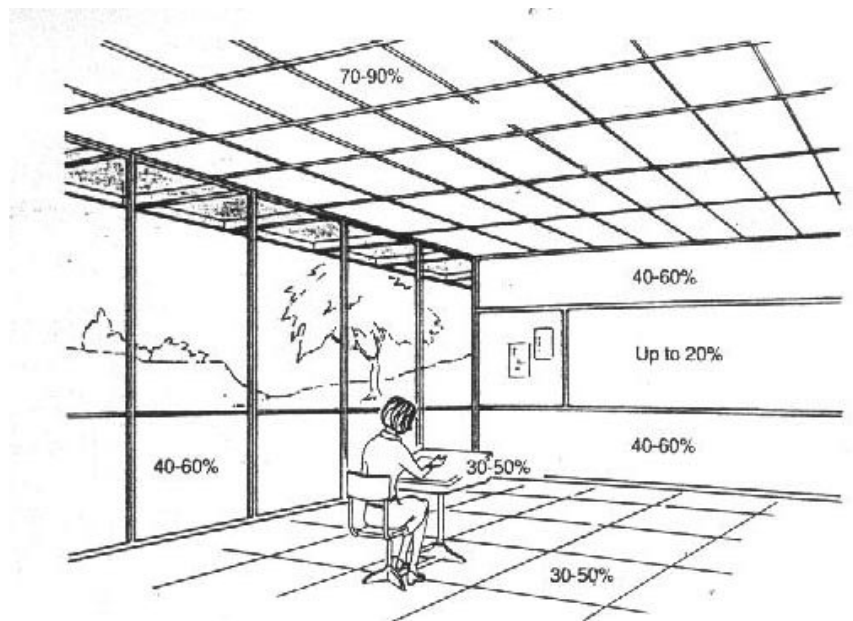


Figure 2.1: Recommended reflectances for surfaces and furnishing in the classroom [3].

The brightness of the various surfaces in the normal field of view must be kept within accepted limits. When the eye fixates on a task, an adaptation level is established. As the eye shifts from one luminance, such as for a book, to another luminance, such as board, it must adapt to the new level. For good visual performance and comfort, the luminance of any surface normally viewed directly should not be greater than five times the luminance of task. No large area, regardless of its position in the room, should have less than one-third the luminance of the task.

Walls, including task boards and large cabinets or cupboards mounted on the wall, should have nonspecular surfaces with 40 to 60 % reflectance (Figure 2.1). The portion of the wall above the level of the luminaries should have minimum reflectance of 80%. The reflectance should be as high as practicable using ready available materials for floor covering with the objective of having a reflectance approaching 25% [3]. An educational space must minimize glare. Electric or natural light sources that are too bright can produce discomfort and impair vision. To minimize the glare, fenestration controls should prevent direct sunlight from entering classrooms. Shades, blinds, louvers, baffle systems, and roof overhangs can be used. Optical control devices, such as louvers, or prismatic lenses should be incorporated into the luminaries well to minimize glare.

Color plays an important role in learning and light sources should have a good color rendering performance: this will enable accurate color judgments to be made. Because this requirement is necessary for number of school activities; art, science and craft subjects, it is recommended that a good color rendering light source is used in all teaching spaces [9].

For good lighting practice it is essential that in addition to the required illuminance, qualitative and quantitative needs are satisfied. Lighting requirements are given in the determined by the satisfaction of three basic human needs; visual comfort (where students have a feeling of well-being; in an indirect way also contributing to a high productivity level), visual performance and safety.

The lighting requirements for educational premises and activities are given in Table 2.1. Column 1 lists the reference number for each interior (area), task or activity. Column 2 lists those interiors, tasks or activities, for which specific requirements are given. If the particular interior (area), task or activity is not listed, the values given for a similar, comparable situation should be adopted. Column 3 gives the maintained illuminance E_m on the reference surface for the interior (area), task or activity given in column 2. Where UGR limits (Unified Glare Rating limit, UGR_L) are applicable to the situation listed in column 2, they are listed in column 4. Column 5 gives the minimum color rendering indices (R_a) for the situation listed in column 2. In column 6, advice and footnotes are given for exceptions and special applications for the situations listed in column 2 [5].

Table 2.1: Lighting requirements for educational premises tasks and activities [5].

Type of interior, task or activity	E_m lx	UGR_L	R_a	Remarks
Classrooms, tutorial rooms	300	19	80	Lighting should be controllable.
Classrooms for evening classes and adults education	500	19	80	Lighting should be controllable.
Lecture hall	500	19	80	Lighting should be controllable.
Blackboard	500	19	80	Prevent specular reflections.
Demonstration table	500	19	80	In lecture halls 750 lx.
Art rooms	750	19	80	
Technical drawing rooms	750	19	80	
Practical rooms and laboratories	500	19	80	
Handicraft rooms	500	19	80	
Teaching workshop	500	19	80	
Music practice rooms	300	19	80	
Computer practice rooms	300	19	80	
Language Laboratory	300	19	80	
Preparation rooms and workshops	500	19	80	
Entrance halls	200	19	80	
Circulation areas, corridors	100	19	80	
Stairs	150	19	80	
Assembly halls	200	19	80	
Teacher rooms	300	19	80	
Library; bookshelves	200	19	80	
Library; reading areas	500	19	80	
Stock rooms for teaching materials	100	19	80	
Sports halls, gymnasiums	300	19	80	For more specific activities; the requirements of EN12193 shall be used.
School anteens	200	19	80	
Kitchen	500	19	80	

European standard prEN 12464-1 specifies lighting requirements for indoor work places, which meet the needs for visual comfort and performance. All usual visual tasks are considered, including Display Screen Equipment (DSE). This standard neither provides specific solutions, nor restricts the designer's freedom from exploring new techniques nor restricts the use of innovative equipment.

2.2 Energy Management and Maintenance

Efficient light sources and luminaries should be carefully selected to work in combination with daylight, in order to provide the proper quantity of high-quality, comfortable lighting. Daylight, if it is to be effectively used, must be carefully controlled. Adequate lighting controls should be installed to allow the building occupants to use only that type of lighting which is actually needed at any particular time. The ultimate aim must be to achieve the desired lighting solution at the lowest practical energy use. It is possible that a higher installed load combined with a suitable control system to give low hours of use will result in lower energy consumption than an alternative installation with a lower power loading but poorer control. It is thus important to consider both aspects [10]. Both initial and running costs should be considered.

It is essential for a lighting installation to be properly maintained. Maintenance of all lighting, including emergency and standby installations, keeps the performance of the system within the design limits, promotes safety and efficient use of energy. The designer should prepare written instructions for the maintenance of the lighting system. Maintenance includes replacement of failed or cleaning of luminaries and cleaning and redecoration of room surfaces at suitable intervals. If such information is not made available, the result will be decreased illumination and a waste of energy and increase of operational costs.

2.3 Lighting Systems for Educational Facilities

Quality lighting is not simply the delivery of adequate illumination to the work area. Numerous factors are involved in the design of premium quality and efficient lighting systems. Two of these factors are closely associated, sharing a symbiotic relationship: glare and uniformity [11]. Lighting quality means visual comfort, good color, uniformity and balanced brightness. This can be achieved with light colored materials, glare control, distribution of light to ceiling and walls, and flexible lighting controls. These factors contribute to long-term system performance and student concentration.

Good lighting promotes better learning. Today's schools must provide a stimulating environment where children will learn best. High quality lighting improves students' moods, behavior, concentration, and therefore their learning [12]. Figure 2.2 shows visual requirements of school children in classrooms.

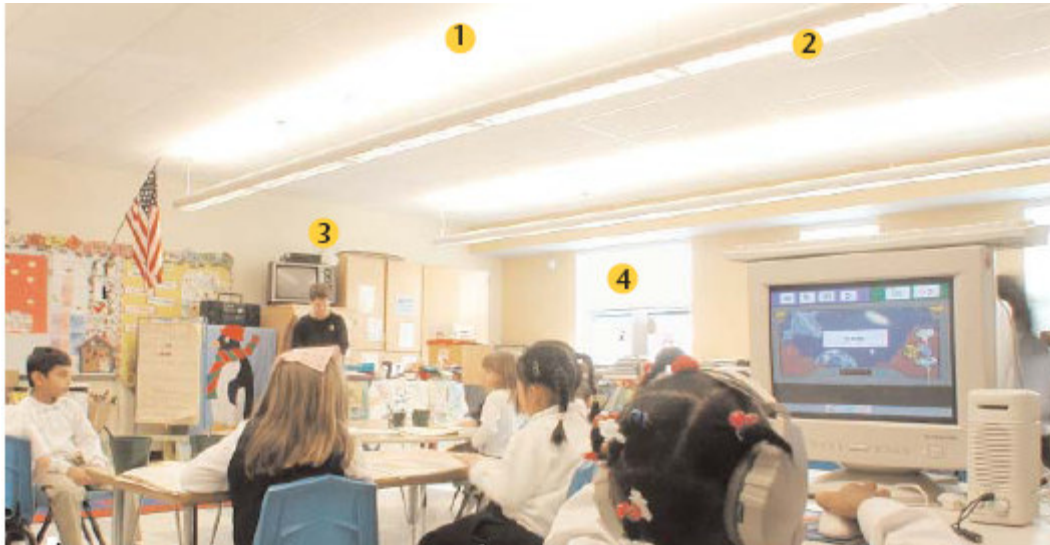


Figure 2.2: Visual requirements in classrooms.

The below given numbers refer to quality issues.

- 1 Light on walls and ceilings
- 2 Control of direct and reflected glare
- 3 Uniformity
- 4 Daylight

Daylight may provide all or part of the lighting for visual tasks. It varies in level and spectral composition with time and therefore provides variability within an interior. Daylight may create a specific modeling and luminance distribution due to its nearly horizontal flow of light from side windows. Windows may provide visual contact with the outside world, which is preferred by most people. In interiors with side windows the

available daylight decreases rapidly with the distance from the window. Supplementary lighting is needed to ensure the required illuminance at the work place and to balance the luminance distribution within the room. To reduce glare from windows, screening should be provided where appropriate [5].

Windows are a complex part of a building design. Both skylight and sunlight need to be considered and the building should be planned to take account of space organization. Windows can also have effect on other environmental factors. It must be considered carefully for maximum benefit together with minimum dissatisfaction. The means for admitting daylight can be broadly classified as follows (Figure 2.3):

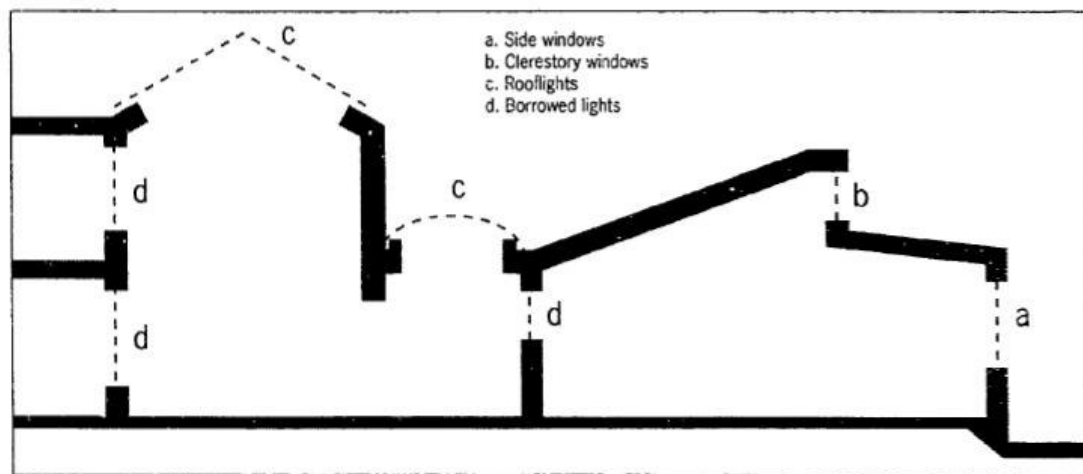


Figure 2.3: Window types (a) Side window, (b) Clerestory windows, (c) Roof lights and (d) Borrowed lights [9].

Recent changes, including energy-efficient windows and skylights and a renewed recognition of the positive psychological and physiological effects of daylighting, have heightened interest in increasing natural daylight in schools. In addition to energy and maintenance benefits, daylighting done well in a school may help to improve student performance, create a healthier indoor environment and increase attendance.

Means of controlling potential glare and maximizing daylight include exterior architectural appendages such as screens, overhangs and awnings as well as interior devices such as shades, blinds, drapes, and solar-reflecting or reducing glazing materials.

(Figure 2.4) Blinds and drapes can be managed by the occupants (in school, teachers) to compensate for daily and seasonal changes in sunlight [3].

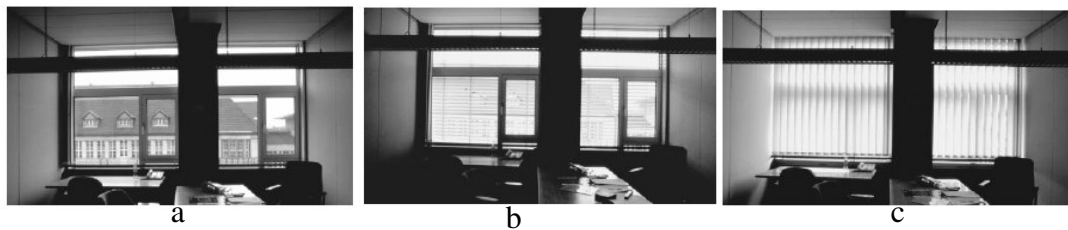


Figure 2.4: (a) Window clear view, (b) Window with exterior louver blinds, (c) Window with interior vertical lamellas [13].

When daylight fades, on dull days and during the hours of darkness, it is necessary to turn to electric lighting. There are many options as in daylighting. The areas that need to be considered are the light sources, luminaries and the installation itself.

At the hearth of any electric lighting system is the light source selection. Of the three main categories of light sources are: florescent, high-intensity discharge, and incandescent.

The most common light source found in schools is the linear fluorescent type which can be used to provide a relatively even pattern of light. These lamps can give good color performance, color rendering and color appearance, good efficiency and good optical and electrical control.

The tungsten filament lamps together with the linear halogen lamp have been used extensively in the past. The optical compactness of tungsten-halogen lamps allow for high degree of light control, making them excellent choices for highlighting, art room display lighting, and featured instructional aids in the classroom. They can be switched on and off instantly and are inexpensively dimmed. These lamps however do have a poor efficacy and a relatively short life and the designer would be advised to consider compact fluorescent lamps as alternative [9].

The last group of lamps is the high pressure discharge type. This includes high pressure discharge sodium, high pressure mercury fluorescent and high pressure metal halide lamps. High-intensity discharge (HID) lamps have long been used in school

gymnasiums and for outdoor applications. Care should be taken in the selection of HID sources with regard to color rendering, correlated color temperature, and stroboscopic effect. In multiphase wiring systems, the serving adjacent lamps from different electrical phases reduce the stroboscopic effect. Most HID lamps require start-up times that can range from 2 to 6 minutes. For quiet areas, such as libraries and study halls, HID lamp ballasts should be located remotely in order to minimize their inherent hum or buzzing.

While the scientific foundation linking daylighting to learning is accumulating, there have been distractions and fads that affect school lighting decisions. For example, there has been an ongoing controversy about so-called “full-spectrum” fluorescent lighting, and some schools have been re-lamped at considerable expense to offer this perceived benefit (the lamps themselves are several times more expensive than conventional lamps and produce significantly less light). But according to Gifford, research on the effects of full-spectrum lighting has been “inexpert” and the strong claims made about such lighting have been based on poor research that does not meet even rudimentary standards of scientific investigation [13]. Indeed, in 1986, the U.S. Food and Drug Administration instructed the Duro Test Corporation, to cease and desist from making claims about any health benefits from non-clinical applications of this type of light source [13, 14]. While there are serious questions about the effects of full-spectrum fluorescent lighting, there is sufficient reason to believe that daylight provides the best lighting conditions.

From another point of view Full-Spectrum lamps create bright and positive mood for learning, concentration and achievement. Full Spectrum Solutions, Inc. which supports lighting research membership and partnerships with medical and scientific researchers, state that exposure to Full-Spectrum light has an important influence on the endocrine system and can reduce the risks of many diseases, including cancer [15].

In school buildings most of spaces will be predominantly daylit but some spaces not always sufficient over the whole area. In these cases, it will be necessary to employ a system combining both daylighting and artificial lighting to be used when required.

For combined lighting installations the task and the appearance effects should be considered. Properly controlled daylight promotes comfort and productivity. To achieve energy savings, electric lights must be turned off (either manually or automatically) when sufficient daylight is available.

General classrooms are usually provided with side windows. As seen in Figure 2.5 the daylight rapidly falls with the depth of the room. Nevertheless a reasonable uniformity of illuminance at the desks is usually required over the entire room. For that reason electric lighting will be needed throughout the day in zones away from the window.

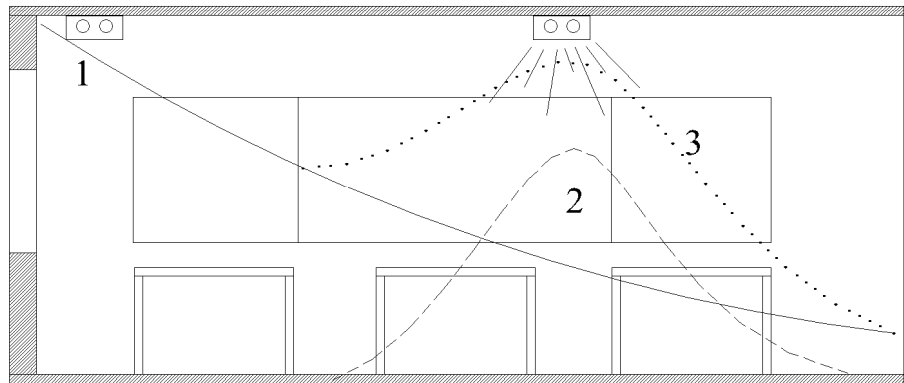


Figure 2.5: Light illuminance curves

Curve 1 shows the falling off at the daylight illuminance. This excessive non-uniformity can be compensated for by switching on one row of electric lighting (curve 2) resulting in more uniform illuminance at the desks (curve 3) over the entire room [7].

The principle of offending zone is the most effective for conventional classroom, where the luminaries should be mounted above the aisles between the desks, as indicated in Figure 2.6.

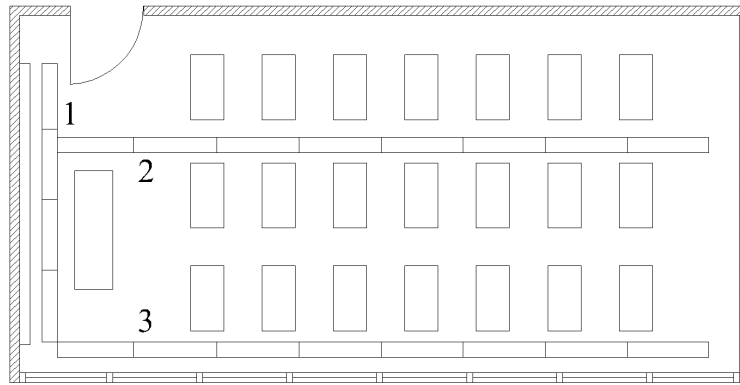


Figure 2.6: Lay-out of the lighting system in conventional classroom [7].

1: chalk-board lighting luminaries

2: general lighting luminaries used in day- and night time

3: general lighting luminaries used when dark outside

The electric lighting should be designed to provide balanced and sufficient illumination under nighttime conditions, but it should also be circuited to supplement partial daylight when needed on dark days. The electric lighting designer should understand the patterns of daylight illumination expected during different times of the day and year, so that the electric lighting design can supplement the daylight, filling in darker areas of the room or highlighting a wall when needed.

An energy-efficient, high-quality integrated lighting system can be created by the following three strategies. First, efficient lamps, ballasts, lenses, and fixtures should be selected that address the needs of each space and achieve the highest output of lumens per input of energy. Second, occupancy sensors, time clocks, and other controls should be provided that limit the time the lights are on to only hours when the space is occupied and the light are needed. And third, automated daylighting controls that dim the electrical lighting should be provided when sufficient natural light is present [13].

2.4 Specific Applications

The most specific spaces in schools and other educational buildings, that are distinct from those in other application fields are classrooms and lecture halls. The lighting of these spaces will be dealt with in full. Other spaces in schools and educational establishments such as workshops, libraries, gymnasiums, corridors, stairs, canteens, offices, are similar to those in other application fields and will be commented on in general sense only. For detailed information reference should be made to the relevant application or application guides [7]. A few specific applications are reviewed here to emphasize different lighting requirements for educational facilities.

2.4.1 Classrooms

The academic classroom is most commonly considered space in educational facilities. Regular classroom floor areas range from 61 to 83 m² or more. Daylight is often a primary consideration. Windows range from a “vision strip,” the length of one wall but only one meter high, to a full floor-to-ceiling window wall. Some classrooms are windowless or have a small window in one corner. More typically, classroom windows reach almost to the ceiling above a solid spandrel usually 760 to 910 mm high. Windows are almost always perpendicular to the usual line of sight between teacher and students; nevertheless, good control of sunlight and daylight are essential.

