SECTION 9 LIGHTING – artificial and daylight

ENERGY EFFICIENCY BUILDING DESIGN GUIDELINES FOR BOTSWANA

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ENERGY EFFICIENCY BUILDING DESIGN GUIDELINES FOR BOTSWANA

Sections:

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9. LIGHTING

9.1. Overview

This Section addresses the subject of lighting, including artificial lighting and daylighting. The different topics that are covered are briefly described below.

9.1.1. Basic principles

The basic concepts relating to measurement of light and lighting efficiency are defined and discussed.

9.1.2. Artifical light sources

The different sources of artificial light are described, with some information on their relative efficiency.

9.1.3. Daylight as a light source

Characteristics of daylight as a light source are described in this section, including the advantages and problems that can be associated with use of daylight in buildings.

9.1.4. Light Fittings

The fittings into which a light source is installed are considered, with emphasis on their energy efficiency.

9.1.5. Light requirements

The amount of light required for different spaces is discussed. There are various standards that define light requirements for particular applications, some of which are reviewed.

9.1.6. Lighting control

Different approaches to lighting control are discussed, in relation to their impact on lighting energy efficiency.

9.1.7. Strategies for energy efficient lighting

Various strategies for achieving energy efficient lighting are discussed, and recommendations are made for approaches to lighting design.

9.1.8. Standards for energy efficient lighting

Many codes and standards for energy efficient building include specific targets for the amount of energy that my be consumed for lighting, including limits on installed capacity and actual consumption.

Fig. 9.1 Visible light.

9.2. Basic Principles

Visible light is electromagnetic radiation with a wavelength that is visible to the eye.

Light has an intensity that is determined by the amplitude of the radiation, and determines the perception of the brightness of the light. It also has a wavelength or frequency that determines the colour. Light may include a range of different frequencies or colour, and sunlight includes the full spectrum of visible light (as well as frequencies beyond the sensitivity of the eye, known as ultra violet and infrared).

The intensity of light (or luminous flux) is measured in lumen (lm). This is the unit used to measure the amount of light emitted by a light source.

Illuminance is a measure of the intensity of light falling on a surface. It is measured in lux (lx) that has units of lumen per meter squared (lm/m^2). This is the unit commonly used to specify the level of lighting required on a surface for different activities.

The efficiency with which a light source converts electrical energy into light is know as its luminous efficacy and is measured in units of lm/W, where lm is the luminous flux emitted by the source, and W is the electrical power consumed.

A luminaire is the fitting that a light source is installed in. The efficiency of a luminaire is know as the luminaire efficiency (or light output ratio), and is the ratio of the luminous flux emitted by the luminaire and the luminous flux of the source or lamp.

As important as the quantity or brightness of light is the quality. The three main problems that compromise the quality of light are glare, veiling reflections or excessive brightness ratios.

Glare

Glare is experienced when a bright light source such as a lamp, the sun, or the reflection of a light source is in a person’s field of view.

Veiling Reflections

Veiling reflections are caused by bright light sources reflected from a task surface, such as a book.

Brightness Ratio

When moving from indoors to outdoors on a clear day, one experiences a very large change in brightness. This is unpleasant for a short period of time during which it is difficult to see detail. Then the eye adjusts to the new level of brightness and can see well again. The problem occurs when there are surfaces within the same space with large differences in brightness. Brightness ratio is the ratio of the brightest surface to the least bright.

9.3. Artificial Light Sources

9.3.1. Incandescent lamp.

Until recently the most common electric light source was the incandescent lamp. This is still widely used, although its relatively low energy efficiency is leading to its replacement by other more efficient lamps such as the CFL. The connection to a light fitting is either by screw thread or bayonet.

A large variety of shapes, sizes and power is available, as well as different colour ranges. Typical lamps for household use range from about 40 to 100 W, giving a light output of 420 to 1360lm at the typical lamp efficiency of about 12%.

9.3.2. Compact fluorescent lamp.

The compact fluorescent lamp (CFL) was designed as a more efficient replacement for incandescent lamp. It is supplied with the same fixing system (screw or bayonet), and can be used in many light fittings designed for incandescent lamps.