Windows play such an important role in classrooms that there is invariably excellent energy-saving potential from dimming and switching electric lights. However, since classrooms are also used at night or when direct sunlight requires pulling or shades and blinds, it is necessary to design the electrical illuminance distribution as if daylight would not be available [3].

Two categories of classrooms have to be considered:

- General classrooms, which are used for a great variety of subjects to be taught,
- Specific classrooms, which are used for acquiring specific skills.

For the specific classrooms the general principles for the specific type of workshop or laboratory and for general classrooms in so far as relevant should be applied.

General classrooms usually have side windows and horizontal smooth floors. Two types may be distinguished:

- Classrooms with fixed seating arrangements, usually in rows and fixed orientation,
- Classroom with free seating arrangements, usually in groups with multiple orientations.

The first type will be referred to as conventional classrooms and the second type as group classrooms [7].

In classrooms a floor to ceiling height of 3.15m is desirable, taking into account an even distribution of natural light and natural ventilation across the whole floor area of the room.

The position and size of opening window sashes must take ease of operation into account and maintain an adequate level of safety, i.e. avoid sashes opening dangerously over adjacent paths at ground floor level; use restrictors where necessary, etc. Windows should be double glazed, easy to clean and maintain, and have permanent ventilation louvers in addition to high and low level opening sashes. Vents should contain baffles for noise, wind and rain. Permanent vents and opening sashes should exceed the current guidelines set out in the Technical Guidance Documents to the Building Regulations, and should be designed to suit the class environment having regard to the high levels of humidity generally in classrooms [16].

2.4.2 Lecture Halls

Lecture halls as commonly found in universities and colleges have capacities that range from 50 or fewer occupants to several hundred. Lecture halls may be windowless and may have raked auditorium but always have a fixed seating arrangement with fixed orientation. Floors may be flat, slightly sloping, or steeply ramped. The problems of

lighting lecture halls become more complex with an increase in floor area and the demand for good observation during demonstrations. A lecture hall should have a general lighting system that is flexible enough to provide at least two lighting systems, illuminance the higher level for note-taking and a subdued one for demonstrations and film projections.

If a demonstration table is used, directional downlights should be located at 40 or 60° angles above horizontal in relation to the location of the lecturer or speaker. This minimizes glare and provides good lighting for the speaker's face. Lighting can be arranged for audiovisual presentations at the same time that the lecturer is speaking [3].

2.4.3 Physical Education and Multipurpose Spaces

Physical education facilities in schools are usually the largest spaces in the building. For this reason they are sporadically used as multipurpose spaces to accommodate large groups for activities not related to physical education and athletics. For sports events, uniformity and minimization of shadows are important considerations, whereas for activities such as physical education class, graduation, concerts, dances and community meetings.

The elementary multi purpose room is often planned to provide for physical education classes, after-school recreation, dining, and auditorium activities such as musical and dramatic rehearsals and presentations. Community activities can also be accommodated. The lighting should be appropriate for the uses planned and should be adaptable to levels suited to assemblies and other activities. When appropriate, lighting can contribute to perception of “sparkle” in these spaces for certain events. If there is a stage, either built in or portable, suitable stage lighting of an appropriate type should be provided.



Figure 2.7: HID luminaries are among the products recommended for gymnasiums.

HID and florescent light sources are suitable for high ceiling gymnasiums because of their high lumen packages (Figure 2.7). Due to the inherent high ballast noise, HID systems can be unacceptable for many functions and so, other forms of lighting are required. Incandescent and fluorescent lighting systems can be successful as secondary or alternate light sources. They are particularly useful if immediate start and restart or dimming is required [17].

2.4.4 Entrance, Lobbies, Corridors and Cafeterias

Lighting in entrance vestibules and lobbies should create an atmosphere suitable for the particular type of space. The lighting may emphasize the architectural features and provide a transition to the functional areas.

Corridors (Figure 2.8-a) should be adequate lighted to promote safety and discipline. Direct glare from overhead luminaries should be avoided. Corridors lined with lockers require higher levels than those used simply for passage. Supplementary lighting may be required at the positions where monitors or security personnel are stationed. If appropriate, control of daylight must also be provided.



Figure 2.8: In school building; (a) Corridor, (b) Stairwells, (c) Cafeterias.

The lighting of stairwells (Figure 2.8-b) requires special attention, because during class changes they are full of students moving rapidly in opposite directions. Significantly higher illuminance is required for stairs than for corridors. Automatically programmed stair and corridor lights can be coordinated with the class changes. Emergency alarms also must coordinate with stair lighting to provide illuminance.

In school cafeterias (Figure 2.8-c), color appearance is important in the dining area, since color contributes to relaxation and well feeling. In the food preparation area, where any specular surfaces can be present, attention must be paid to reflected glare, as well as to the appropriate illuminance needed for performing kitchen tasks. Modeling of objects is also an important design issue for cafeterias [7].

2.4.5 Emergency Lighting, Outdoor and Security Lighting

Temporary lighting should be provided in all areas of the school during power outages to allow students to move quickly and safely through the path of egress. In schools, emergency lighting luminaires should be protected where mischievous students may be attracted to the unit.

Many educational buildings are used after dark. Building facades approaches and outdoor activity areas should be illuminated for nighttime activities, for general safety and as a deterrent to vandalism and theft [3].

Consideration should be given to the installation of site lighting for the school. The design level should reflect the school's location and use of the building outside of normal school hours [16].

3. ENERGY EFFICIENT LIGHTING SYSTEM DESIGN

An effective and efficient use of energy is an important aspect of any lighting proposal. This is in order to minimize the use of primary energy and reduce the carbon dioxide emission as well as to reduce the running cost of each lighting installation.

Daylighting strategies and architectural design strategies are inseparable. Daylight not only replaces artificial lighting, reducing lighting energy use, but also influences both heating and cooling loads. Planning for daylight therefore involves integrating the perspectives and requirements of various specialists and professionals. Daylighting design starts with the selection of a building site and continues as long as the building is operated [18].

Parameters affecting efficient lighting design can be divided in two groups like natural parameters and artificial environmental related design parameters.

3.1 Natural Parameters

All daylighting strategies make use of the luminance distribution from the sun, sky, buildings, and ground. Daylight strategies depend on the availability of natural light, which is determined by the latitude of the building site and the conditions immediately surrounding the building, e.g. the presence of obstructions. Daylighting strategies are also affected by climate, thus the identification of seasonal, prevailing climate conditions, particularly ambient temperatures and sunshine probability, is a basic step in daylight design [19].

Natural parameters like external illuminance level and building site features must be accepted as input data by the architect. Regional characteristics, such as geographic

position, climate, height above sea level, turbidity of the atmosphere etc. affect the external illuminance values. External illuminance should be determined either by measurements or calculations. The slope of settlement field, its orientation, plant cover and natural obstructions affect building's possible benefit from daylight. These variables should be considered during the building design stage [20].

3.2 Built Environmental Parameters

The building's overall design scheme determines daylighting strategies and daylight potential in all building zones. During the initial design phase, the daylighting designer's goal is to make sure that the specified performance can be achieved within the framework of the design. Therefore performance parameters should be checked during the initial design phase [19].

In building design stage, built environmental design parameters depend on the architect's decisions. If the architect wants to design an energy efficient lighting system, lighting energy consumption during the daytime must be reduced by optimum utilization of daylight. Built environmental design parameters can be classified in different scales, like settlement, building, room, element and material.

- Positions, dimensions and light reflectances of buildings

In settlement design, depending on architect's decisions, determined building height and building distances between each other and their location constitute settlement texture. These values have an important role on determining the available daylight in interiors [21]. In addition the light reflectance of the building and the ground cover affect the amount of reflected light in the interiors.

All these parameters should be determined correctly for most effective utilization of daylight. The distance and height of the buildings in a settlement are expressed as the obstruction angle, which is given in Figure 3.1. For correct determination of this angle different kinds of graphics and calculation methods are available. Effect of direct sunlight on the building façade and penetration through windows should be analyzed

during the day and year. Based on these analyses, it is possible to design daylight systems, which can provide visual comfort conditions.



Figure 3.1: In settlement design, buildings location and obstruction angle.

- Orientation of the room

Relating to the orientation of the rooms the “window’s direction” is determined and resulting, effect of direct sunlight and daylight are different. The influence of the sun according to the orientation of the building is given Figure 3.2. Shading systems should be designed according to the occupation time and function of rooms. To obstruct direct sun beam, recently developed systems can lead daylight into the room and transmit it to the further distant parts of the room while simultaneously providing sun control. (Figure 3.2)

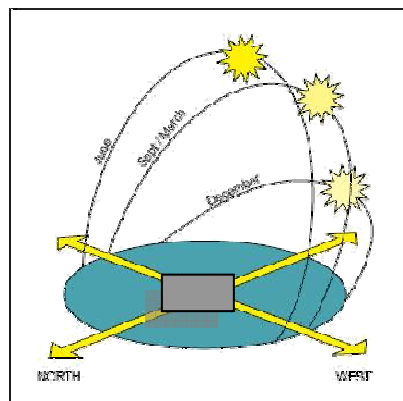


Figure 3.2: The influence of the sun according to the orientation of the building.

- Dimensions of the room

The aims of room daylighting are to adequately illuminate visual tasks, to create an attractive visual environment, and to save electrical energy. Both the building design scheme and the application of systems play roles in meeting these goals. The performance of a daylighting strategy for rooms depends on:

1. Daylight availability on the building envelope which determines the potential to daylight a space.
2. Physical and geometrical properties of the windows and how windows are used to exploit and respond to available daylight.
3. Physical and geometrical properties of the space.

The width (a), depth (d) and height (h) of the rooms affect the daylight availability and its distribution. Daylight is usually not sufficient in deeper parts of the rooms in relation with window dimensions. In Figure 3.3 the variables according to the room are expressed.

- Light reflectance of internal surfaces

Colored surfaces are secondary light sources. In relation with their light reflectance values the amount of the reflected light from the internal surfaces of a room is one of the components of the interior illuminance.

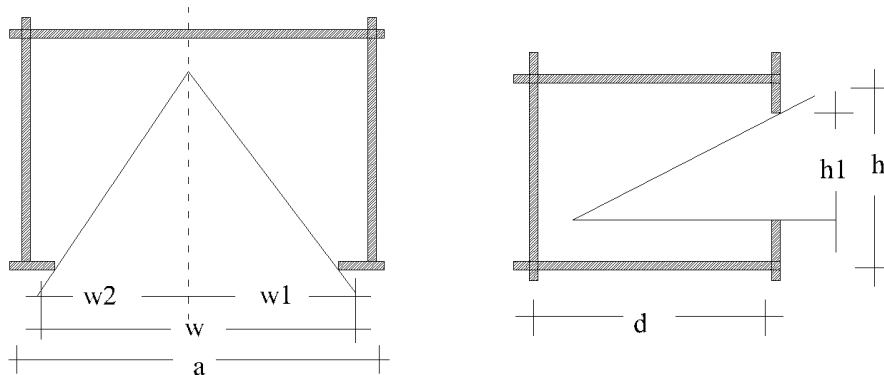


Figure 3.3: Variables related to space [22].

- Dimensions and location of the window

A window system must address the range of a building's exterior conditions to fulfill the range of interior requirements. The placement and sizing of windows are among the most powerful features of architectural design for daylight. Because the design of windows has a decisive effect on the potential daylight and thermal performance of adjacent spaces, it needs to be checked very carefully [23].

Window as an aperture in an opaque room envelope is a vertical or nearly vertical area. Window dimensions are generally defined as transparency ratio, which is the percentage of window area in the window wall area. Transparency ratios should be determined in relation with region, room direction, and room dimension and obstruction angles in order to provide the comfort conditions.

Daylighting is one of the main functions of windows. The window design determines the distribution of daylight to a space. Windows chosen solely for their architectural design features may perform satisfactorily in many cases. For dwellings and other buildings that have relatively minimal visual requirements, application of advanced daylighting systems is not usually appropriate.

When possible, it is always better to locate daylighting apertures in the ceiling plane. Toplighting reduces the glare and allows for a more even distribution of daylight within the space. But, it can only be provided for one-story buildings or for the top floor of multi-story buildings. With sidelighting windows, uniform illuminance is more difficult to provide, as there is always more light next to the window. Glare is also more difficult to control.

- Window glazing

Glazing types differ from each other according to their physical properties, like the heat transmission, light transmission, light, reflection and sound absorption coefficients, which should be considered carefully during the design stage.

Selection of the right glazing is of major importance for a building's daylighting strategy. The combined application of new glass and new daylighting systems, particularly those that provide solar shading, glare control, and the redirection of light, can increase daylight and decrease cooling loads.

Glazing with high light transmittance can cause the same advantages and disadvantages like large windows. Designers should consider all the environmental factors, like light, heat and noise while deciding on window glazing.

Low transmission glazing reduces the effectiveness of daylight but cannot reduce intensities enough to provide comfort in direct sun. These types produce an effect of gloom and ambiguity, regardless of the weather and time of day.

Clear glazing is the best way to admit the amount of light desired. But they need to be used with shading, in order to reduce the heating gain. Low-transmission glazing is useful when the amount of light is not as important as the view. It still must be shaded to reduce heat gain and glare.

Daylight penetration related to the light transmittance of different glazing types is given in Figure 3.4.

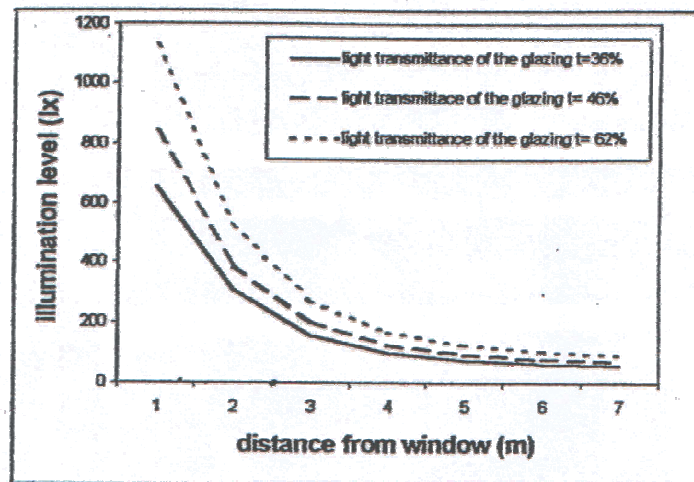


Figure 3.4: Daylight penetration in a room related to the light transmittance of different glazing types [22].

In energy efficient lighting design process of buildings, before all else, natural parameters should be determined. According to this, most appropriate built environmental parameters must be evaluated considering the building function. Settlement, building, room, building element and material related decisions, which are built environmental parameters, determine the amount of daylight in the room. At the same time the visual comfort conditions related to the building function should be provided. During the design process different alternatives should be compared taking into account artificial lighting systems and energy consumption of the chosen alternatives to finally select the lowest energy consuming system.

Once the required illuminance has been determined, other factors, such as direct and reflected glare, shadows and color, should be considered in the luminary and lamp selection.

Certain classrooms may be specifically designed for handicapped students. In most cases partially sighted individuals benefit from higher-than- normal illuminance levels as long as direct and reflected glare are carefully controlled. There are some exceptions, however, and special provisions should be made for who need lower level [3].

The type of luminary selected also depends on the ceiling height and type. In high ceiling spaces, suspended direct-indirect luminaries provide downlighting and reflected light from the ceiling. Well-designed in direct lighting systems provide low-brightness, shadow-free illumination. Many school classrooms, however, have low ceilings that necessitate ceiling-mounted or recessed luminaries.

Classroom luminaries should be selected and arranged with regard to following factors:

- b. Position and orientation of desk (this may not be predictable)
- c. Location of chalkboard or white board
- d. Location and proximity of windows
- e. Ceiling height
- f. Photometric characteristic of luminaries
- g. Flexibility of space for other functions

3.3 Climate Responsive Daylighting Strategies

Daylight system must be designed proper to climatic condition, because building heating and cooling loads are affected from direct sunlight and solar beam radiation belonging to the climate.

In temperate-humid, hot-dry and hot-humid climates where buildings are generally cooling-dominated, it is important to consider if passive heating would provide benefits without negatively impacting summer cooling. Properly designed monitors or windows with lightshelves can accomplish both. That can be maximizing winter gain and block the majority of direct solar gain by overhangs during summer peak cooling times. Because cooling loads are a greater concern, it is very important to size the glass area so that during times of peak cooling no more solar gain is allowed to enter into the space than is necessary to provide the required lighting levels. If designed correctly, this sunlight will generate less heat for the same amount of light. This means that, in addition to the lights being off, the peak cooling mechanical load will be reduced [24].

Cairo, Egypt (Figure 3.6.) and Palm Springs, USA are hot and dry desert climate regions characterized by very clear skies and low precipitation. The general effort is to achieve a good daylight performance with small opening index to prevent the building from overheating. Design objectives are to maximize daylight efficacy and redirection per unit glazing area to increase the uniformity of the distributed daylight within the interior year around [19].

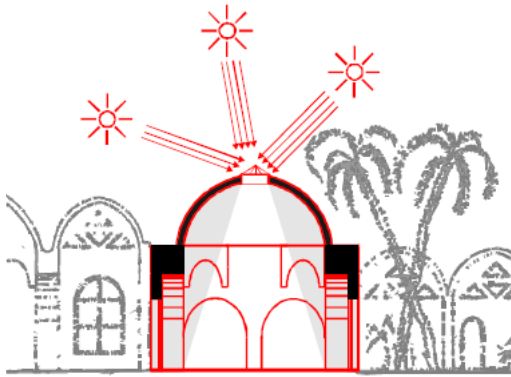


Figure 3.5: Cross-section showing the dome of the entrance hall with the lantern with holo-graphic elements to shade and to redirect sunlight [19]. (Cairo, Egypt)

In cool-dry, cool-humid, cold-humid, temperate-mixed climates, it is important to consider how passive heating can provide benefits without negatively impacting summer cooling. South-facing roof monitors which is shown in Figure 3.7, is better to provide natural light in the classrooms



Figure 3.6: South-facing roof monitors in cool and cold climates.

Properly designed daylighting in the arctic and subarctic climates, can help lower the electricity needed for lighting during certain parts of the year. Although, the reduced daylight hours will limit the applicability of using daylighting to supplement electric lighting, daylighting can help reduce electricity use during the longer daylight hours of late spring and early fall. For schools that operate year round, good daylight design could eliminate the need for electric lighting during the summer months. Daylighting design should be developed with primary emphasis on south-facing windows and roof monitors. The high ceilings and position windows are used as near as possible to the ceiling. Light shelves are considered inside the window. Snow removal makes exterior light shelves impractical [25].

Daylighting apertures have to be considered in order to limit the amount of beam radiation that enters during the hottest part of the day. East- and west-facing glass should be minimized. In tropical areas, south-facing vertical glazing can be incorporated, (north-facing in the southern hemisphere) if roof overhangs are designed to effectively admit low angle winter radiation for daylighting and exclude excessive higher-angle sunlight in the warmer months. North glazing (or south glazing in the southern hemisphere) is favored, because it does not create overheating problems during the hottest part of the warmest months. As an example, the charts below indicate seasonal

sun angles for Honolulu, Hawaii (latitude N21); and Luma, American Samoa (latitude S14) [26].

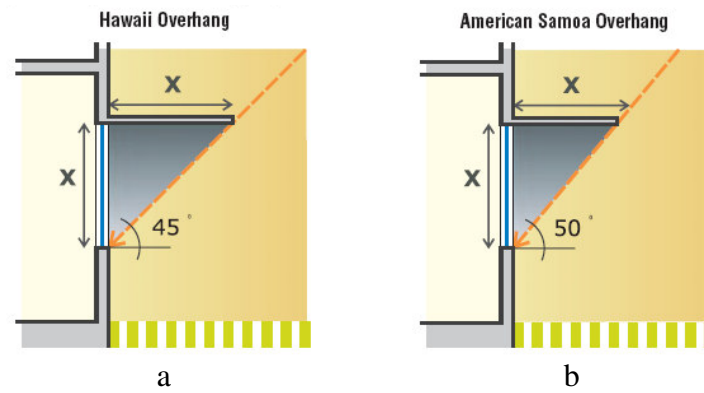


Figure 3.7: Cutoff angle for (a) Honolulu, Hawaii (latitude North 21) and (b) Luma, American Samoa (latitude South 14) [26].

As seen in the Figure 3.8, to shade south facing windows at Tropical Island schools in the northern hemisphere during school hours, the overhang should have a cutoff angle of approximately 45° . To shade north facing windows at Tropical Island schools in the southern hemisphere during school hours, the overhang should have a cutoff angle of approximately 50° .

4. INTEGRATIVE DAYLIGHTING STRATEGIES FOR EDUCATIONAL BUILDINGS

There is a growing concern about the environmental and societal implications of energy. Today, energy costs over the life of a school will far exceed the initial cost of the building. As prices rise, it will become even more critical to comprehensively address this issue. Schools can make a strong statement that saving energy and resources, while protecting our environment, is important [25].