Power ratings of CFLs that can provide approximately the equivalent light output to incandescent lamps are shown in the table below, together with their efficacy ratings.

Power [W]	Light [lm]	Efficacy [lm/W]
	CFL	
7	400	57
11	630	57
15	900	60
20	1200	60
	Incandescent	
40	420	11
60	710	12
75	940	13
100	1360	14

Table 9.1 Efficiency of incandescent and CFL lamps.

Fig. 9.2 Lamp types.

9.3.3. Fluorescent tube.

Fluorescent tubes are the main form of lighting for offices and commercial buildings.

They are a form of gas discharge lamp, and are formed in a long thin glass cylinder with contacts at either end that secure them to the fitting (or luminaire) and provide the electrical connection.

The tube contains mercury vapour at low pressure, and the inner wall of the glass is coated with a phosphor that reacts to ultra-violet radiation. When electricity is passed through the vapour it emits UV radiation that is converted by the phosphor to visible light.

The most efficient fluorescent tubes are the T5. With a smaller diameter (16mm) than earlier tubes, these can achieve a luminous efficacy of up to 104lm/W.

9.3.4. Discharge lamps.

Discharge lamps work by striking an electrical arc between two electrodes, causing a filler gas to give off light.

Different metals and filler gasses can be used to provide a range of colour and brightness.

Discharge lamps provide high luminous efficacy combined with long life, resulting in the most economical light source available.

9.3.5. Light Emitting Diode (LED).

LEDs use semi-conductors to convert electrical energy directly into light. They are only recently becoming available as a light source for lighting purposes, and are highly efficient and long lasting.

LED torches are becoming very popular, as they provide a far longer battery life than other types of light source.

Fig. 9.3 Light emitting diodes.

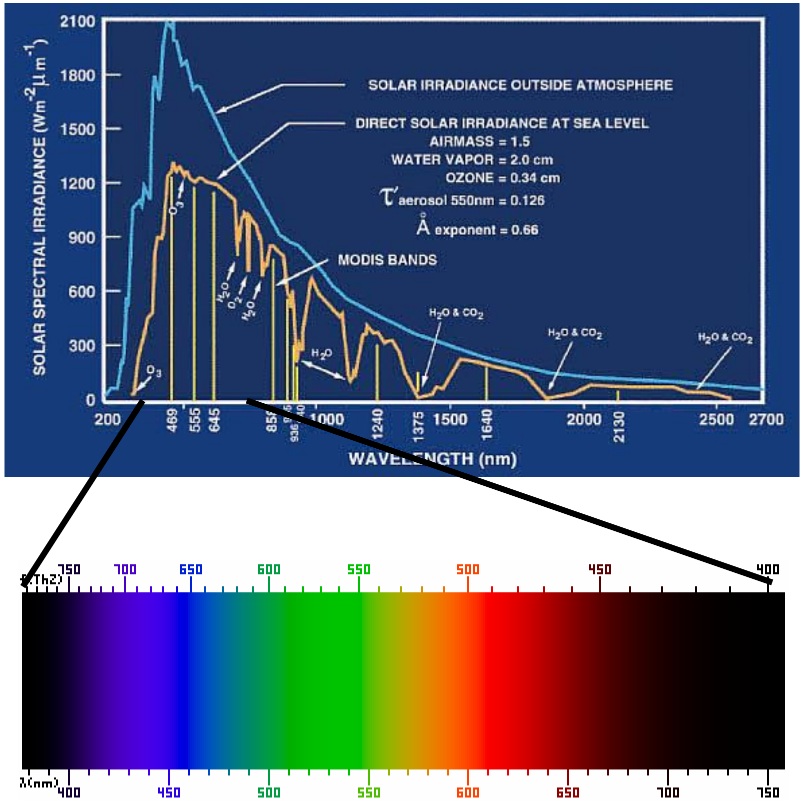


Fig. 9.4 The spectrum of solar radiation.

9.4. Daylight as a light source

Daylight entering a building all originates from solar radiation, but it may have arrived by a number of different routes, each of which will have modified it in various ways.