Cost-effective energy- and resource-efficient schools start with good planning. Working closely with the school's design and planning staff, the architects and engineers should develop objectives that reflect local conditions and priorities, balance short-term needs and long-term savings, and address environmental issues. Goals can include reducing operating costs; designing buildings that teach; improving academic performance; protecting the environment; increasing health, safety and comfort; supporting community values and considering emerging solutions.

Lighting electricity use in the European non-residential sector represents more than 160 TWh/year. This has a substantial impact on the environment, accounting for up to 40% of electricity used in non-residential buildings. Schools spend a significant portion of their annual operating budgets on electricity. Most of this consumption is lighting. The economic impact of lighting their facilities is one not taken lightly by school administrators. [27]

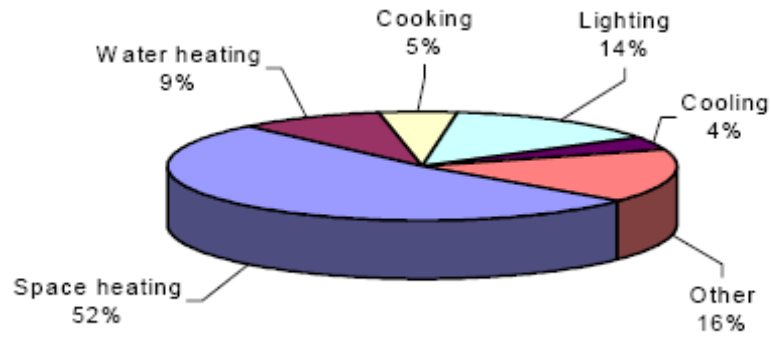


Figure 4.1: Energy consumption by end use in the European non-residential buildings [27].

4.1 Daylighting Design Efficiency in Educational Buildings

Daylighting forms the cornerstone of resource efficient, high performance design for schools. Affecting individuals on both conscious and subconscious levels, it provides light to see the work environment, a natural rhythm that determines the cycles of days and seasons, and biological stimulation for hormones that regulate body systems and moods. In addition, it offers opportunities for natural ventilation and, if properly integrated with the electric lighting system, can provide tremendous energy savings. The advantages of daylighting translate to higher performance in schools. Children achieve significantly higher test scores in classrooms that are daylit than in those that are not, making daylighting one of the best building-related investments for the learning environment [28].

Following explanations provide an overview of daylighting and fenestration design.

- View Windows
- High Sidelighting
 - Clerestory
 - Clerestory with Light Shelf or Louvers
- Toplighting
 - Wall Wash
 - Central Toplighting

- Patterned Toplighting
- Linear Toplighting
- Tubular Skylights

To fully daylight most spaces, daylight strategies should be combined with each other or repeated as a pattern across the space. For example, Wall Wash Toplighting on an interior wall could be combined with High Clerestory Sidelighting and View Windows on an exterior wall to fully daylight a classroom. Since daylight is additive, the total amount of daylight in the space is the sum of the daylight available from each individual pattern. Each strategy represents a daylight delivery system with inherent advantages and disadvantages, which are summarized below in Table 4.1.

Table 4.1: Selection criteria for daylighting strategies [26].

Design Criteria	View Windows	High Sidelight	Wall Wash Toplighting	Central & Patterned Toplighting	Linear Toplighting	Tubular Skylights
Uniform Light Distribution	○○	●/○	●	●●	○	○
Low Glare	○	●	●	●	●	●/○
Reduced Energy Costs	○	●	●	●●	●	●
Cost Effectiveness	●	●	●	●	●	●●
Safety/Security Concerns	○	●/○	●	●	●	●●
Low Maintenance	○	●	●	●	●	●

●●	Extremely good application
●	Good application
○	Poor application
○○	Extremely poor application
○●	Depends on space layout and number and distribution of daylight apertures
●/○	Mixed benefits

The fundamentals of daylit school design are as follows:

1. To prevent direct sunlight penetration into glare-sensitive teaching spaces.
2. To provide gentle, uniform light throughout space.
3. To avoid creating sources of glare.
4. To allow teachers to control the daylight with operable louvers or blinds.

5. To design the electric lighting system to complement the daylighting design, and encourage maximum energy savings through the use of lighting controls.
6. To plan the layout of interior spaces to take advantage of daylight conditions.

Good daylighting design typically relies on maximizing the use of gentle, diffuse daylight, and minimizing the penetration of direct beam sunlight. In general, sunlight should only be allowed to enter a space in small quantities, as dappled light, and only in areas where people are not required to do work.

Excessively high contrast causes glare. Direct glare is the presence of a bright surface relative to the surroundings (for example, a bright diffusing glazing or direct view of the sun) in the field of view that causes discomfort or loss in visual performance. This glare can have negative effects on student and staff performance. A recent study showed that skylights admitting direct sun (and presumably glare) into classrooms are correlated with a decrease in student performance on standardized tests [29].

4.1.1 View Windows

A view window (Figure 4.2) is vertical glazing at eye level, which provides a view to the exterior or interior adjacent spaces. View windows are essential in all school spaces (except spaces requiring visual privacy) to provide relaxing views and information about exterior natural conditions and to allow people outside of a space to view and connect with activities inside. They are applicable to all climate regions and should be planned in the schematic design phase.

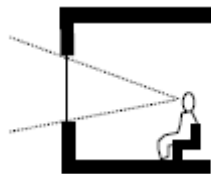


Figure 4.2: View window

There are numerous benefits provided by view windows. They are serving a broad range of important functions for view, social communication, egress, ventilation, and energy conservation. The outward views they provide are essential for mental stimulation and relaxation for eye muscles. Optometrists recommend access to long views for any sedentary workers (such as students) for frequent shifting of eye focal length, which promotes eye health and good vision. This may be especially important for young children while their eyes are still developing.

View windows provide occupants a connection with nature, weather, cardinal orientation, and some natural light (though not evenly distributed across the space). Occupant productivity and connection with place may increase through the associated views. Studies have shown that the primary reason people prefer having a window is view, preferably a view of nature. Research suggests that natural views elicit positive feelings, hold interest, and reduce fear and stress [30]. Teachers have reported a reduction in stress levels when they have access to a relaxing view from their classroom.

View windows should be oriented toward the north or south to avoid low angle east/west sun. Up to 15° variance from true north or south is acceptable, but will reduce performance. Because view windows are within the occupants' normal field of view, the contrast between the bright window view and other interior surfaces is an important glare consideration. To eliminate direct sun and reduce brightness exterior shading devices (overhangs fins, etc.) or landscaping should be used. If this is not possible, a lower transmission glazing adjusted for the window orientation should be considered. On south, east and west orientations, an interior shade (shade screen, blinds, or drapes) can be added, so the teacher can adjust brightness and sun penetration as needed. In general, visible transmission of view glazing should not be reduced below 30% in clear sky climates or below 50% in heavily overcast climates. If tinted glazing is used, its effect on distortion of colors in both overcast and clear skies has to be evaluated and blackout capability for view windows should be provided if needed [31].

4.1.2 High Sidelighting

High side lightings can be examined in two groups; Clerestory and Clerestory with Light Shelf or Louvers.

4.1.2.1 Clerestory

High sidelighting clerestories (Figure 4.3) are vertical glazing in an exterior wall above eye level. High clerestory windows can be used in all school spaces to provide deep penetration of daylight. They are applicable to all climate regions and should be planned in the schematic design phase.

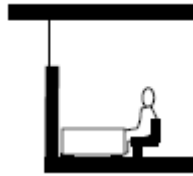


Figure 4.3: High sidelighting clerestory

High sidelighting requires high ceilings and perimeter walls. North and (shaded) south orientations are preferable; although east and west orientations can be acceptable if diffusing glazing is used or if low-angle sun penetration will not be bothersome in the space. High sidelighting is most appropriate for open plan interior layouts that allow unobstructed daylight penetration and should be considered in the early schematic design phase [32].

High sidelighting provides a moderate level of benefits; the general energy saving, productivity and visual comfort benefits. Clerestory sidelighting both saves energy and improves lighting quality. Energy savings come from reduced electric lighting energy use. Lighting quality is improved by a more uniform distribution of daylight across the space. High sidelighting glazing works best in spaces with high ceilings. A minimum perimeter ceiling height of 2 m. recommended. As a rule of thumb can serve the higher the ceiling height is the better.

Clerestories are most effective on south and north orientations, but should be carefully evaluated on east and west orientations to assure that low sun angle penetration and

direct solar gain into the space is minimized. Exterior glazing with an overhang on east-, west-, and south-facing glazing should be glazed, to minimize solar gain or a selective low-e coating should be used. With exterior shading, diffusing glazing, operable blinds or light shelves to eliminate direct sun penetration. Horizontal blinds are better for bouncing light deeper into a room, especially when facing south. Vertical blinds may be more appropriate to catch low angle east and west sunlight and bounce it into the room, while allowing light coming from south to enter directly. Mini-blinds positioned between the panes of glass in a double glazed window accomplish this with minimal maintenance. Blinds or shades for the upper clerestory glazing can allow lower view windows to be controlled separately for glare and blackout shades may need to be provided [33].

4.1.2.2 Clerestory with Light Shelf or Louvers

A light shelf is a horizontal panel placed below high clerestory glazing (with a view window generally below it) to bounce daylight deeper into the space. An example of high sidelighting clerestory with exterior lightshelves is shown in Figure 4.4. Light distribution is improved as daylight reflects off the top surface of the light shelf or louver onto the ceiling. There is a common misconception that light shelves increase light levels deep within the room. Light levels are instead reduced near the windows and, while being maintained deep in the room, keeping the contrast significantly lower within the room as well as reducing glare near the windows.



Figure 4.4: High sidelighting clerestory exterior lightshelves in elementary school [33].

A series of smaller horizontal louvers can replace a single large light shelf with a slight sacrifice in performance. The larger the louver, the deeper it will deliver daylight into the space. Light shelves and louvers can be located on the exterior, interior, or both. Exterior shelves shade the lower window from solar heat gain and reflect high angle summer sun into the room. Interior shelves reflect lower angle winter sun while blocking the penetration of direct sun and reducing glare from the upper glazing. (Figure 4.5)

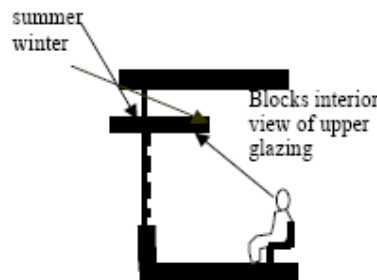


Figure 4.5: Exterior light shelves shade lower window and reflect summer sun into room. Interior shelves reflect winter sun while reducing glare.

High clerestory windows can be used in most school spaces to provide deep penetration of daylight. They are applicable to all climate regions and should be planned in the schematic design phase. Clerestories with light shelves or louvers produce a high level of benefits. Clerestories with light shelves or louvers both save energy and improve lighting quality. Energy savings come from reduced solar gains (when an exterior light shelf shades lower glazing) and reduced lighting energy use. Lighting quality is improved because daylight is delivered deeper in the space, creating a more even distribution. Interior light shelves and louvers restrict the view of the bright upper glazing and eliminate the direct sunlight hitting the desk level, which minimizes glare [26].

Light shelves are most effective on south orientations and occasionally on the north (to reduce glare from the upper glazing). They should be avoided on east and west orientations.

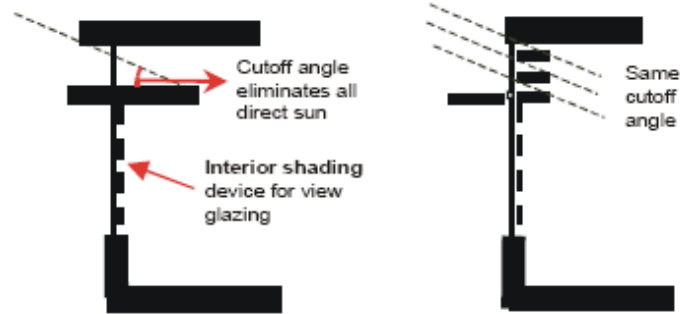


Figure 4.6: Cutoff Angle of light shelves [26].

The cutoff angle of the light shelf or louvers (see the figure above) should be set in a way that eliminates direct sun penetration during normal school hours. The cutoff angle can be increased by 10° if there are operable shades on the upper glazing, and increased by 20° if operable louvers will be seasonally adjusted. (Figure 4.6)

Daylight guiding systems on vertical façades are generally used for transporting direct sunlight into the interior. Therefore, the efficiency of daylight guiding systems depend on the geographical location (possible sun positions), on local meteorological conditions, particularly on the sunshine probability and on the orientation of the façade.

To further investigate the performance of light shelf systems “Daylight - Artificial Light Integration According to the Climate Conditions” project has been executed at the Istanbul Technical University. (Figure 4.7) Two offices are in used for reference rooms in the Electric Electronic Faculty Buildings’ top floor oriented to South. The light shelf system was delivered by the Berlin Technical University and mounted to these offices. Also an automatic control system was installed to control the existing lamps of the rooms in order to optimize the required daylight level of working space. The automatic control system dimes the lamps when the daylight value reaches 500 lux. In this respect, energy save would be achieved with this automatic control. In relation to the azimuth and following seasons, significant energy savings could be achieved. By the automated light control system is can be with the improved light shelf system [34].

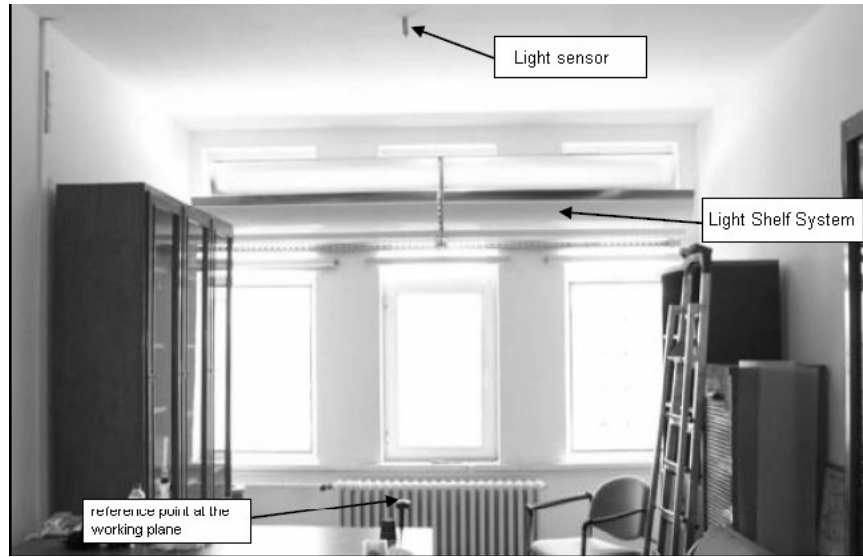


Figure 4.7: Test room with the Light Shelf System at Istanbul Technical University

According to the results and the meteorological data of cities of Turkey in different climatic zones, the system is highly efficient and viable where the sun light duration is high like the cities of Antalya and Diyarbakır [35].

4.1.3 Toplighting

4.1.3.1 Wall Wash Toplighting

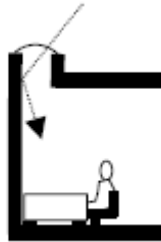


Figure 4.8: Wall wash toplighting

As seen in Figure 4.8, wall wash toplighting provides daylight from above through a linear skylight or monitor to wash an interior wall. The glazing is obscured from direct view by the skylight or monitor well. Daylight is diffused with diffusing glazing, baffles, or reflections of matt reflective light well and interior walls.

A toplighting scheme applies to single-story buildings or the top floor only of a multistory building. Appropriate spaces for wall wash toplighting may include classrooms, libraries, multipurpose spaces, gyms, corridors and administration offices. It is applicable to all climate regions

Wall wash toplighting provides a moderate to high level of benefits. This approach washes a wall with light, and bounces glare-free daylight into the classroom. It will make the space appear larger and brighter. The uniform light from this approach can easily light the inner two-thirds of a classroom. It is excellent when combined with another wall wash or a sidelighting technique that increases daylight on the opposite side of the room to create even, balanced daylight across the whole room [30].

This approach saves electric lighting energy if the first row or two of lights adjacent to the wall wash are switched off or dimmed in response to the daylight. Savings for controlled fixtures may be 40% to 80% during daylight hours.

The toplighting design must be optimized for the climate, orientation and budget. A skylight will perform better in a predominantly overcast sky condition and for non-north/south orientations. A well-designed monitor with north- or south-facing glazing will be more expensive, but may perform better than a skylight in sunny climates with high air conditioning loads.

4.1.3.2 Central Toplighting

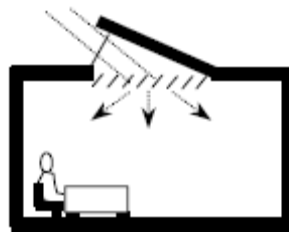


Figure 4.9: Central top lighting

Central top lighting (Figure 4.9) uses a central monitor or skylight (or cluster of skylights) to distribute daylight evenly across the room. Daylight is diffused with

diffusing glazing or baffles that can be fixed or operable. Daylight levels are highest directly under the aperture and gradually reduced toward the perimeter of the space.

Central toplighting is applicable in single-story or top floor spaces including classrooms, libraries, multipurpose spaces, and administrative offices. It is appropriate for all climate regions and should be considered during the programmatic, schematic, and design development phases of a school building project.

Central toplighting provides a high level of benefits. With good diffusion, this approach creates even, balanced daylight across the classroom, which has been correlated with higher standardized test scores [32].

This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Operable louvers can provide variable amounts of daylight for different classroom activities.

The toplighting has to be designed for the climate and budget. A skylight will perform better in a predominantly overcast sky condition, or non-optimum orientation. A well-designed, north- or south-facing monitor will be more expensive, but may perform better than a skylight for sunny climates with high air conditioning loads. A two-sided monitor with glazing facing both east and west will also be more expensive but is another way to use monitors even in non-optimal orientations while still providing even light levels throughout the day.

4.1.3.3 Patterned Toplighting

Patterned toplighting (Figure 4.10) provides daylight through a two-dimensional grid of skylights or rows of linear monitors (sawtooth or square). It provides even, glare-free daylight across large areas. Spacing of the pattern is largely a function of the ceiling height.

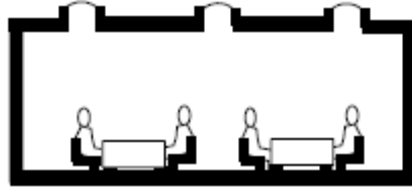


Figure 4.10: Patterned top lighting

This day lighting pattern is useful for any large area that needs even daylight levels. It is most suitable for gymnasiums, libraries, multipurpose or cafeteria spaces. For gymnasium ball courts, baffles have to be added or high light well cutoff angles have to be used to minimize direct views of bright glazing surfaces during ball games. Patterned toplighting is appropriate for all climates and should be considered during the programmatic, schematic, and design development phases [30].

Patterned toplighting provides a high level of benefits. This approach creates even, balanced, low-glare daylight across the space and saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight.

4.1.3.4 Linear Toplighting



Figure 4.11: Patterned linear top lighting

Figure 4.11 shows linear toplighting is a downlighting scheme. That provides a line of high intensity daylight directly under it, which diminishes as an individual moves perpendicularly away from it. It establishes a strong longitudinal orientation in the space and is best coupled with a corresponding circulation pattern or linear visual cue. Used bilaterally, it can frame a larger space.

This daylighting pattern is useful for enclosed hallways and linear walkways within a larger space, or for use bilaterally to frame centrally focused areas like gymnasiums, libraries, and multipurpose areas. Linear toplighting may also be used in covered exterior walkways to minimize their shadow, especially in covered walkways adjacent to rooms with sidelighting [36].

This approach creates bright, welcoming corridors that link important functions in the building. It can provide a strong visual cue for circulation that guarantees daytime egress lighting independent of electric power. In a bilateral scenario, it can provide balanced daylighting that graduates from high at the perimeter to moderate between the two linear toplights.

4.1.4 Tubular Skylights

Tubular skylights are small clear-domed skylights with mirrored reflective ducts connecting them to the ceiling plane of the space. They have an interior diffuser at the ceiling plane to spread daylight in the space. They may have electric lighting within the duct or diffuser that is switched or dimmed in response to the available daylight. Since they depend on multiple reflections to deliver daylight to the space, they perform better under direct sun than under overcast sky conditions.

Tubular skylights are especially useful for small spaces, such as toilet rooms, locker rooms, kitchens, interior corridors, enclosed staff work areas and other interior spaces that are sporadically occupied and would benefit from a low-cost toplighting solution. (Figure 4.12) They are also suitable for retrofitting into existing school spaces that need extra daylight or need to balance an existing asymmetric daylight distribution.

Tubular skylights provide a moderate level of benefits. This approach provides daylight “fixtures” that deliver daylight through a ceiling plenum to an interior space. Arranged in a grid, they can provide even, balanced daylight across the space, though daylight levels will fluctuate widely between direct sun and overcast sky conditions.

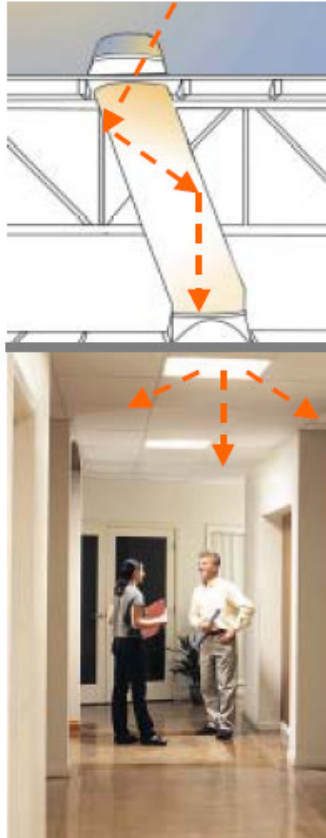


Figure 4.12: Tubular skylights work well for small spaces, such as toilets, locker rooms, kitchens and interior corridors [36].

In predominantly sunny climates, a tubular skylight with a south-facing, reflective half-dome under the skylight “bubble” should be used to increase the reflection of low angle winter sun into the skylight (see Figure 4.13 below). In predominantly overcast climates a full clear dome should be preferred. Special lenses or geometric shapes can help to catch low angle sun and direct it downward.

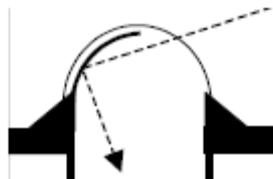


Figure 4.13: Section of Reflective Half dome [26].

4.2 Artificial Lighting Systems for Educational Facilities

There are mainly two ways to illuminate a space using electric light:

- General lighting
- Localized lighting

Artificial lighting systems which provide approximately uniform illuminance over the whole working plane are called general lighting systems. The luminaries are normally arranged in a regular layout. Localized lighting systems employ an arrangement of luminaries designed to provide the required maintained illuminance on work areas together with a lower illuminance for the other areas. The average illuminance on the other areas should not be less than one-third of the average illuminance over the work areas. Local lighting provides illumination only over the small area occupied by the task and its immediate surroundings. A general lighting system must be installed to provide sufficient ambient illumination for circulation and non-critical tasks. This is then supplemented by the local lighting system to achieve the necessary design illuminance over the task areas [10].

In any lighting system, six different luminaries types (Table 4.2) can be used. An electric lighting luminary is usually defined as an electric lighting fixture equipped with the appropriate lamping the six types of luminaries are:

- Direct
- Semi Direct
- General Diffuse
- Direct-Indirect
- Semi-Indirect
- Indirect

Table 4.2: Light distribution from luminaries [9].

Category	Upward Light	
Direct	0 - 10%	
Semidirect	10 - 40%	
General diffusing	40 - 60%	
Direct-indirect	40 - 60%	
Semi-indirect	60 - 90%	
Indirect	90 - 100%	

The choice of lamp will affect the range of luminaries available, and vice versa. Therefore, one cannot be considered without reference to the other. One method of design is to follow a procedure which does not start with identifying a single lamp and luminary combination but rather rejects those combinations which are unsatisfactory. The most efficient, economical and architecturally acceptable luminary and lamp combination can be selected [10]. Lamps must have color rendering properties suited to their intended use. Good color rendering may be required in order to achieve better discrimination between colors where this is part of visual task. The choice of color appearance can be used by the designer to create an appropriate ‘atmosphere’. The life and lumen maintenance characteristics of the lamps must be considered arriving at a practicable and economic maintenance schedule. Standardization of a limited selection of lamp types and sizes without compromising visual requirements for a particular site or company can simplify maintenance and stocking.

4.2.1 Artificial Light Sources

Once the design illuminance has been determined, the designer has several choices of artificial light sources that can be used to provide the appropriate quantity of light. These light sources are given in Figure 4.14. The most common artificial light sources used inside the educational buildings, are florescent, high-intensity discharge and incandescent lamps.

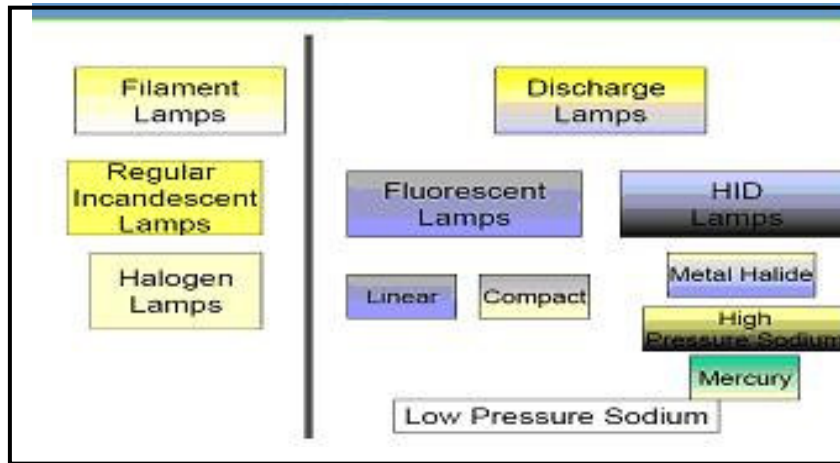


Figure 4.14: Light Source Options

4.2.1.1 Fluorescent lamps

Fluorescent lamps have a tubular glass envelope. The light output comes from phosphors which convert energy from a low pressure mercury discharge. The spectral light distribution is ‘tailored’ by the mix of phosphors. A wide range of ‘white’ triphosphor, multi-band and halophosphate phosphors plus special colors is available. ‘White’ lamps are differentiated by color appearance or correlated color temperature and color rendering group. The main advantages are high efficacy, long life and relatively low cost. However, the efficiency of fluorescent lamps is affected by the ambient temperature in which they operate [10]. All fluorescent lamps need some form of current-limiting device, or ballast, and most fluorescent lamps need some form of starting device. Recent advances in fluorescent design include improving lamp output, controls, and ballast and lamp depreciation characteristics. Some typical characteristic lamp information is given in Table 4.3.

Table 4.3: Lamp data reproduced from CIBSE code for Interior Lighting, 1994

Lamp Type	Color Rendering group / Color Temperature, K	Efficiency (Approximate) Lumens/Lamp Watt	Typical Lamp life (hours)	Typical range of lamp power rating (wattage)	Control gear required	Lamp start-up time	Lamp re-strike time
Tungusten							
Mains(230V)	1A/2700K	8-12	1000	15-1000	No	Instant	Instant
PAR	1A/2700K	10-12	2000	80-500	No	Instant	Instant
Tungusten halogen	1A/2900K	10-18	2000	50-100	No	Instant	Instant
Linear tungusten	1A/2900K	14-22	2000	60-2000	No	Instant	Instant
12V Tungusten hologen	1A/3000K	12-25	3000-5000	5-100	Transformer	Instant	Instant
Fluorescent							
T12	2/3000/5000 K	8-12	7500	20-125	Yes	1- 3 secs.	1- 3 secs.
T8	1A/1B/3000-6000 K	10-12	7500-15000	18-70	Yes	1- 3 secs.	1- 3 secs.
T5	1B/3000-4000 K	10-18	10000-15000	14-50	Yes	1- 3 secs.	1- 3 secs.
Circular	2/3000-5000 K	14-22	7500	22-60	Yes	1- 3 secs.	1- 2 secs.
Compact	1B/3000-6000 K	12-25	7000-10000	5-55	Yes	1- 3 secs.	1- 3 secs.
Low pressure Sodium	None	100-190	12000-16000	18-180	Yes	8-12 mins.	prompt<55w
High pressure Sodium							
Standartd	4/2000	65-140	16000-20000	50-1000	Yes	1.5-6 mins.	>1 min.
De Luxe	2/2200	75-90	12000-16000	150-400	Yes	5-6 mins.	>1 min.
White	18/2500	35-50	5000-10000	35-100	Yes	5-6 mins.	>30 secs.
Mecury Vapour							
Standartd	3/4000	40-60	24000-29000	50-1000	Yes	2-5 mins.	4-7 mins.
De Luxe	2/3400	40-60	24000-29000	50-400	Yes	2-5 mins.	4-7 mins.
Metal Halide							
Single ended	2/3000/5000 K	8-12	7500	20-125	Yes	1- 3 secs.	6-10 mins.
Double ended	1A/1B/3000-6000 K	10-12	7500-15000	18-70	Yes	1- 3 secs.	6-10 mins.
Tubular / elliptical	1B/3000-4000 K	10-18	10000-15000	14-50	Yes	1- 3 secs.	6-10 mins.
Ceraic a.c. Tube	2/3000-5000 K	14-22	7500	22-60	Yes	1- 3 secs.	6-10 mins.
Induction							
Standartd	1B/3000-4200	70	60000	55-85	Yes	prompt	prompt
Reflector	1B/3000	47	10000	23	Built in	prompt	prompt

4.2.1.2 Incandescent lamps

In incandescent lamps, light is produced by an incandescent filament sealed in a glass bulb, usually containing an inert gas filling. There are many types of filament lamps. The most common types are known as general lighting service (GLS). Incandescent lamps also score very high on CRI (Color Rendering Index) ratings, but because standard incandescent lamps produce very little radiant energy in the short wavelength end of the spectrum, they do not render blue tones very well [37]. The use of incandescent lamps in overhead task lighting situations has been reduced over the past few years because of their low luminous efficiency in comparison to gaseous discharge and HID lamps. The luminous efficiency of an electric light is the radiating power of the light source, over the entire visible spectrum, with respect to the human eye's ability to

detect the light produced. Almost all light sources used in schools, including daylight, have higher luminous efficacies than incandescent lamps do [38]. (Table 4.4) The advantages of the filament lamps are: low initial cost, simple operation, ease of dimming, good color rendering and lumen maintenance. The disadvantages are: low efficacy and relatively short life with increased life only being obtained at the cost of a substantial reduction in efficacy.

Table 4.4: Luminous efficacy of lamps and daylight [38].

Source	Efficacy (lm/w)
Candle	0.1
Oil Lamp	0.3
Original Edison Lamp	1.4
1910 Edison Lamp	4.5
Incandescent Lamp	14-20
Tungsten Halogen Lamp	16-20
Fluorescent Lamp	50-80
Mercury Lamp	30-60
Metal Halide Lamp	60-80
Low-pressure Sodium	90-100
High-pressure Sodium	120-140
Sunlight	92
Skylight, Average	125
Skylight, Very Clear	175
Clear Sky+ Sun, Average	111
Overcast Sky	110

4.2.1.3 High-intensity discharge lamps

There are three primary types of HID lamps: metal halide, sodium, and mercury vapor. HID technology is very similar to fluorescent technology: an arc is established between two electrodes in a gas filled tube which causes a metallic vapor to produce radiant energy. The major difference is that HID lamps can produce visible light without any phosphors. In addition, the electrodes are only a few inches apart and the gases in the tube are highly pressurized. The arc acquires an extremely high temperature, causing metallic elements within the gas atmosphere to vaporize and release massive amounts of radiant energy [36]. Ballast is required in order to operate the HID lamp. Unlike fluorescent lamps, the ballast must be specifically designed for the lamp type and wattage being used. Also, the lamps require a warm-up period to achieve full light

output, and in some cases require several minutes before they can be re-ignited after they are shut off.

4.2.2 Luminaries

Luminaries can take many different forms, but all have to provide support, protection and electrical connection to the lamp. In addition luminaries have to be safe during installation and operation and have to withstand the conditions in the operating environment. Luminaries vary in their construction, mounting position, distribution of light, maintenance characteristics, the intensity with which they are likely to cause discomfort glare and the manner in which they light an interior [10]. The main items to be examined in the choice of luminaire are:

- Luminous efficiency and light distribution.

These are characterized by the Light Output Ratio values, (total, downward and upward) and the shape of the luminous intensity distribution (polar curve).

- Appearance

The appearance of luminaries, when lit and unlit, should complement the general design of the interior. The contribution which the luminaries will make to the character of the space will have to be examined mounting position (ceiling recessed, surface mounted, suspended etc.) is very important in this respect.

- Ease of maintenance

The luminaire design should, avoid surface on which dust and dirt can be deposited. It should also allow maintenance cleaning and re-lamping be performed easily without the need for a special procedure [9].

4.3 Integration of Daylight and Artificial Lighting Systems

When the visual recommendations cannot be achieved throughout the space, a supplement of electric lighting should be provided, but it is usual to require the space to appear predominantly daylit.

The first requirement is for the electric lighting to supplement the daylight so that the combined illuminance is suitable for the task or activities being undertaken, an effective use of control is necessary.

The use of daylight and electric lighting together can both contribute towards reduced primary energy use and simultaneously increase the satisfaction of users. Problems of coordination in installations where electric lighting is only used during the hours of darkness are virtually restricted to those of transition from one lighting system to the other. These may concern: Light incidence and luminance pattern, color aspects (color rendering, color adaptation and atmosphere of environment) [3].

The daylight and the electric light systems must be designed together so that they complement each other in order to create high quality lighting and produce energy savings. This requires an understanding of how both systems deliver light to the space.

For general lighting of common working environments such as classrooms and offices, if due attention is paid to recommendations with respects to both systems, then transition will usually not cause any problem.

Control systems are an inherent part of any lighting installation. They can take many forms, varying from a simple wall switch to being a part of a sophisticated microprocessor-controlled, building management system. Whatever the method used, the aim of a control system is always to ensure that the lighting is only operating when it is required and that, when required, it is operating in the desired state. Control systems vary the light output of the installation, either by switching or by controlling the output of the lamps and so reducing energy use [39].

The factors which influence the specification of controls include occupancy pattern, available daylight, type of lighting, the desired level of control sophistication and of course cost.

Designing for maintained illuminance means, that initially, when lamps are new and luminaries and room surfaces are clean, the illuminance will depend on the characteristics of the installation and the maintenance program, which the user intends to follow [10].

Any control system must be ensuring that acceptable lighting conditions are always provided for the occupants. Safety and visual effectiveness and comfort must take priority over energy saving.

Daylighting is also more thermally efficient than electric lighting, meaning that the cooling load created by daylighting illumination is much lower than that created by electric lighting providing the same light level. Since electric lighting is a major contributor to the cooling load in schools, substituting electric lighting by daylight reduces cooling costs as well as lighting costs. But these energy savings will only be achieved if the electric lights are turned off or dimmed in response to the daylight.

The electric lighting should be circuited and controlled to coincide with the patterns of daylight in the space, so that the lights can be turned off in areas where daylight is abundant and left on where it is deficient. Controls can either be manual or automatic. Automatic controls use a small photosensor that monitors light levels in the space. Manual controls are substantially less expensive, but need to be convenient and well labeled to ensure their use. Automatic controls guarantee savings, but are more expensive and must have overrides so the teacher can darken the room for audio/visual use.

Daylight is highly variable throughout the day and the year, requiring careful design to provide adequate illumination for the maximum number of hours while contributing the least amount possible to the cooling load. The ideal daylighting design would have variable apertures that respond to changes in the availability of daylight. The apertures

would become smaller when daylighting is abundant and larger on cloudy days or at times when daylight is less available. While electro chromic glazing may permit variable daylighting apertures in the future, with today's technology the size of the aperture and its transmission are fixed. The principal means of control is through the use of shades or blinds located inside or outside the window [25].

If view windows are the only daylight apertures in the room, and they appear on only one wall of the space, their brightness in the room should be balanced by washing other interior walls with electric light.

The linear daylight zones created by high sidelighting run parallel to the clerestory windows. Electric lighting should be circuited parallel to this and photocontrolled (or manually controlled) in response to available daylight.

Clerestories with light shelves create linear zones of daylight that run parallel to the clerestory windows. Electric lighting should be circuited parallel to these zones and photocontrolled (or manually controlled) in response to available daylight. Light shelves and louvers deliver daylight indirectly to the space; they work well when coupled with direct/indirect pendant electric lighting. Sometimes the first row of electric lighting is incorporated into the light shelf itself.

Electric lighting has to be designed in a way that it provides adequate daylighting and/or electric light under the light shelf on the wall and work surfaces directly adjacent to the wall, especially for evening use or where view windows are not located under interior light shelves.

Central daylighting schemes often fail to provide bright illumination on interior walls. Electric lighting wall wash fixtures may be needed to supplement the daylight. Electric lighting should be aligned with the linear toplighting without blocking it and causing shadows on the floor. Some tubular skylights come equipped with compact fluorescent (or incandescent) electric lights within the duct or ceiling plane diffuser that can be switched or dimmed in response to daylight. It has to be ascertained that any included electric light does not block the daylight delivered through the device [26].

5. CASE STUDY: DESIGN OF ENERGY EFFICIENT LIGHTING SYSTEM IN “MUNICIPAL SCHOOL OF LA TOUR DE SALVAGNY”

The case study has been carried out to emphasize the importance of energy efficient lighting system design and energy consumption comparison of the sample educational building in different two cases.

5.1 Description of Project

“Municipal School of La Tour De Salvagny” is chosen to determine the lighting energy consumption and develop energy efficient lighting system proposals. This project is one of the subjects which are being studied in **Sustainable Architecture Applied to Replicable Public-Access Buildings** SARA project.

SARA aims to construct sustainable, cost effective, high energy performance, public-access eco-buildings that are immediately replicable at large scale in many locations. These eco-buildings will be equipped with advanced sustainable energy technologies integrated by an innovative architectural approach.

During the Demonstration Activities stage in SARA project there are eight demonstration sites from eight different countries.

- Primary Health Care Centre In Barcelona, Spain
- Office And Exhibition Halls In Sinabelkirchen, Austria
- Educational Office Building In Southampton, Uk
- Supermarket In Ljubljana, Slovenia
- Office Building In Warsaw, Poland
- Municipal School Of La Tour De Salvagny, France
- Municipality Offices In Napoli, Italy
- Training Centre In Bukhara, Uzbekistan

All projects were developed according to the state of the art, including integrated project planning, active and passive solar design, low energy construction, sustainable materials and components and renewable energy technology and building energy management systems.

Energy efficient design modifications have been performed in order to reduce the existing buildings energy consumption. The aim is to reduce the lighting energy consumption of Municipal School of La Tour De Salvagny therefore a sample design is put in practice.

The Municipal School of La Tour De Salvagny's main features are as follows:

Demonstration site: La Tour de Salvagny, as seen Figure 5.1.

Typology: School

Useful floor area: 2200 m², 11 classrooms for 300 pupils

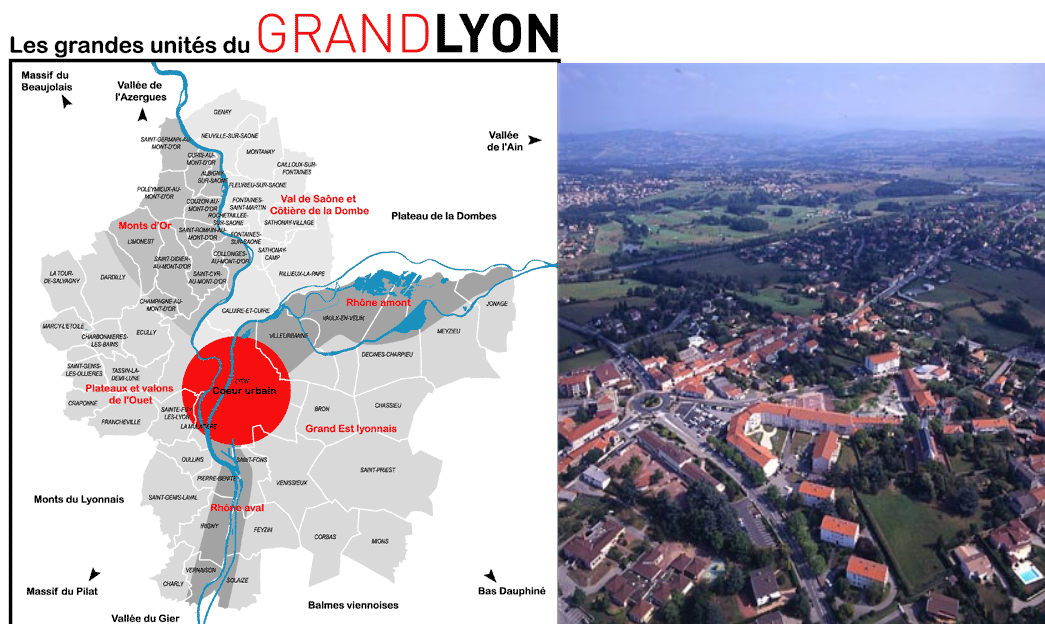


Figure 5.1: Location and view of Lyon, France

The School of la Tour de Salvagny will be designed and constructed in accordance with the High Environmental quality framework.

Passive solar principles will be used to benefit from the heat and the light of the sun with a limitation of overheating in summer. For instance, the classrooms have a double orientation (East-West) to increase natural light.



Figure 5.2: Planning and architecture of Municipal School of La Tour de Salvagny and selected classroom.

5.1.1 Room specifications

Classrooms have to be considered in two categories; general classroom, which are used for a great variety of subjects to be taught and specific classrooms, which are used for acquiring a specific skill [7]. This study deals with a general classroom, which is a conventional classroom with fixed seating arrangement in rows and fixed orientation.