Solar radiation when it reaches the earth's atmosphere covers a wide spectrum of wavelengths, including the range of visible light, ranging ranging from red at the longest wavelengths of about 700 nm to violet at the shortest wavelengths of about 400 nm.

This is selectively filtered by the atmosphere, so that the radiation reaching the surface of the earth is less than that above the atmosphere.

The daylight entering a building may include direct sunlight when the window has a view of the sun, as well as diffuse sunlight that has been refracted by clouds, and reflected from various surfaces such as clouds, ground or other buildings.

Daylight can therefore vary greatly with weather conditions, ranging from total cloud cover to clear sky with direct sunlight.

Daylight has the potential to provide large amounts of effectively free energy, reducing the amount of electricity required to achieve a given level of lighting.

However day lighting must be designed with care to ensure a high quality of light for the users.

The effectiveness of daylight as a light source is measured as the “Daylight Factor”. This is the average illuminance (lux) inside a room at a standard height above floor level compared to the illuminance outdoors on an overcast day. It is usually stated as a percentage. Typically the daylight factor should be between 2-5%. Less than 2% is experienced as a dim space, whereas over 5% results in unnecessary heat gain.

The illuminance of the sky is typically in the range 20,000 to 100,000 in direct sun, and between 5,000 to 20,000 when the sky is overcast.

Two potential problems associated with the use of daylight in buildings are glare and heat.

Glare occurs when a bright light source such as the sun is in the field of view of users. It can also occur when reflections of the sun are in the field of view. The simplest way to control glare is to avoid large windows on the east and west elevations, and ensure that windows on the north elevation are shaded to control the low winter sun. The south elevation is very seldom exposed to direct sun, and even then it is at an oblique angle that is less of a problem.

For windows that are exposed to direct sun at certain times of day and year, this can be controlled by careful design of the geometry of windows and the use of shading devices such as blinds or shutters.

Daylight is always associated with heat, and the challenge is to maximise the benefit from daylight with minimum heat gain. Daylight actually has a far better luminous efficacy than any electrical light source as can be seen in the graph.

Generally daylight entering through windows provides far higher light levels than are actually required, resulting in significant associated heat gains. Typically the heat input from direct solar radiation on a horizontal plane is about $900W/m^2$, whereas indirect radiation through a window is typically $350W/m^2$ at midday in summer.

9.5. Light Fittings

The fitting into which a light source is installed is an important consideration in achieving energy efficiency.

The Fittings for fluorescent tubes are called luminaires and come in a variety of types, suitable for different applications.

The important consideration in selecting a fitting is to achieve maximum efficiency without compromising the quality of light. This requires a fitting that transfers as much light as possible from the lamp to the working surfaces, without resulting in direct glare, veiling reflections or excessive brightness ratios.

The important features of a luminaire are the reflector and the lens. Common types of luminaire are described below.

Channel luminaires.

This simplest form of luminaire is simply a tube holder with a white reflector. This has a high efficiency, but can result in glare problems since the lamp is visible.

Prismatic diffuser.

This uses an acrylic prismatic diffuser to conceal the lamps, resulting in low surface brightness, reducing glare problems. It is not very efficient, due to light losses in the diffuser.

Parabolic louvre.

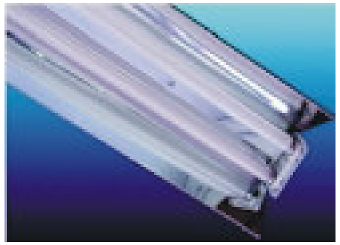
This provides excellent glare control without compromising efficiency, using reflective aluminium louvres to conceal the lamps from low viewing angles.

Uplighter.

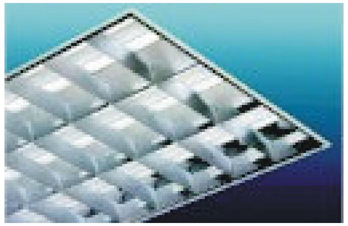
In this system the lamp is concealed by a reflector that directs the light onto a curved reflector that in turn directs it down into the room.