As seen in Figure 5.2 pointed classroom is chosen from school to examine lighting efficiency. Because students mostly spent their times in classrooms, a classroom is selected as a test space in Municipal School of La Tour de Salvagny. The classroom is oriented to the east. Room width is 11,61m and room depth is 7,58m. Desk dimensions are 40x120cm and seats are 40x40 cm and between two seat rows there is 149 cm space. (Figure 5.3)

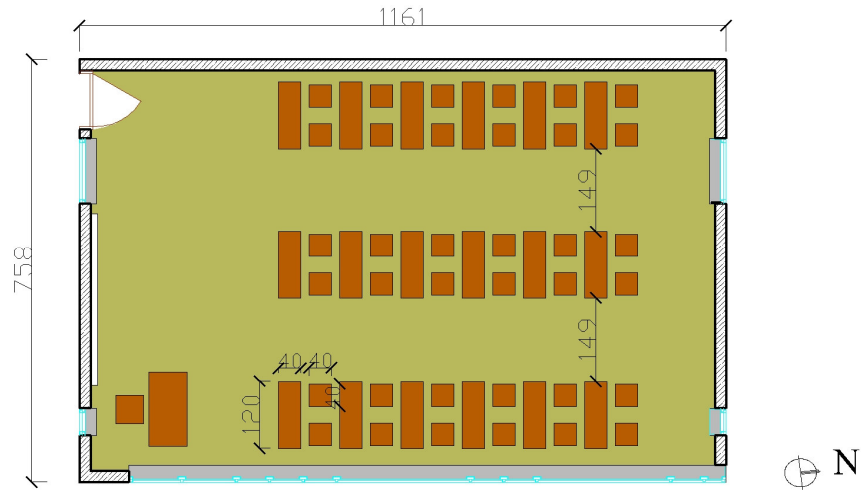


Figure 5.3: Plan of chosen classroom.

Light transmittance of the windows and light reflectance of the internal surfaces of classroom are given below in Table 5.1.

Table 5.1: Construction element specifications of classroom

	Walls	Floor	Ceiling	Glazing
<i>Color:</i>	RAL 1020 Olive Yellow	RAL 105 Concrete grey	RAL 1002 Beige Paint	2.21mm Clear Coated Low-E
<i>Reflectance:</i>	56.26 %	20.00 %	71.00 %	3.80 %
<i>Transmittance:</i>	0.00%	0.00%	0.00%	77.80 %
<i>Specularity:</i>	0.00%	3.00 %	0.00%	0.00%
<i>Roughness:</i>	0.00%	2.00 %	0.00%	0.00%

The artificial lighting system of classroom space and the schematic configuration of the system are given Figure 5.4 and Figure 5.5.

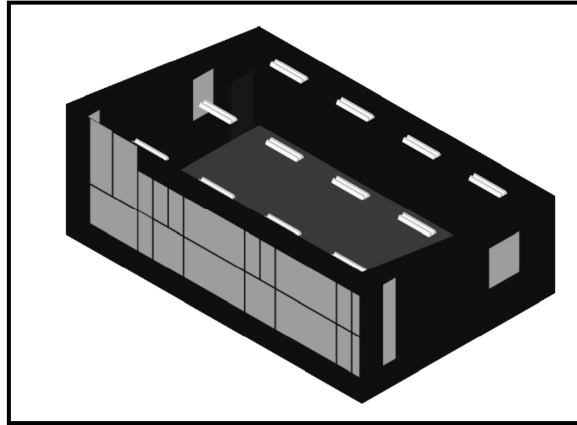


Figure 5.4: Three dimensional projection of the artificial lighting system

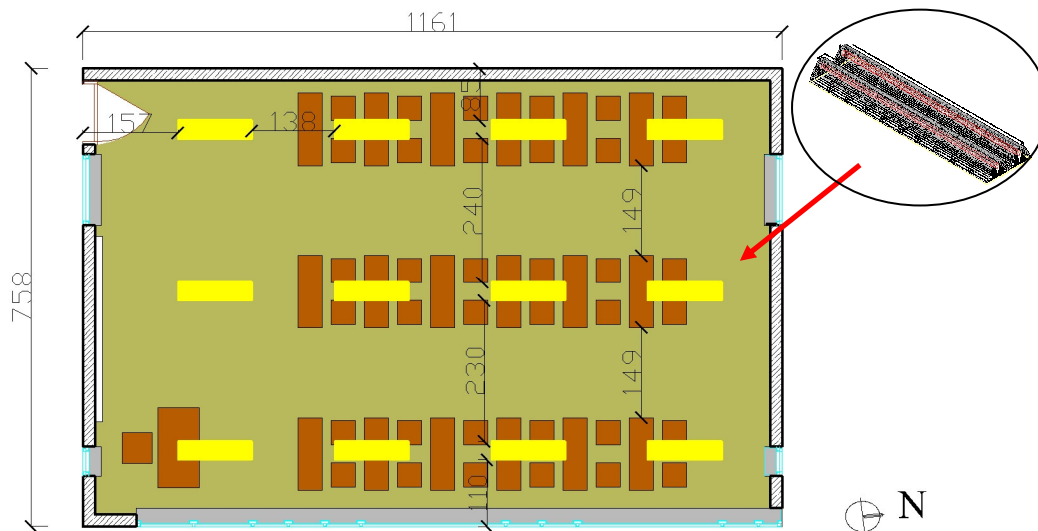


Figure 5.5: Schematic configuration of the artificial lighting system

Each lamp in the artificial lighting system has 32 W and 5760 lumen. These fluorescent lamp dimensions are 1284*94*33. Each luminary has 150 x 150mm parabolic Wedge Louvers for preventing from glare.

A unique griddle system is used for the classroom both at the distribution analyses of original design and new design analyses (Figure 5.6.).

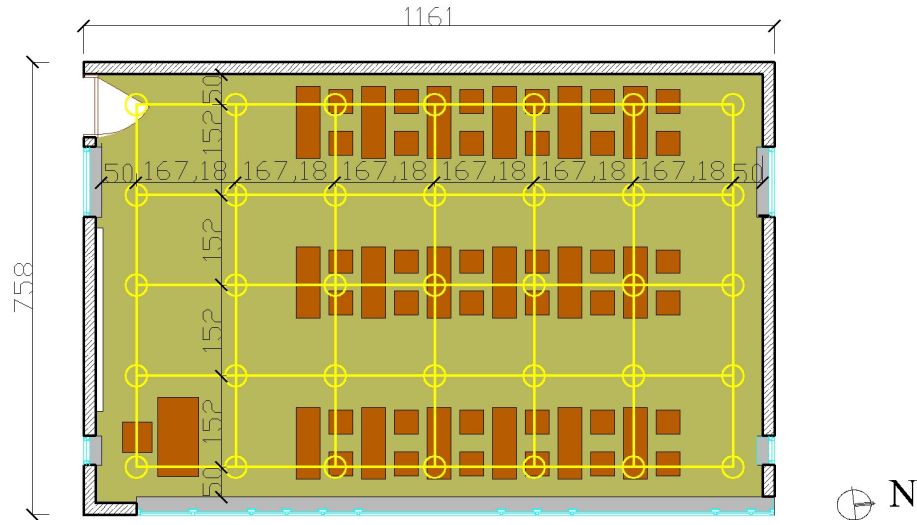


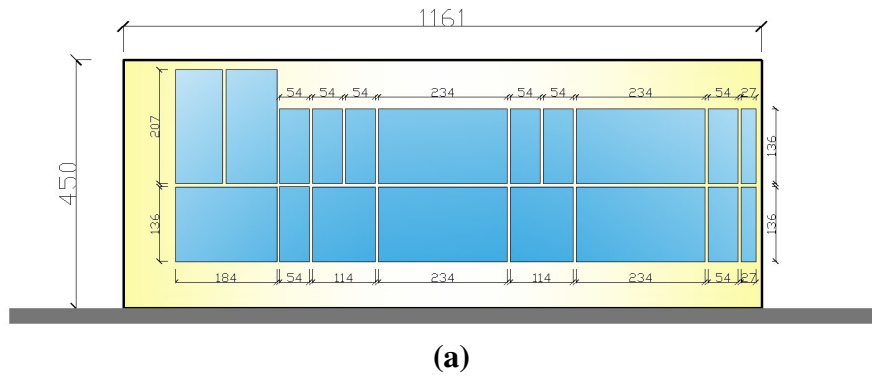
Figure 5.6: Grid system of the classroom

5.2 Comparison of Energy Consumptions in Existing and Proposed Projects

In order to compare the artificial lighting energy consumption related to the daylight distribution inside the room, existing and proposed conditions of the classroom are investigated.

5.2.1 Calculation of artificial lighting energy consumption in existing project

The plan and seating arrangement of the existing classroom are shown in the Figure 5.3. Moreover, window and façade configurations are stated in Figure 5.7.



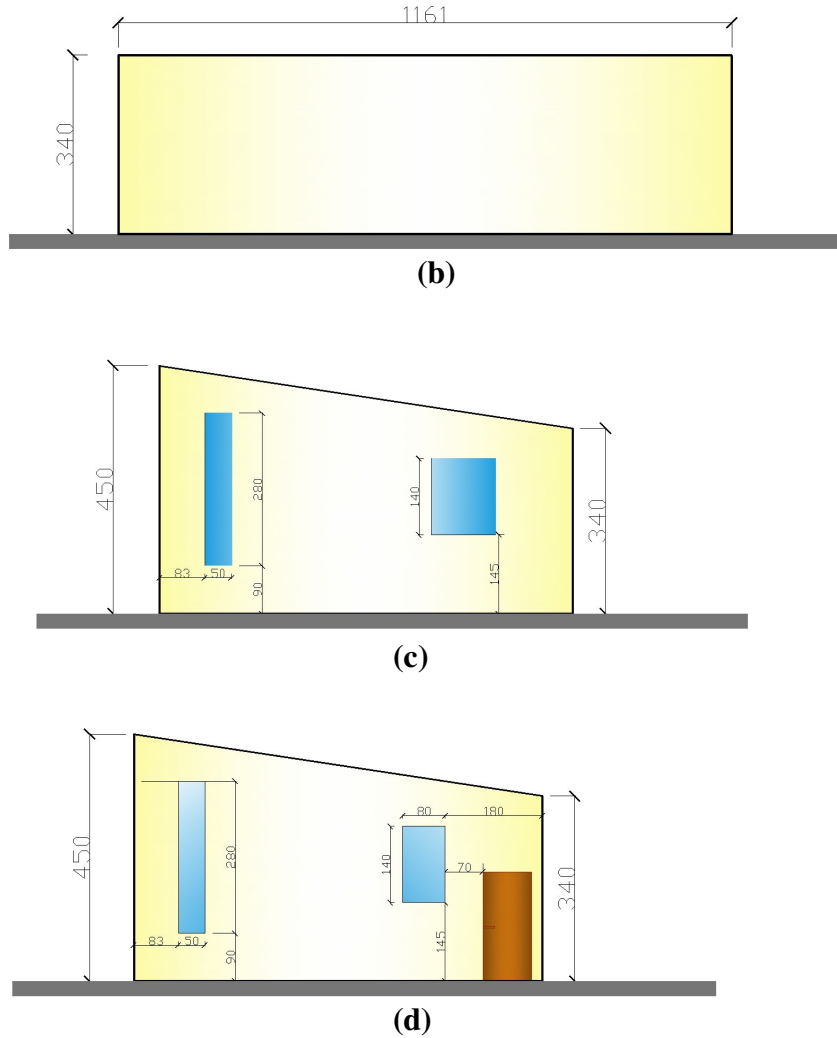


Figure 5.7: (a) East, (b) West, (c) North, (d) South facade of existing classroom.

5.2.1.1 Determination of external daylight values

The sky conditions should be specified in order to carry out the calculations for the prospected simulation of classroom space internal illumination level. INSEL, software for planning, monitoring and visualizing energy systems, is used to obtain the hourly values throughout the day and the year for the specification of the sky model. For this purpose, INSEL provides state-of-the-art functions in the form of blocks that can be linked to a concrete solution, for example for simulating meteorological data, electrical and thermal energy components [40].

The analysis of real sky types is a complex matter, because weather conditions have a quite unpredictable influence on the quantitative behavior of the sky illuminance. Plenty of attempts have been made of classify weather situations and in a European project which is continuing. Real skies types can be classified by the nebulosity index (k_n).

$$k_n = \frac{1 - G_{dh}/G_h}{1 - 0.12 \cdot \sin^{-0.82} \alpha} \quad (5.1)$$

The term $0.12 \sin^{-0.82} \alpha$ represents an empirical mean value of the cloud ratio as a function of the solar altitude α .

The weather data used come from program's database (also has the so-called gen.g – block for generation of weather data at any point in the world) but can also be taken from Meteonorm. From existing blocks of INSEL, the simulation model is put together and calculated [40]. Steps of calculating process of “ k_n ” are shown in Appendix 1. The limits of the nebulosity index defining the five sky types are given in Table 5.2.

Table 5.2: Sky type classification [40].

Sky type	Nebulosity index
Overcast sky	$0.00 \leq k_n \leq 0.05$
Intermediate overcast sky	$0.05 < k_n \leq 0.20$
Intermediate mean sky	$0.20 < k_n \leq 0.70$
Intermediate clear sky	$0.70 < k_n \leq 0.90$
Clear sky	$0.90 < k_n \leq 1.00$

The output of the software; 5 different sky models generated with hourly data, can be seen in Table 5.3.

Table 5.3: Different sky models generated with hourly data

Month	clear sky [h/month]	intermediate clear sky [h/month]	intermediate mean sky [h/month]	intermediate overcast sky [h/month]	overcast sky [h/month]	Sum
January	18	9	100	96	24	247
February	11	18	98	107	21	255
March	15	33	144	120	30	342
April	23	58	160	119	18	378
May	27	45	216	111	30	429
June	60	79	166	126	17	448
July	115	69	182	80	8	454
August	42	82	167	94	20	405
September	65	68	133	74	11	351
October	46	33	134	81	17	311
November	19	28	65	110	24	246
December	17	14	75	98	32	236

Software –Radiance- is used to perform the space daylight analysis. The five types are summed up into three sky types, in order to apply the Radiance simulations mode. The limits of the nebulosity index defining the 3 sky types are given below.

$0 < kn < 0,20$ overcast, $0,20 < kn < 0,70$ intermediate, $0,70 < kn < 1$ Clear.

Final values of the number of days in each month for 3 sky types are given in Table 5.4.

Table 5.4: Number of days for three sky types

Month	Clear Sky (day)	Intermediate Sky (day)	Overcast Sky (day)	Sum (day)
January	4	11	16	31
February	3	11	14	28
March	4	13	14	31
April	7	12	11	30
May	7	14	9	30
June	13	9	8	30
July	13	12	6	31
August	12	11	8	31
September	12	11	7	30
October	11	12	8	31
November	5	8	17	30
December	4	10	17	31

5.2.1.2 Determination of internal daylight values

Radiance Desktop 2.0 BETA software is used to obtain the illumination level in the space.

Desktop Radiance is a design tool that facilitates the design and analysis of buildings to optimize the efficiency of daylighting systems and lighting technologies. Desktop Radiance is a plug-in module that works with other popular computer aided design (CAD) tools to provide the user interaction and 3-d modeling capabilities. Desktop Radiance relies upon the popular Radiance Synthetic Imaging System to provide its renderings and analytical results. The first step in the process of performing a daylighting analysis is the creation of a 3D model in a Graphic Editor program, such as AutoCAD. The 3D model can then be detailed appropriately using the Desktop Radiance library of materials, glazing, luminaries and furnishings. Once the model is complete, analysis parameters such as camera views or reference point calculations, building orientation and zone of interest should be defined. A rendering or point calculation using the simulation menu commands that initiate the export of the geometry and analysis parameters are set up [41].

The Radiance standard release includes the sky model generator program Gensky. This utility program will produce Radiance format sky luminance distributions for four sky model types, with the option to create a sun description for the non-overcast sky models.

The Gensky program can produce sky luminance distributions based on:

- The uniform luminance model,
- The CIE overcast sky model,
- The CIE clear sky model and,
- The Matsuura intermediate sky model.

- ***The CIE overcast sky model:***

$$L(\gamma) = L_z (1 + 2 \sin \gamma) / 3 \quad (5.2)$$

Where the L_z is the luminance at the Zenith. A sky luminance distribution is three times brighter near the zenith than at the horizon.

$L(\gamma)$: luminance of sky element

γ : angle of elevation of the sky element above the horizon

The external horizontal illumination caused by the CIE standard overcast sky is the following,

$$E_{oc} = 300 + 21000 \sin \gamma_s \quad (5.3)$$

- ***The CIE clear sky model:***

A reference cloudless sky condition having the greatest luminance near the sun and least luminance 90 degrees from the sun.

$$E_{cl} = 280 \arctan (\gamma_s / 18.9) \quad (5.4)$$

γ_s : solar altitude at a given time

- ***The “Matsuura intermediate sky” model***

This formulation is based on a model that was proposed by Matsuura to describe sky conditions that have a higher turbidity than the CIE clear sky model. At the time that the Matsuura model was implemented into the **Gensky** program, it was recognized from CIE. Hereafter, it is referred to as the intermediate sky model. This model takes the form:

$$L(\gamma, \theta) = \frac{L_z \cdot a \cdot b}{2.326} \quad (5.5)$$

$$a = [1.35 \sin(5.631 - 3.59\xi) + 3.12] \sin(4.396 - 2.6\xi_s) + 6.37 - \xi \quad (5.6)$$

$$b = \text{EXP}\{-0.5630[(2.629 - \xi)(1.562 - \xi_s) + 0.812]\} \quad (5.7)$$

L_z = zenith luminance

$$\xi = \pi/2 - \gamma \quad (5.8)$$

$$\xi_s = \pi/2 - \gamma_s \quad (5.9)$$

θ = angle from sun to sky point

γ = sky point altitude

γ_s = sun altitude

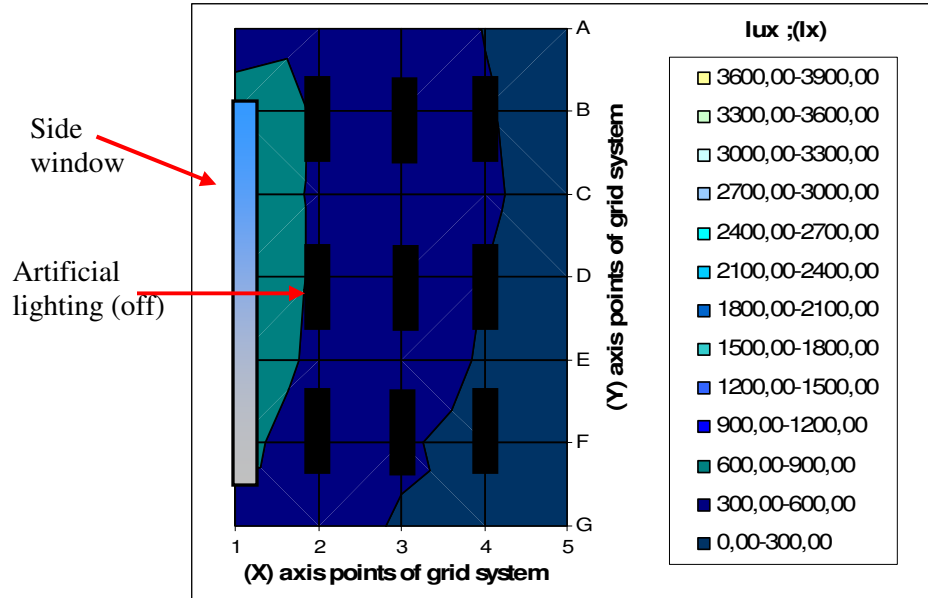
The zenith luminance (actually, radiance) is normalized to the diffuse horizontal irradiance [42].

The space is depicted 3D in AutoCAD 2000 and material assignment is done convenient with the Radiance software. In addition, a griddle system is formed from the wall edge at 35 points in the defined 75cm height which is the working plane. The analyses are made with 2 hours intervals for the 15th day of every month in three different sky models. The illumination levels of these points are enclosed in Appendix 2.

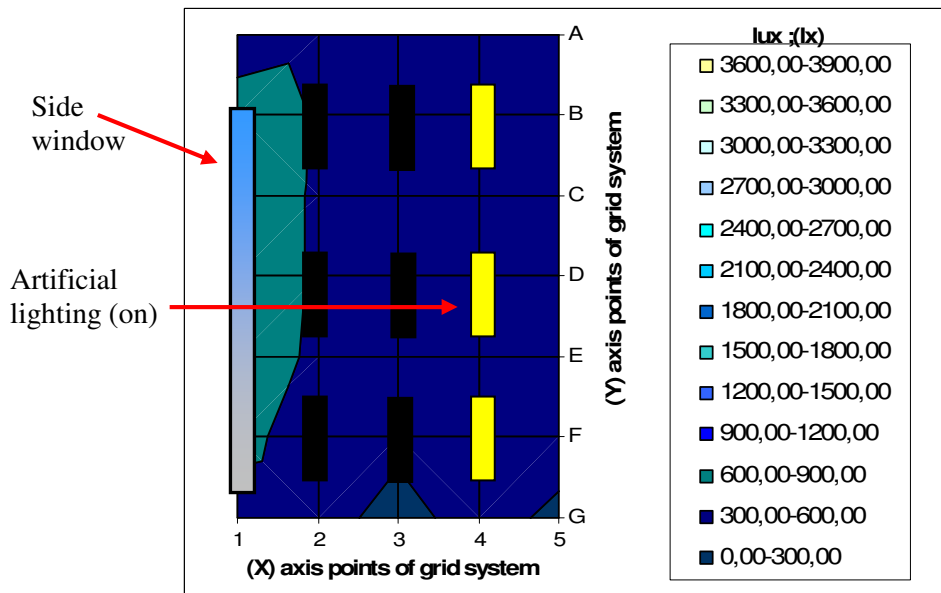
5.2.1.3 Determination of energy consumption

Required electric lighting hours for the classroom space are set according to the day light distribution data. The existing artificial lighting is assumed to have an automatic switch system which is programmed to provide the required illumination level 300 lux and finally the electric energy consumption is calculated.