Luminaire	**Typical total light output ratio (% of lamp flux)**
Channel	80 – 90
Prismatic diffuser	55
Parabolic louvre	70
Uplighter	60

Table 9.3 Performance characteristics of luminaires (source: Lascon catalogue)



Channel



Parabolic louvre

Diffuser

Concealed lamp

Fig. 9.5 Typical luminaires for fluorescent lamps.

Task and examples of applications	**Illuminance [Lux]**
Lighting to infrequently used areas	
Minium service illuminance	20
Interiror walkway and car-park	50
Hotel bedroom	100
LIft interior	100
Corridor, passageways, stairs	100
Escalator, travellator	150
Entrance and exit	100
Staff changing room, cloak room, lavatories, stores	100
Entrance hall, lobbies, waiting room	100
Inquiry desk	300
Gate house	200
Lighting for working interiors	
Inrequent reading and writing	200
General offices, shops and stores, reading and writing	300 - 400
Drawing office	300 – 400
Restroom	150
Restaurant, cafeteria	200
Kitchen	150 – 300
Lounge	150
Bathroom	150
Toilet	100
Bedroom	100
Classroom, library	300 – 500
Shop, supermarket, department store	200 – 750
Museum and gallery	300
Localised lighting for exacting task	
Proof reading	500
Exacting drawing	1000
Detailed and precise work	2000

Table 9.4 Recommended average illuminance levels. (Source: Malaysian Standard MS 1525:2001)

9.6. Light Requirements

Indoor light requirements vary depending on the task to be carried out. Typical lighting requirements for a variety of tasks are given in table 9.4.

In work environments such as offices or schools it is generally more effective to provide a low level of background lighting, sufficent for orientation and general activities, say 150 - 200lux and local task lighting at each work station as required for the particular activity. This results in savings both on the initial installation cost as well as recurrent expenses compared to providing a sufficient background light level for typical office tasks (300-400lux).

9.7. Lighting Control

Control of lights may be manual or automated. Effective zoning of lights in different circuits is critical to enabling energy efficient behaviour. This should provide enough flexibility to allow for variations in use patterns and availability of daylight.

Sensors including light level sensors and occupancy sensors are available that can be used in automatic control systems and combined with dimmers, on/off switches and time switches to achieve energy savings. Light level sensors combined with dimming controls can automatically reduce levels of artificial light in relation to the availability of daylight.

Fig. 9.6 Examples of lighting control

9.8. Strategies for Energy Efficient Lighting

The challenge in lighting design is to provide sufficient light where it is required at the times when it is required, without providing excess light. If this is done using the most appropriate light sources and fittings, and combined with an effective control system, then substantial energy savings can be achieved.

The key strategies to achieving this are as follows:

- Define light requirements.
- Use daylight as much as possible.
- Select efficient sources and fittings.
- Effective design of lighting layout.
- Effective control systems.

9.8.1. Define light requirements.

An accounting approach is probably best, establishing a clear 'budget' that specifies the lighting levels required at different locations at different times. Avoid specifying lighting levels that are higher than actually needed. Providing low background light levels with flexible task lighting at workstations ensures sufficient light where it is actually needed.

Quality of light should also be considered, including particular requirements regarding glare, brightness ratio, etc.

These requirements should be included in the Design Brief, and agreed with the client at the pre-design stage of the project.

9.8.2. Use daylight as much as possible.

The availability of daylight is greatly affected by the overall shape and orientation of the building, so this is an important opportunity for coordination between different members of the design team. Generally north and south facing walls offer easier opportunity for daylight without problems from direct sunlight. The east and west facing walls are subject to direct sunlight in the morning and evening respectively, and windows facing these directions therefore need to be provided with shading devices.

The use of daylight is limited by access to external walls. Various features can be used to increase the penetration of daylight further into the interior of a building, including light shelves, light pipes, and skylights.