The sample below is the visualized analyses of the intermediate sky model of January at 15:00. At the deep side of the room the illumination level is not sufficient. The illumination value is shown after commence of the artificial lighting system which afterwards meet the required comfort condition (min. 300lux [5]).



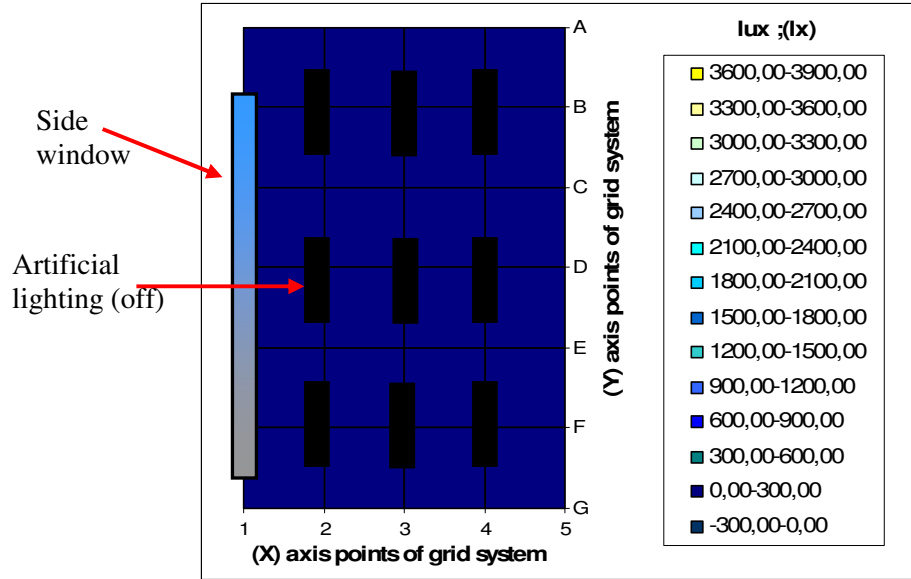
(a)



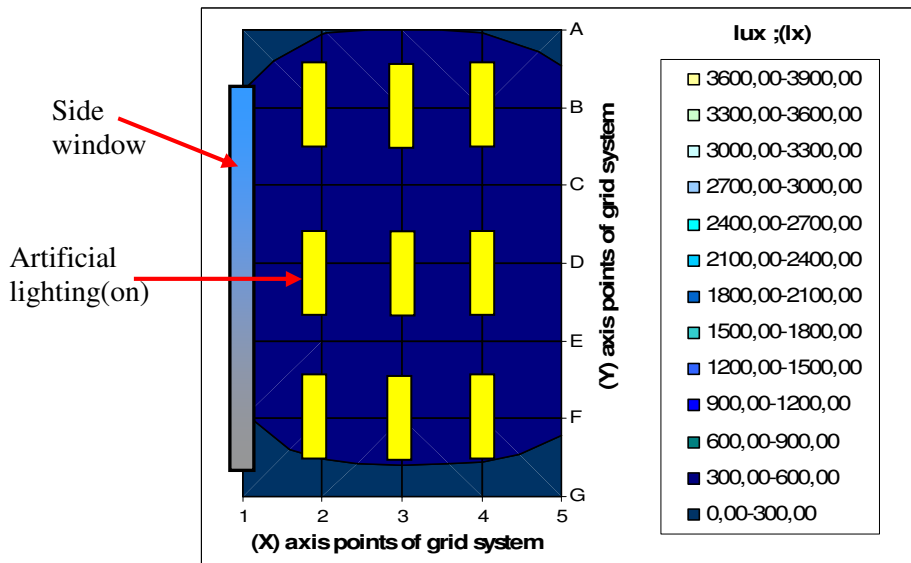
(b)

Figure 5.8: Illumination levels (a) without artificial lighting, (b) with artificial lighting, according to the intermediate sky model in January at 15:00.

With the same principle, the results evaluated for January at 17:00 for turning on the unique light line can be seen at the table below.



(a)



(b)

Figure 5.9: Illumination levels (a) without artificial lighting, (b) with artificial lighting, according to the intermediate sky model in January at 17:00

According to this principle, the required artificial lighting energy need is calculated for each month of the school year related to the daylight distribution of the classroom.

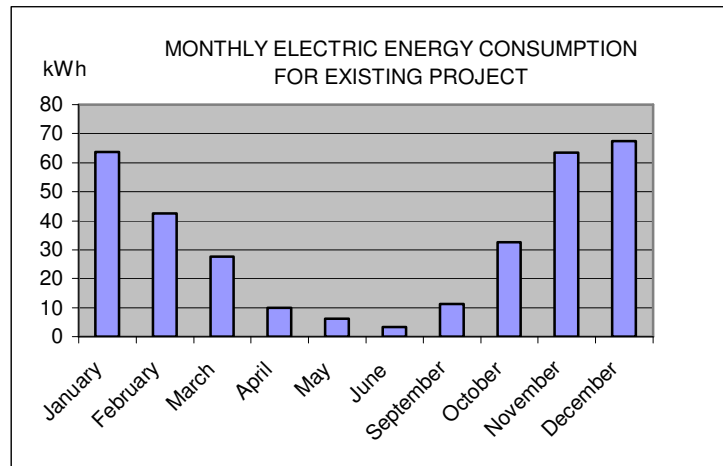
Table 5.5: Electric energy calculations of original design classroom (Appendix 3)

January	09:00 - 11:00	2h (32W x 12 Lamp) = 768Wh	768	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 6)	384	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 6)	384	13:00 - 15:00	2h (32 x 6)	384	13:00 - 15:00	2h (32 x 3)	192
	15:00 - 17:00	2h (32 x 18)	1152	15:00 - 17:00	2h (32 x 18)	1152	15:00 - 17:00	2h (32 x 12)	768
January 63744 Wh		overcast sky condition 16 day x 2688Wh	2688 43008 Wh		intermediate sky condition 11 day x 1536Wh	1536 16896 Wh		clear sky condition 4 day x 960Wh	960 3840 Wh
February	09:00 - 11:00	2h (32W x 6 Lamp) = 384Wh	384	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 6)	384	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 6)	384	13:00 - 15:00	2h (32 x 6)	384	13:00 - 15:00	2h (32 x 3)	192
	15:00 - 17:00	2h (32 x 12)	768	15:00 - 17:00	2h (32 x 12)	768	15:00 - 17:00	2h (32 x 12)	768
February 42432 Wh		overcast sky condition 14 day x 1920 Wh	1920 26880 Wh		intermediate sky condition 11 day x 1152 Wh	1152 12672 Wh		clear sky condition 3 day x 960 Wh	960 2880Wh
March	09:00 - 11:00	2h (32W x 3 Lamp) = 192Wh	192	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 3)	192	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 12)	768	15:00 - 17:00	2h (32 x 12)	768	15:00 - 17:00	2h (32 x 6)	384
March Total 27648 Wh		overcast sky condition 14 day x 1152 Wh	1152 16128 Wh		intermediate sky condition 13 day x 768 Wh	768 9984 Wh		clear sky condition 4 day x 384 Wh	384 1536 Wh
April	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 6)	384	15:00 - 17:00	2h (32 x 6)	384	15:00 - 17:00	2h (32 x 3)	192
April Total 9984 Wh		overcast sky condition 11 day x 384 Wh	384 4224 Wh		intermediate sky condition 12 day x 384 Wh	384 4608 Wh		clear sky condition 6 day x 192 Wh	192 1152 Wh
May	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 6)	384	15:00 - 17:00	2h (32 x 3)	192	15:00 - 17:00	2h (32 x 0)	0
May Total 6144 Wh		overcast sky condition 9 day x 384 Wh	384 3456 Wh		intermediate sky condition 14 day x 192 Wh	192 2688 Wh		clear sky condition 7 day x 0 Wh	0 Wh
June	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 3)	192	15:00 - 17:00	2h (32 x 3)	192	15:00 - 17:00	2h (32 x 0)	0
June Total 3264 Wh		overcast sky condition 8 day x 192 Wh	192 1536 Wh		intermediate sky condition 9 day x 192 Wh	192 1728 Wh		clear sky condition 13 day x 0 Wh	0 Wh
September	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 6)	384	15:00 - 17:00	2h (32 x 9)	576	15:00 - 17:00	2h (32 x 3)	192
September Total 11328 Wh		overcast sky condition 7 day x 384 Wh	384 2688 Wh		intermediate sky condition 11 day x 576 Wh	576 6336 Wh		clear sky condition 12 day x 192 Wh	192 2304 Wh
October	09:00 - 11:00	2h (32W x 6 Lamp) = 384Wh	384	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 3)	192	13:00 - 15:00	2h (32 x 6)	384	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 15)	960	15:00 - 17:00	2h (32 x 15)	960	15:00 - 17:00	2h (32 x 6)	384
October Total 32640 Wh		overcast sky condition 8 day x 1536 Wh	1536 12288 Wh		intermediate sky condition 12 day x 1344 Wh	1344 16128 Wh		clear sky condition 11 day x 384 Wh	384 4224 Wh
November	09:00 - 11:00	2h (32W x 6 Lamp) = 384Wh	384	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 3)	192	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 12)	768	13:00 - 15:00	2h (32 x 12)	768	13:00 - 15:00	2h (32 x 3)	192
	15:00 - 17:00	2h (32 x 18)	1152	15:00 - 17:00	2h (32 x 18)	1152	15:00 - 17:00	2h (32 x 15)	960
November Total 63552 Wh		overcast sky condition 17 day x 2496 Wh	2496 42432 Wh		intermediate sky condition 8 day x 1920 Wh	1920 15360 Wh		Clear sky condition 5 day x 1152 Wh	1152 5760 Wh
December	09:00 - 11:00	2h (32W x 6 Lamp) = 384Wh	384	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 3)	192	11:00 - 13:00	2h (32 x 3)	192	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 12)	768	13:00 - 15:00	2h (32 x 12)	768	13:00 - 15:00	2h (32 x 3)	192
	15:00 - 17:00	2h (32 x 18)	1152	15:00 - 17:00	2h (32 x 18)	1152	15:00 - 17:00	2h (32 x 12)	768
December Total 67392 Wh		overcast sky condition 17 day x 2496 Wh	2496 42432 Wh		intermediate sky condition 10 day x 2112 Wh	2112 21120 Wh		Clear sky condition 4 day x 960 Wh	960 3840 Wh

Monthly energy requirement is calculated basing on the number of days of different sky types according to INSEL software. The monthly distribution of annual energy consumption values (kWh) can be seen below.

Table 5.6: The monthly distribution of annual energy consumption of the existing design

	kWh
January	63,744
February	42,432
March	27,648
April	9,984
May	6,144
June	3,264
September	11,328
October	32,64
November	63,552
December	67,392
TOTAL	328,128



5.2.2 Calculation of artificial lighting energy consumption in proposed project

For providing visual comfort conditions and minimizing artificial lighting consumption, several changes are planned at the existing daylight system of the classroom. These changes are given below.

Plan and section of the proposed classroom are given in Figure 5.10 and Figure 5.11.

- Side windows

The side windows of the existing classroom have different dimensions and random configuration which causes irregular distribution of daylight. Therefore, side windows are equally scaled and appropriately configured and then placed as seen in Figure 5.12 (a).

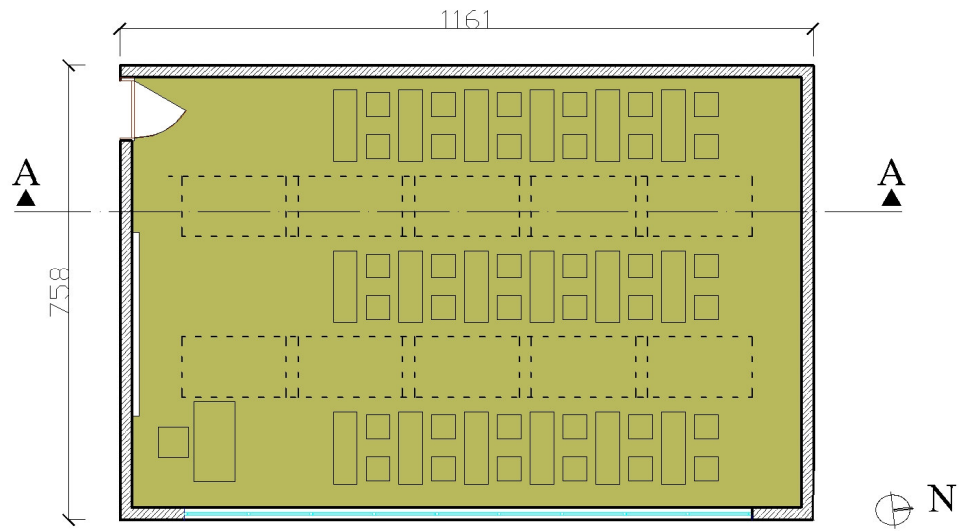


Figure 5.10: Plan of the proposed classroom.

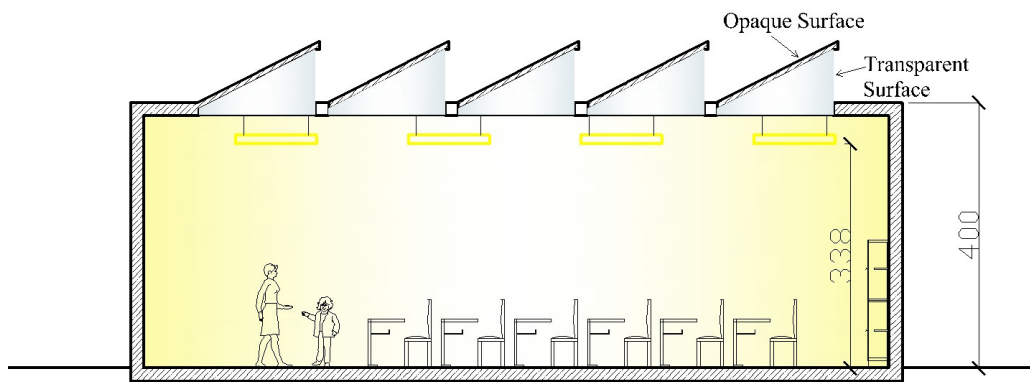
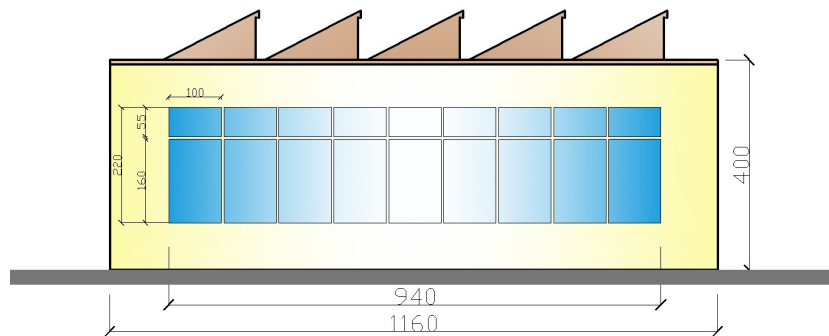


Figure 5.11: AA section of the proposed classroom.



(a)

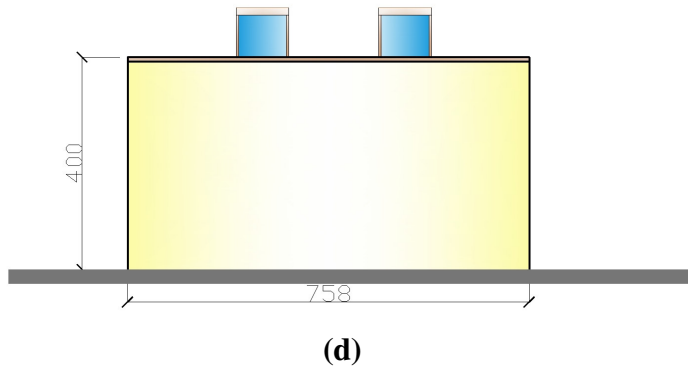
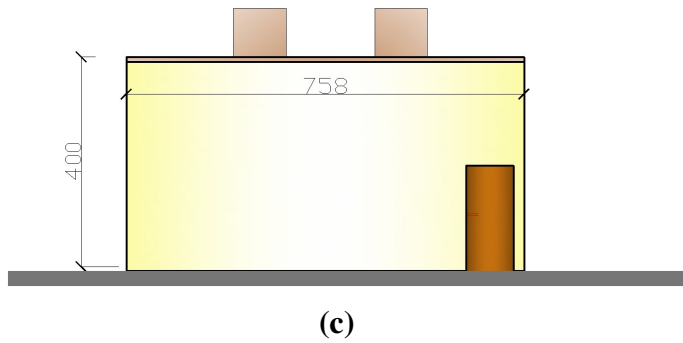
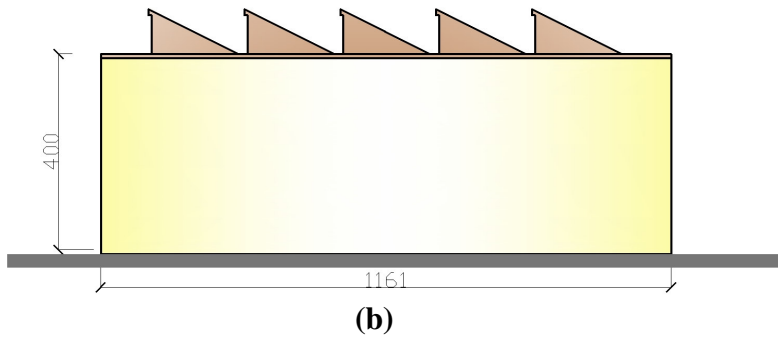


Figure 5.12: (a) East, (b) west, (c) south, (d) north facade of the proposed classroom.

- Shading System

This design is realized with these steps:

- 1) Determination of the daily and yearly shading period by depending on occupation time of the school building,

Occupation time: From September to June 09:00 - 17:00

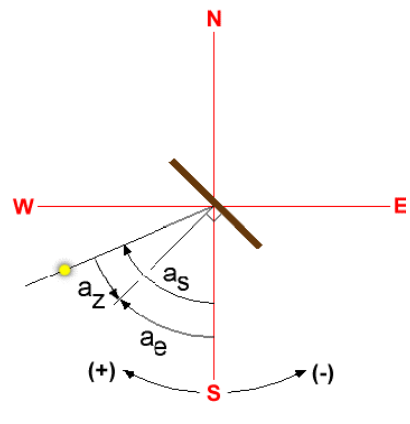
- 2) Determination of the critical solar angles (altitude, azimuth) for shading device design basing on the classroom direction. [Difference between local time and solar time and daylight saving time (March-October) are considered in the calculations.]

Lyon latitude: 45.8N, longitude 31.17

Classroom direction: East.

- 3) Calculation of the profile angle and solar elevation azimuth angle, according to the determined solar angles.

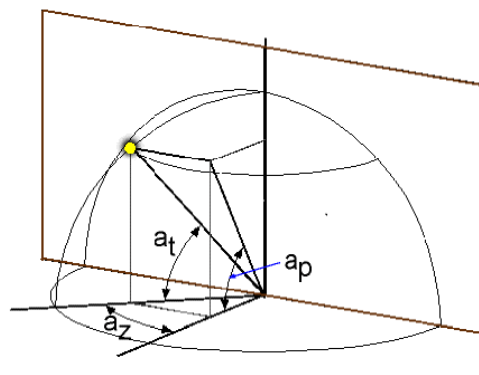
The solar elevation azimuth angle is calculated with this formula;



$$a_z = a_s - a_e \quad (5.10)$$

Figure 5.13: The solar elevation azimuth angle projection [43].

The solar profile angle is calculated with this formula;



$$a_p = \frac{\tan a_t}{\cos a_z} \quad (5.11)$$

Figure 5.14: The solar profile projection [43].

Based on the calculated angles, it is clear that to use horizontal shading devices in different inclination angles at different hours more efficient than other alternatives. As a result, the calculated angles are given in table 5.7.

Table 5.7: Inclination angles for shading

Skytype	Months Hours	January	February	March	April	May	June	September	October	November	December
<i>clear</i>	09:00	20°	30°	40°	30°	40°	40°	30°	20°	20°	20°
	11:00	90°	90°	90°	90°	90°	90°	90°	90°	90°	90°
	13:00	90°	90°	90°	90°	90°	90°	90°	90°	90°	90°
	15:00	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open
	17:00	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open
<i>intermediate</i>	09:00	90°	30°	40°	30°	40°	40°	30°	90°	90°	Open
	11:00	90°	90°	90°	90°	90°	90°	90°	90°	90°	Open
	13:00	90°	90°	90°	90°	Open	Open	90°	Open	90°	Open
	15:00	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open
	17:00	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open
<i>overcast</i>	09:00	Open	Open	Open	90°	90°	90°	Open	90°	Open	Open
	11:00	Open	Open	Open	90°	90°	90°	Open	90°	Open	Open
	13:00	Open	Open	Open	90°	90°	90°	Open	Open	Open	Open
	15:00	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open
	17:00	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open

- Determination of the physical properties of the shading devices (Figure 5.13.)

Type: Adjustable horizontal shading device

Material: Aluminum panels

Number of elements: 10

Dimension of each shading device: 100 x 22 x 0,5 cm

Surface reflectance: 88,60 %

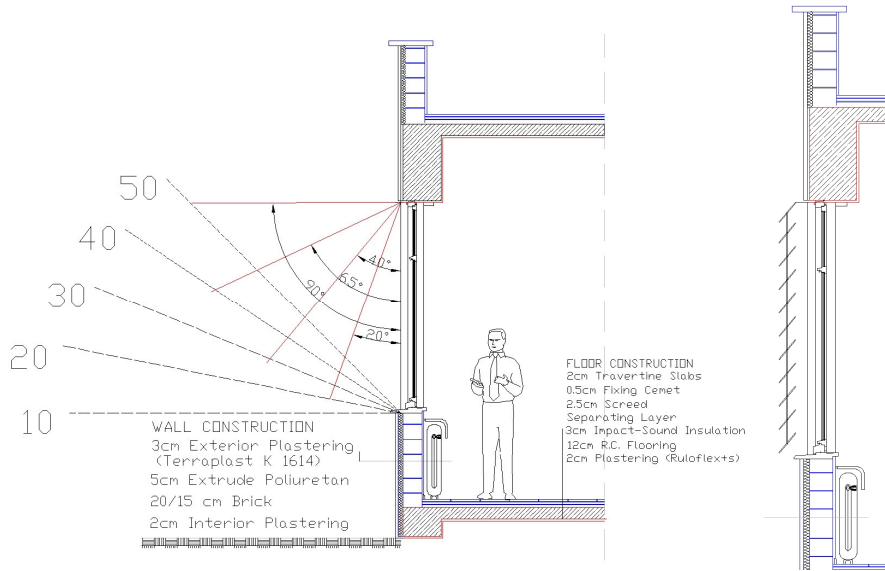


Figure 5.15: System section of classroom, profile angles and designed shading device

- In order to maximize the daylight entrance into the classroom while preventing the direct sunlight, shading elements should be adjusted with 20°, 30°, 40°, 50° angles or completely open. (Figures 5.15-5.16) according to the solar position. Control mechanism manual or automatical.

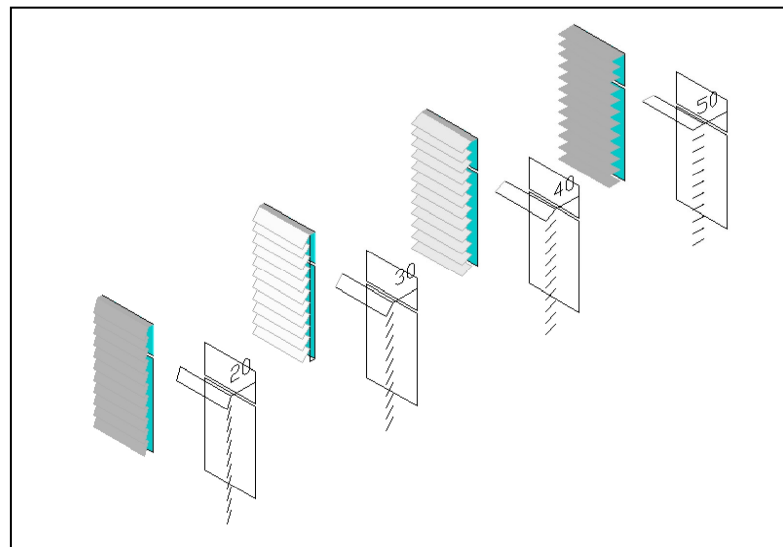


Figure 5.16: Shading devices adjustment angles.

- Sky lights

Infront of the side window daylight level has the highest value and gradually reduces towards the inside of the space. Sky light distributes daylight across the room. This type of daylighting system has an advantage. It is appropriate for all climate regions.

Dimensions of the sky light system which is used in the proposed design are given in Figure 5.15. The system provides good diffusion and balanced daylight across the classroom. Also this approach saves electric energy.

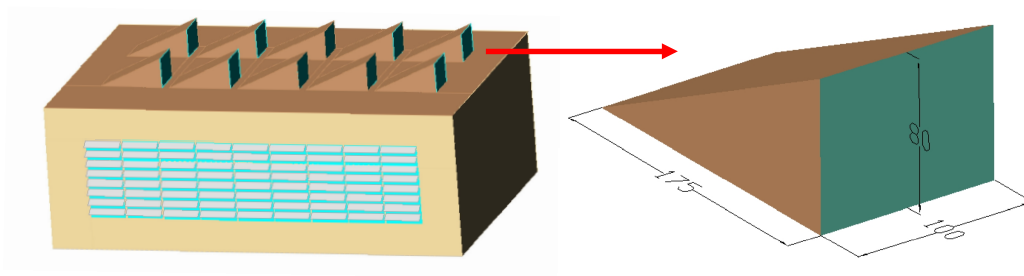


Figure 5.17: Dimensions of the skylight

5.2.2.1 Determination of external daylight values

The sky conditions are specified by using the INSEL program as described in Section 5.2.1.1.

5.2.2.2 Determination of internal daylight values

The results achieved by carrying out the steps described in Section 5.1.1.1 for the proposed condition are placed in Appendix 4.

5.2.2.3 Determination of energy consumption

The calculation of the energy consumption of the proposed condition is carried out according to the same principles given in Section 5.1.2.2. Results are given in Table 5.8.

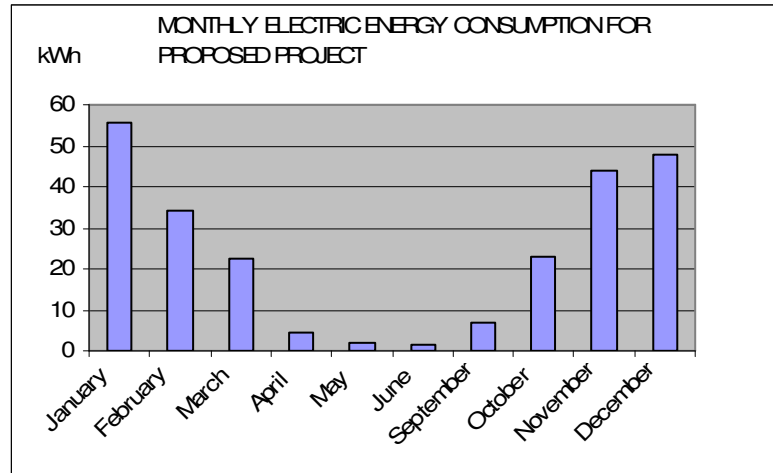
Table 5.8: Electric energy calculations of new designed classroom (Appendix 5)

January	09:00 - 11:00	2h (32W x 9 Lamp) = 576Wh	576	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 3	192
	11:00 - 13:00	2h (32 x 3)	192	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 6)	384	13:00 - 15:00	2h (32 x 6)	384	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 15)	1152	15:00 - 17:00	2h (32 x 15)	960	15:00 - 17:00	2h (32 x 12)	768
January 55488 Wh		overcast sky condition 16 day x 2688Wh	2304 36864 Wh		intermediate sky condition 11 day x 1344Wh	1344 14784 Wh		clear sky 4 day x 960Wh	960 3840 Wh
February	09:00 - 11:00	2h (32W x 6 Lamp) = 384Wh	384	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 3)	192	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 3)	192	13:00 - 15:00	2h (32 x 3)	192	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 12)	768	15:00 - 17:00	2h (32 x 12)	768	15:00 - 17:00	2h (32 x 12)	768
February 34368 Wh		overcast sky condition 14 day x 1536 Wh	1536 21504 Wh		intermediate sky condition 11 day x 960 Wh	960 10560 Wh		clear sky 3 day x 768 Wh	768 2304 Wh
March	09:00 - 11:00	2h (32W x 3 Lamp) = 192Wh	192	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 3)	192	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 9)	576	15:00 - 17:00	2h (32 x 9)	576	15:00 - 17:00	2h (32 x 6)	384
March 22464 Wh		overcast sky condition 14 day x 1152 Wh	960 13440 Wh		intermediate sky condition 13 day x 576 Wh	576 7488 Wh		clear sky 4 day x 384 Wh	384 1536 Wh
April	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 3)	192	15:00 - 17:00	2h (32 x 3)	192	15:00 - 17:00	2h (32 x 0)	0
April Total 4416 Wh		overcast sky condition 11 day x 192 Wh	192 2112 Wh		intermediate sky condition 12 day x 192 Wh	192 2304 Wh		clear sky 6 day x 0 Wh	0 0 Wh
May	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 3)	192	15:00 - 17:00	2h (32 x 0)	0	15:00 - 17:00	2h (32 x 0)	0
May Total 1728 Wh		overcast sky condition 9 day x 192 Wh	192 1728 Wh		intermediate sky condition 14 day x 0 Wh	0 0 Wh		clear sky 7 day x 0 Wh	0 0 Wh
June	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 3)	192	15:00 - 17:00	2h (32 x 0)	0	15:00 - 17:00	2h (32 x 0)	0
June Total 1536 Wh		overcast sky condition 8 day x 192 Wh	192 1536 Wh		intermediate sky condition 9 day x 192 Wh	0 0 Wh		clear sky 13 day x 0 Wh	0 0 Wh
September	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 6)	384	15:00 - 17:00	2h (32 x 6)	384	15:00 - 17:00	2h (32 x 0)	0
September 6912 Wh		overcast sky condition 7 day x 384 Wh	384 2688 Wh		intermediate sky condition 11 day x 384 Wh	384 4224 Wh		clear sky 12 day x 0 Wh	0 0 Wh
October	09:00 - 11:00	2h (32W x 6 Lamp) = 384Wh	384	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 3)	192	13:00 - 15:00	2h (32 x 3)	192	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 12)	768	15:00 - 17:00	2h (32 x 12)	768	15:00 - 17:00	2h (32 x 3)	192
October 22848 Wh		overcast sky condition 8 day x 1152 Wh	1344 9216Wh		intermediate sky condition 12 day x 960 Wh	960 11520 Wh		clear sky 11 day x 192	192 2112 Wh
November	09:00 - 11:00	2h (32W x 3 Lamp) =192Wh	192	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 9)	576	13:00 - 15:00	2h (32 x 6)	384	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 15)	960	15:00 - 17:00	2h (32 x 15)	960	15:00 - 17:00	2h (32 x 12)	768
November 43938 Wh		overcast sky condition 17 day x 1728 Wh	1728 29346 Wh		intermediate sky condition 8 day x 1344Wh	1344 10752Wh		clear sky 5 day x 768 Wh	768 3840 Wh
December	09:00 - 11:00	2h (32W x 3 Lamp) = 384Wh	192	09:00 - 11:00	2h (32W x 0 Lamp) = 0Wh	0	09:00 - 11:00	2h (32W x 0	0
	11:00 - 13:00	2h (32 x 0)	0	11:00 - 13:00	2h (32 x 3)	192	11:00 - 13:00	2h (32 x 0)	0
	13:00 - 15:00	2h (32 x 9)	576	13:00 - 15:00	2h (32 x 6)	384	13:00 - 15:00	2h (32 x 0)	0
	15:00 - 17:00	2h (32 x 15)	960	15:00 - 17:00	2h (32 x 15)	960	15:00 - 17:00	2h (32 x 12)	768
December 47778 Wh		overcast sky condition 17 day x 2496 Wh	1728 29346 Wh		intermediate sky condition 10 day x 1536 Wh	1536 15360 Wh		clear sky 4 day x 768 Wh	768 3072 Wh

The monthly distribution of annual energy consumption values (kWh) can be seen in Table 5.8.

Table 5.9: The monthly distribution of annual energy consumption of proposed design

	kWh
January	55,488
February	34,368
March	22,464
April	4,416
May	1,728
June	1,536
September	6,912
October	22,848
November	43,938
December	47,778
TOTAL	241,476



The shading system considered as an automatical system, for movement of devices a motor system is necessary. That electric energy consumption is added to calculate the final electric energy consumption. The method and the results are in Table 5.10.

Table 5.10: Energy consumption of electricity belong to shading device control

January	starting	0	0,00	starting	60'	1,67	starting	60'	1,67
	09:00	0	0,00	09:00	0	0,00	09:00	20'	0,57
	11:00	0	0,00	11:00	0	0,00	11:00	20'	0,57
	13:00	0	0,00	13:00	0	0,00	13:00	0	0,00
	15:00	0	0,00	15:00	60'	1,67	15:00	60'	1,67
	17:00	0	0,00	17:00	0	0,00	17:00	0	0,00
	January	overcast sky	0,00	intermediate sky	3,34		clear sky	4,48	
54,66	16	0,00	11	36,74	4	17,92			
February	starting	0	0,00	starting	60'	1,67	starting	60'	1,67
	09:00	0	0,00	09:00	15'	0,42	09:00	15'	0,42
	11:00	0	0,00	11:00	15'	0,42	11:00	15'	0,42
	13:00	0	0,00	13:00	0	0,00	13:00	0	0,00
	15:00	0	0,00	15:00	60'	1,67	15:00	60'	1,67
	17:00	0	0,00	17:00	0	0,00	17:00	0	0,00
	February	overcast sky	0,00	intermediate sky	4,18		clear sky	4,18	
58,52	14	0,00	11	45,98	3	12,54			
March	starting	0	0,00	starting	60'	1,67	starting	60'	1,67
	09:00	0	0,00	09:00	10'	0,28	09:00	10'	0,28
	11:00	0	0,00	11:00	10'	0,28	11:00	10'	0,28
	13:00	0	0,00	13:00	60'	1,67	13:00	60'	1,67
	15:00	0	0,00	15:00	0	0,00	15:00	0	0,00
	17:00	0	0,00	17:00	0	0,00	17:00	0	0,00
	March	overcast sky	0,00	intermediate sky	3,90		clear sky	3,90	
66,30	14	0,00	13	50,70	4	15,60			
April	starting	60'	1,67	starting	60'	1,67	starting	60'	1,67
	09:00	0	0,00	09:00	15'	0,42	09:00	15'	0,42
	11:00	0	0,00	11:00	15'	0,42	11:00	15'	0,42
	13:00	0	0,00	13:00	0	0,00	13:00	0	0,00
	15:00	60'	1,67	15:00	60'	1,67	15:00	60'	1,67

	17:00	0	0,00	17:00	0	0,00	17:00	0	0,00
April Total		overcast sky	3,34		intermediate sky	4,18		clear sky	4,18
111,98		11	36,74		12	50,16		6	25,08
May	<i>starting</i>	60'	1,67	<i>starting</i>	60'	1,67	<i>starting</i>	60'	1,67
	<i>09:00</i>	0	0,00	<i>09:00</i>	10'	0,28	<i>09:00</i>	10'	0,28
	<i>11:00</i>	0	0,00	<i>11:00</i>	60'	1,67	<i>11:00</i>	10'	0,28
	<i>13:00</i>	0	0,00	<i>13:00</i>	0	0,00	<i>13:00</i>	0	0,00
	<i>15:00</i>	60'	1,67	<i>15:00</i>	0	0,00	<i>15:00</i>	60'	1,67
	<i>17:00</i>	0	0,00	<i>17:00</i>	0	0,00	<i>17:00</i>	0	0,00
		overcast sky	3,34		intermediate sky	3,62		clear sky	3,90
May Total		9	30,06		14	50,68		7	27,30
June	<i>starting</i>	60'	1,67	<i>starting</i>	60'	1,67	<i>starting</i>	60'	1,67
	<i>09:00</i>	0	0,00	<i>09:00</i>	10'	0,28	<i>09:00</i>	10'	0,28
	<i>11:00</i>	0	0,00	<i>11:00</i>	10'	0,28	<i>11:00</i>	10'	0,28
	<i>13:00</i>	0	0,00	<i>13:00</i>	0	0,00	<i>13:00</i>	0	0,00
	<i>15:00</i>	60'	1,67	<i>15:00</i>	60'	1,67	<i>15:00</i>	60'	1,67
	<i>17:00</i>	0	0,00	<i>17:00</i>	0	0,00	<i>17:00</i>	0	0,00
		overcast sky	3,34		intermediate sky	3,90		clear sky	3,90
June Total		8	26,72		9	35,10		13	50,70
September	<i>starting</i>	0	0,00	<i>starting</i>	60'	1,67	<i>starting</i>	60'	1,67
	<i>09:00</i>	0	0,00	<i>09:00</i>	15'	0,42	<i>09:00</i>	15'	0,42
	<i>11:00</i>	0	0,00	<i>11:00</i>	15'	0,42	<i>11:00</i>	15'	0,42
	<i>13:00</i>	0	0,00	<i>13:00</i>	60'	1,67	<i>13:00</i>	0	0,00
	<i>15:00</i>	0	0,00	<i>15:00</i>	0	0,00	<i>15:00</i>	60'	1,67
	<i>17:00</i>	0	0,00	<i>17:00</i>	0	0,00	<i>17:00</i>	0	0,00
		overcast sky	0		intermediate sky	4,18		clear sky	4,18
September		7	0,00		11	45,98		12	50,16
October	<i>starting</i>	0	0,00	<i>starting</i>	60'	1,67	<i>starting</i>	60'	1,67
	<i>09:00</i>	0	0,00	<i>09:00</i>	0	0,00	<i>09:00</i>	20'	0,57
	<i>11:00</i>	0	0,00	<i>11:00</i>	0	0,00	<i>11:00</i>	20'	0,57
	<i>13:00</i>	0	0,00	<i>13:00</i>	60'	1,67	<i>13:00</i>	0	0,00
	<i>15:00</i>	0	0,00	<i>15:00</i>	0	0,00	<i>15:00</i>	60'	1,67
	<i>17:00</i>	0	0,00	<i>17:00</i>	0	0,00	<i>17:00</i>	0	0,00
		overcast sky	0		intermediate sky	3,34		clear sky	4,48
October		8	0,00		12	40,08		11	49,28
November	<i>starting</i>	0	0,00	<i>starting</i>	60'	1,67	<i>starting</i>	60'	1,67
	<i>09:00</i>	0	0,00	<i>09:00</i>	0	0,00	<i>09:00</i>	20'	0,57
	<i>11:00</i>	0	0,00	<i>11:00</i>	0	0,00	<i>11:00</i>	20'	0,57
	<i>13:00</i>	0	0,00	<i>13:00</i>	0	0,00	<i>13:00</i>	0	0,00
	<i>15:00</i>	0	0,00	<i>15:00</i>	60'	1,67	<i>15:00</i>	60'	1,67
	<i>17:00</i>	0	0,00	<i>17:00</i>	0	0,00	<i>17:00</i>	0	0,00
		overcast sky	0		intermediate sky	3,34		clear sky	4,48
November		17	0,00		8	26,72		5	22,40
December	<i>starting</i>	0	0,00	<i>starting</i>	0	0,00	<i>starting</i>	60'	1,67
	<i>09:00</i>	0	0,00	<i>09:00</i>	0	0,00	<i>09:00</i>	0	0,00
	<i>11:00</i>	0	0,00	<i>11:00</i>	0	0,00	<i>11:00</i>	0	0,00
	<i>13:00</i>	0	0,00	<i>13:00</i>	0	0,00	<i>13:00</i>	0	0,00
	<i>15:00</i>	0	0,00	<i>15:00</i>	0	0,00	<i>15:00</i>	60'	1,67
	<i>17:00</i>	0	0,00	<i>17:00</i>	0	0,00	<i>17:00</i>	0	0,00
		overcast sky	0		intermediate sky	0		clear sky	3,34
December		17	0,00		10	0,00		4	13,36
TOTAL ENERGY CONSUMPTION									
760,00	Wh	0,76 kWh	10	devices	7,6 Kwh				

Annual electric energy consumption of shading device system is 7,6 kWh. This amount should be added to the artificial lighting energy consumption. Final result of the consumption in proposed system is 249,076 kWh.

5.3 Discussion of the results

The energy consumption of two different design options, one with randomly placed side windows (original design) and one with regularly placed side windows with skylights and adjustable horizontal shading devices (new design), have been analyzed. The two options are visualized in Figure 5.18.