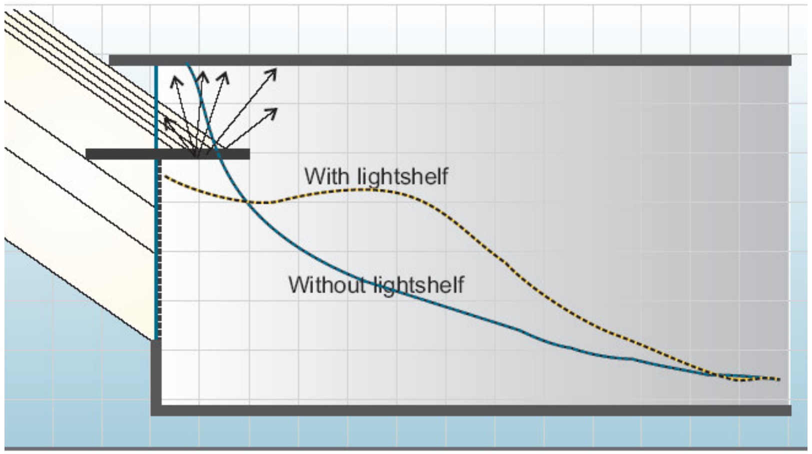


Fig. 9.7 Use of a lightshelf to increase daylight penetration. (Source: Advanced Lighting Guidelines, New Buildings Institute)

Light shelves are usually located near the ceiling, often above a window to reflect daylight onto the ceiling and back into the interior of the building. The increase in interior light levels using a light shelf is illustrated in Fig. 9.7.

Daylight can also be introduced through the roof with skylights. Again the challenge is to avoid heat gain and direct sunlight, which can be done with shading devices and careful orientation.

Light pipes can be used to ‘transport’ light from the roof, through a roof space into the interior of a building. They are basically ducts with highly reflective interior surfaces.

9.8.3. Select efficient light sources and fittings.

For most industrial and commercial applications with low ceiling levels the most effective background lighting will fluorescent tubes. The most efficient are T5 tubes, and the most practical size is 1200mm since these are easy to change and not so vulnerable to breakage as the longer 2400mm tubes. Indirect fittings should be considered where possible, since they provide a more even lighting level (lower luminance ration) and therefore allow for lower absolute light levels than direct fittings.

For localised task lighting and most residential applications, CFL lamps are most appropriate. They should not be undersized, and it is recommended to use a ratio of 3:1, when replacing incandescent bulbs, rather than the more optimistic 4:1 ratio often claimed. (i.e. a 75W incandescent bulb can be replaced with a 25W CFL). (EDR Design Brief: Lighting).

High Intensity Discharge lamps, such as Metal Halide lamps should be used in situations where high intensity point sources of light are required, typically in high ceiling industrial or commercial applications and for outdoor lighting.

9.8.4. Effective design of lighting layouts.

The number and location of light fittings is important to ensure that the required light levels are achieved with a minimum of fittings. The use of formulae and diagrams has largely been replaced with software packages that are available, many for free, that allow modelling of different lighting arrangements.

9.8.5. Effective control systems.

Having achieved an efficient lighting layout, it will only achieve energy efficiency in practice if the lights are effectively controlled, such that they are turned on only when actually required, and off at all other times.

This requires appropriate zoning, whereby the lights that are required at different times are on separate switching circuits. Typically this may result in two or three zones in a room, based on distance from windows. Areas furthest from windows may require lights to be on at all times of occupation. Areas closer to the windows can use daylight for much of the daytime.

Zoning should also relate to occupancy patterns, so that if only one two people are working they have the opportunity to turn on only those lights that are needed.

The choice between manual or automatic control of lights is critical. People tend to switch lights on when there is insufficient light for the task they are doing, but not switch them off when they are no longer required. It is therefore often best to design the system such that the occupants turn lights on, and they turn off automatically.

Using light level sensors in combination with dimmers to maximise the use of daylight can result in large energy savings as illustrated in the following diagram.