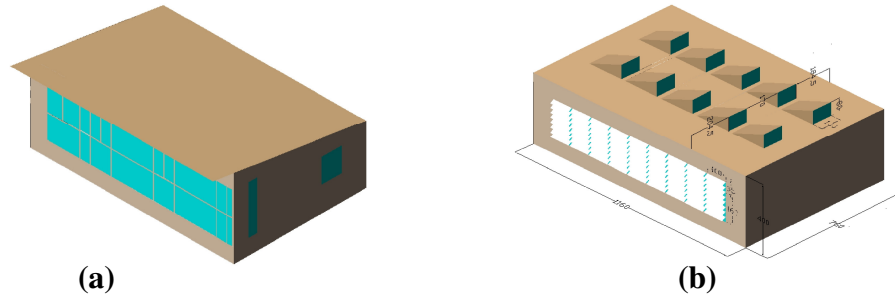


Figure 5.18: View of the two different design options (a) original design, (b) new design.

The main objective of this investigation is, to analyze and compare the annual energy consumption for illumination under consideration of the two different design options.

To show and compare the annual lighting energy demand of the chosen classroom in dependence of the design options, two cases have been analyzed. Detailed daylight calculations have been carried out by Radiance Desktop 2.0 BETA. Daylight illumination levels under clear, intermediate and overcast sky conditions are calculated for every month. Figure 5.19, 5.20 and 5.21 visualize the values in January for the new and original design. Other months' results are given in the Appendix 2 and 4.

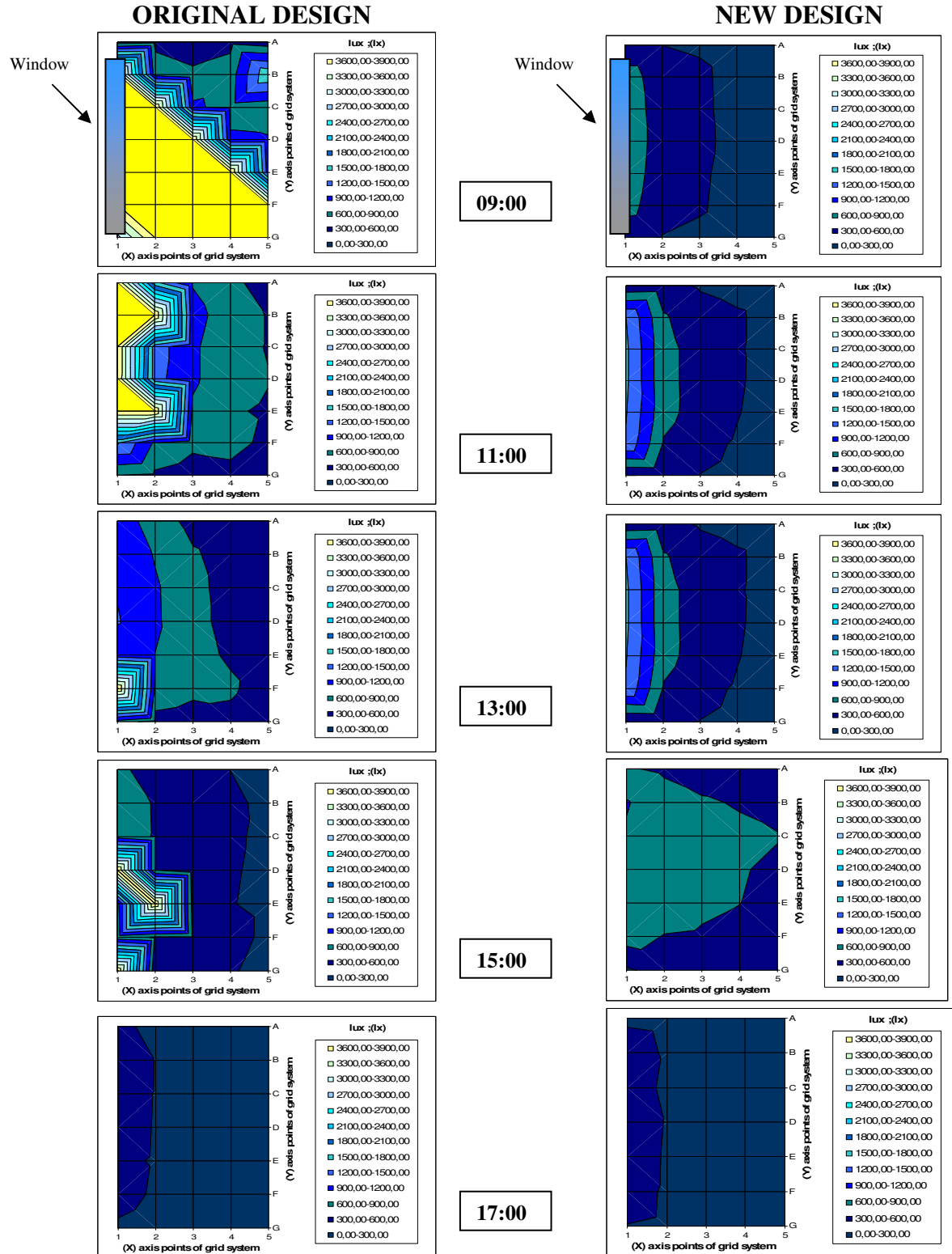


Figure 5.19: Daylight illumination levels under clear sky condition in January 15th for new and original design (Lux).

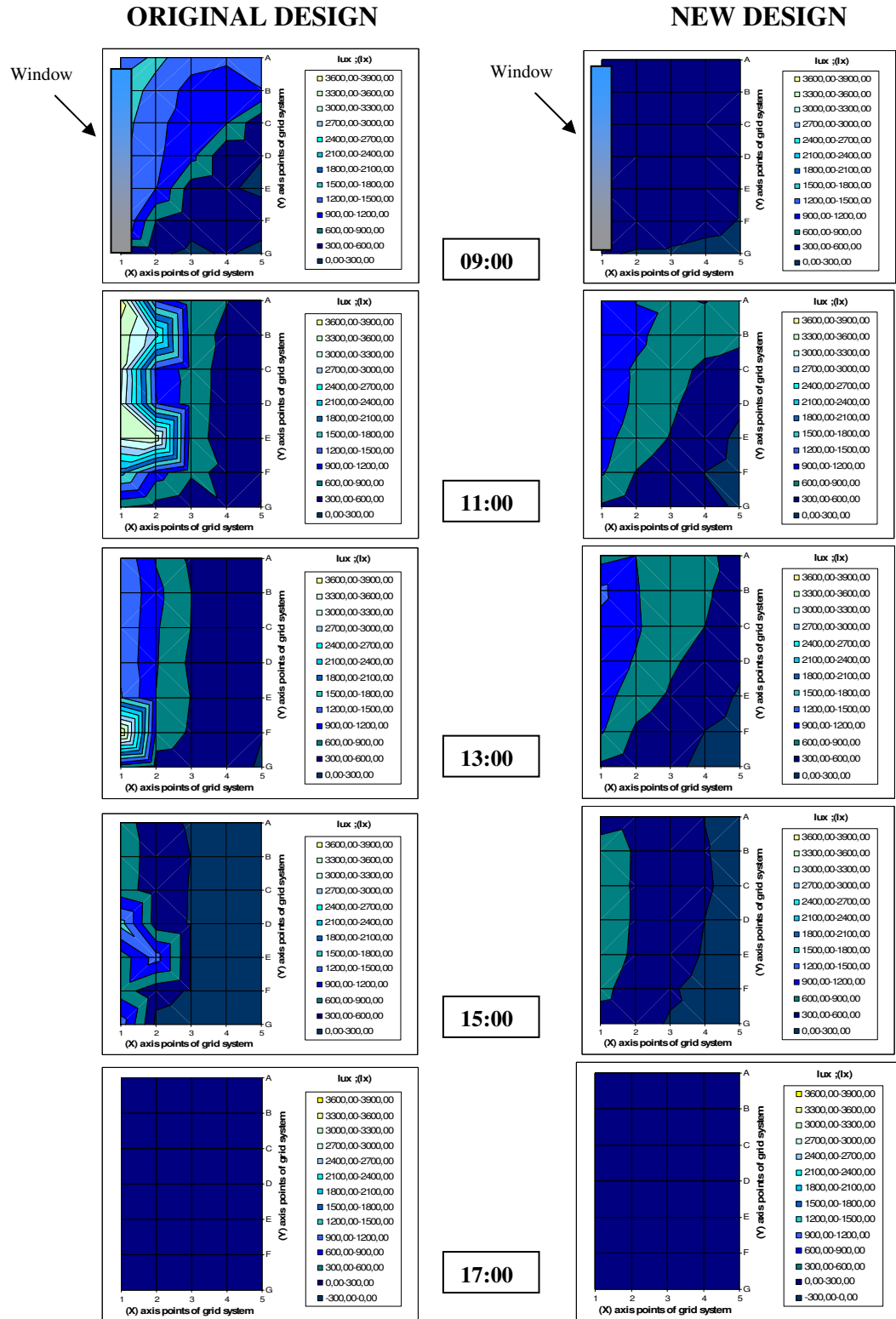


Figure 5.20: Daylight illumination levels under intermediate sky condition in January 15th for new and original design (Lux).

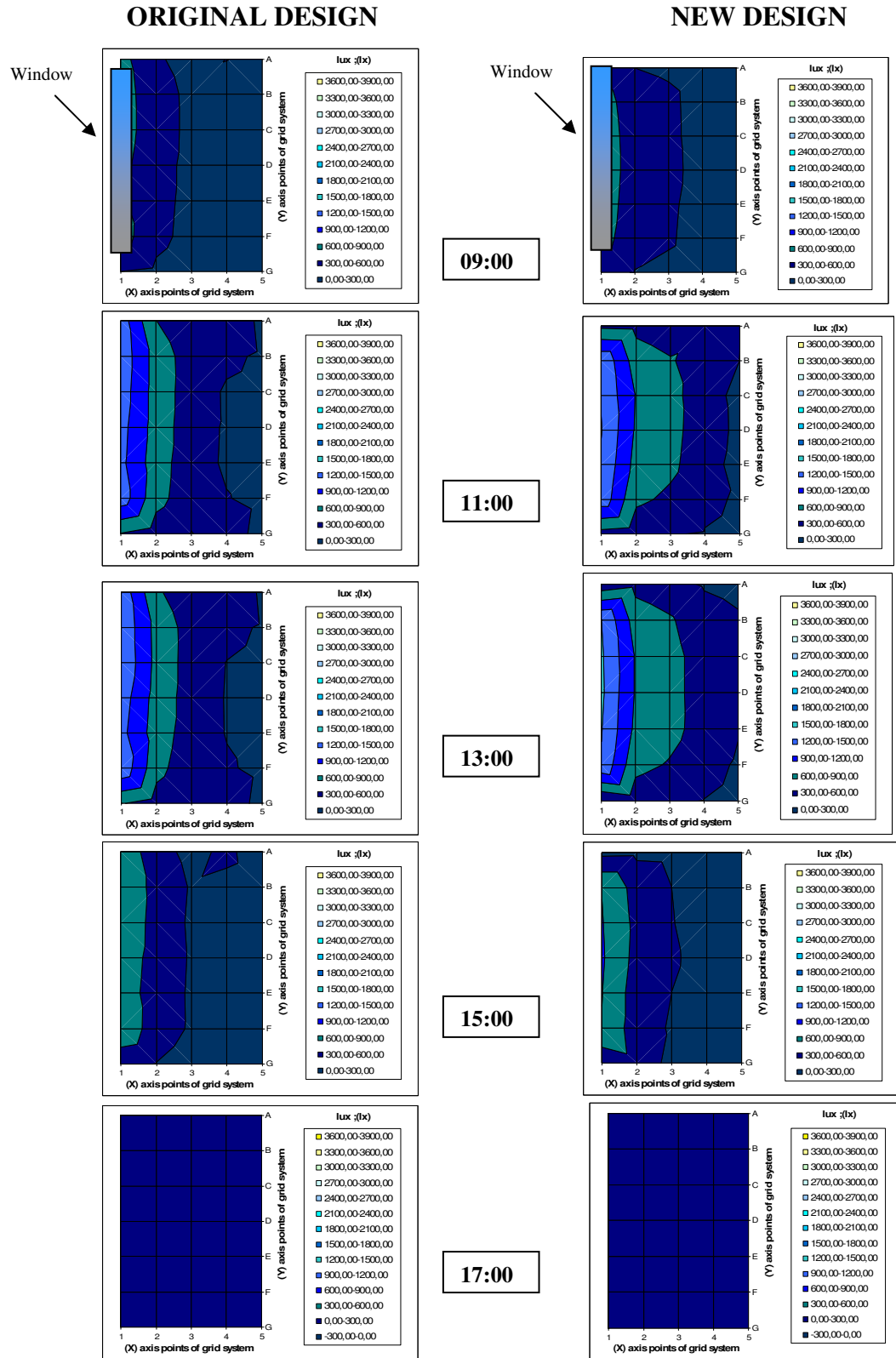


Figure 5.21: Daylight illumination levels under overcast sky condition in January 15th for new and original design (Lux).

The electric energy consumption to provide the required illumination level 300 lux is calculated according to the available daylight values. The monthly energy demand are given Appendix 3 and 5 for both cases; existing and proposed projects.

Energy demand of illumination is significantly higher for the existing design which can be explained as a result of using just side windows. The reduction of daylight through the deeper side of classroom is remarkable. Also high illuminance at the near by place of side windows cause glare which is not recommended. Comparison of monthly energy consumptions between existing and proposed situations is given in Figure 5.22.

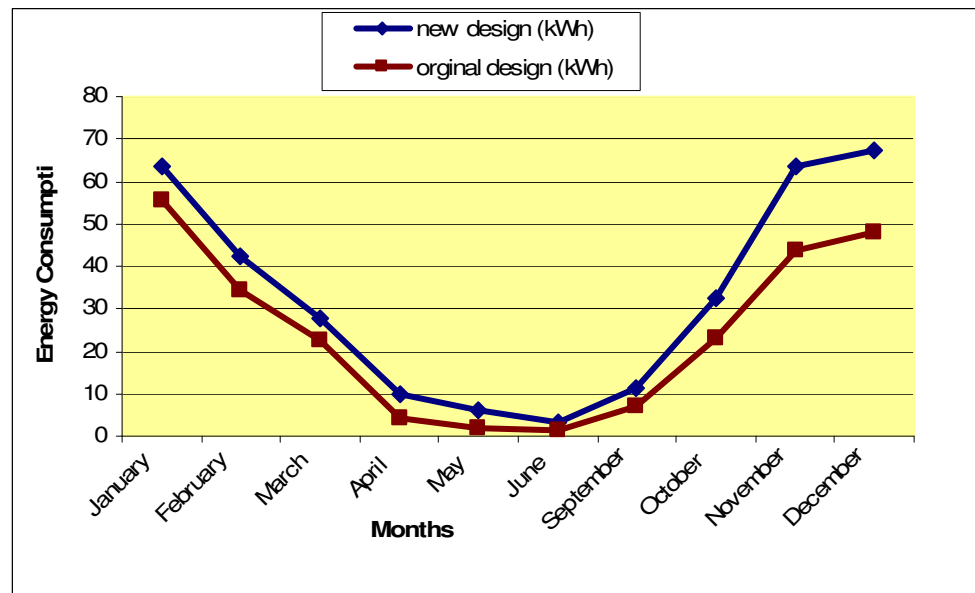


Figure 5.22: Comparison of monthly energy consumptions between existing and proposed situations.

Compared to the proposed design, existing condition leads to 14% higher energy demand. It is shown in Figure 5.23.

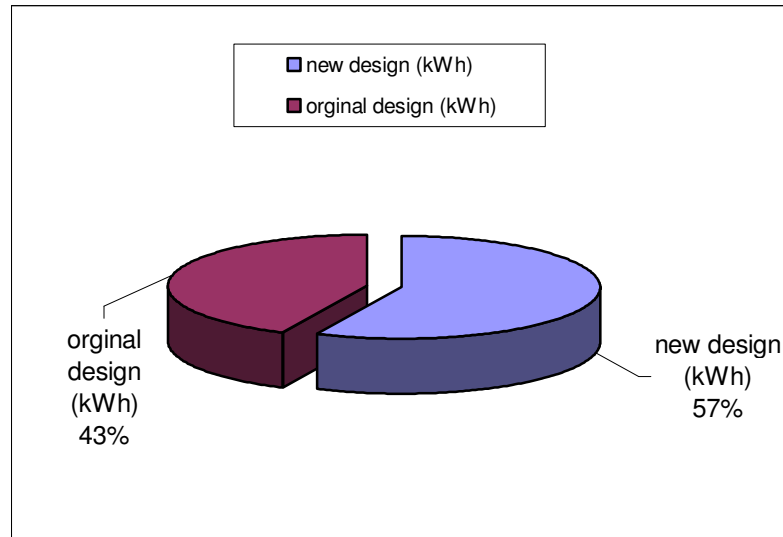


Figure 5.23: Energy demand comparison of the existing and proposed projects.

Finally the results of the comparison can be summed up as following;

- Lighting system design is not in conjunction with the seating arrangement of the classroom in the existing project. Some of the light sources (windows) are in the visual field of the occupants or behind them (Figure 5.4, Figure 5.5).
- Distribution of daylight in the existing project is not uniform, that cause visual discomfort.
- The daylighting system of the existing project is designed with side windows, which cause high illuminance near the window and low illuminance in the deeper parts of the classroom (Figure 5.7).
- The lighting energy consumption of the existing project is given in Table 5.6.
- Lighting system of the proposed project is designed in conjunction with the seating arrangement of the classroom (Figure 5.10).
- In order to provide the uniformity skylights are designed in the proposed project (Figure 5.11).

- In order to provide solar control adjustable shading elements are added to the side windows (Figure 5.15, Figure 5.16)
- The optimum angles for shading elements are calculated basing on the geographical specifications of the location of the Case Study building (Table 5.7).
- The lighting energy consumption of the proposed project is given in Table 5.9.
- The annual lighting energy consumptions of both projects are given in Figure 5.22. The lighting energy consumption of the proposed project is 14% lower than the existing project.

6. CONCLUSION AND RECOMMENDATION

Lighting system design is carried out according to the architect's decisions throughout the design process of the building. The main objective of a lighting system is to provide the visual comfort conditions according to the function while minimizing the energy consumption. Of equal importance to the quantity of light is the quality of light. The quality of light is dependent on both the properties of the light and how that light is delivered to the space. It is essential to analyze the task requirement like; illuminance uniformity, shape and surface texture, color and contrast and light sources' color rendering performance before starting the design. Lighting for visual amenity is as important as task lighting and depends on the balance and composition of light and shade.

In order to design an energy efficient lighting system the values of the design parameters, like positions, dimensions and light reflectances of buildings, orientation of room, dimensions of room, light reflectance of internal surfaces, dimensions and location of window and window glazing should be determined correctly during the design stage of building basing on the exterior conditions, like geographical position and the sky type.

Educational buildings are of great importance in terms of energy consumption because this type of buildings are usually occupied throughout the day and consume a significant portion of the energy for lighting. Energy efficiency, decreased liability, building longevity and durability, and reduced maintenance costs, result in significant life cycle cost savings.

In the case study section of the study the "Municipal School of La Tour De Salvagny" is analyzed in terms of energy consumption with two different design alternatives; one the existing project and the other new proposal. Energy efficiency principles like skylights,

solar control etc., are applied in proposed project. Energy simulations are carried out by using Radiance.

As a result, it is clear that optimum utilization of daylight in school buildings causes a significant reduction in the lighting energy consumption and fulfils the energy efficient design criteria.

The following steps are given as recommendations for high-performance and energy efficient healthy schools:

All future new construction or renovation of school buildings should utilize an integrated design process with climate. This process should facilitate the design and construction of school buildings that include all the essential elements of high-performance, energy-efficient design that are most appropriate to the building site.

All newly-constructed buildings should be designed and built to more energy efficient than current building requires and should utilize properly designed solar orientation and daylighting to the greatest extent possible.

Building Commissioning should be prior to occupancy of any school that is newly built or significantly renovated, in order to ensure proper design and operation of the specified equipment and systems. Maintenance manuals and proper training of maintenance personnel should be given priority along with the establishment of periodic refresher training.

The most effective strategy for a high performance school building is to start with energy efficient design principles at the beginning of the design process.

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CURRICULUM VITAE (CV)

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- Kesten, D. and A. Yener, “Sıcak İklim Bölgelerinde Doğal Aydınlatma – Bir Mardin Evi –” (Daylighting in Hot Climates- Case of Mardin), 5. NATIONAL LIGHTING CONGRESS, October 2004, İstanbul
- Kesten, D. and A. Tereci, “Soğutma Sistemlerinde Güneş Enerjisi Kullanımı” (Solar Cooling Systems), SOLAR ENERGY SYSTEMS SYMPOSIUM AND EXHIBITION, June 2005, Mersin
- Kesten, D., Icin, T., Cetegen, D., and A. Yener, “Comparison Of Daylighting Systems In Traditional And Modern Houses In Hot Climate”, LUX EUROPA 2005, September 2005, Berlin
- Kesten, D., Eicker, U., and D. Pietruschka, “Ofis Binalarında Cephe Tasarima Bağli Enerji Etkin Aydınlatma Tasarımı”, III. NATIONAL LIGHTING SYMPOSIUM AND EXHIBITION, November 2005, Ankara