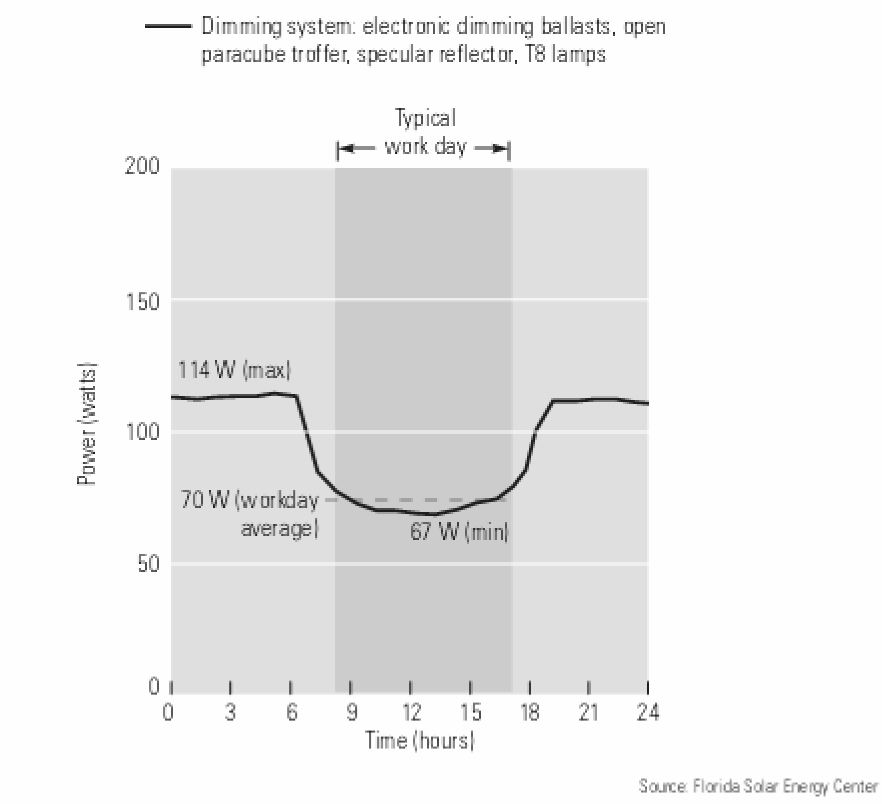


Fig. 9.8 Energy savings from use of dimmers controlled by light sensors. (Florida Solar Energy Center).

In this case an office space with south-facing windows had a control system that used electronic dimming ballasts to control the lights in response to available daylight resulting in a saving of 38%. (EDR Design Guide: Lighting).

9.9. Standards for Energy Efficient Lighting

A large number of lighting codes and standards are available in different countries. These aim to control the amount of energy consumed for lighting by setting limits on the installed lighting capacity for different purposes. They may also have requirements for switching and control to ensure that the building operators have the ability to control lighting efficiently.

The requirements of some typical lighting standards are given in the table below:

	Lighting energy (W/m^2) by building type			
Standard	**Office**	**Retail**	**Hotel**	**School**
ASHRAE 90.1-2001	14	20	18	16
Malaysian Standard 1525-2001	20	20-30	17-20	18-25

9.10. Resource Material

9.10.1. Books and papers

EDR. Design Brief: Lighting. Energy Design Resources.

Lascon. Comprehensive Catalogue, 1998/99.

Lechner, N. 1990. Heating, Cooling, Lighting – Design Methods for Architects. USA. John Wiley & Sons.

Benya, J., et. al. "Advanced Lighting Guidelines" 2003. New Buildings Institute. http://www.newbuildings.org/lighting.htm.

9.10.2. Codes and Standards

ASHRAE Standard 90.1-2001. Energy Standard for Buildings except Low Rise Residential Buildings.

Malaysian Standard MS1525: 2001. Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings. Department of Standards, Malaysia.

9.10.3. Websites

EDR. Energy Design Resources
. http://www.energydesignresources.com/

EERE Building Technologies Program Home Page
http://www.eere.energy.gov/buildings/

New Buildings Institute
http://www.newbuildings.org/

WBDG - Whole Building Design Guide
http://www.wbdg.org/

The Lighting Association
http://www.lightingassociation.com/

CLEAR
http://www.learn.londonmet.ac.uk/packages/clear/index.html