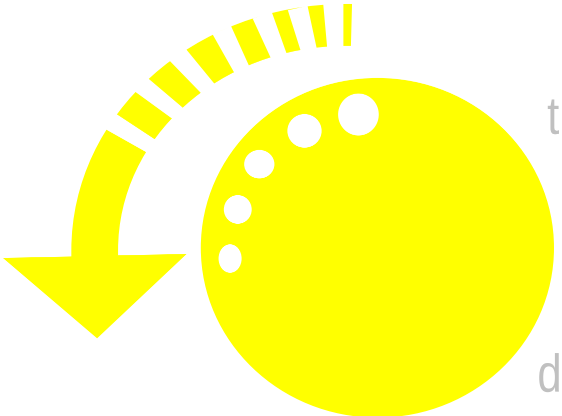
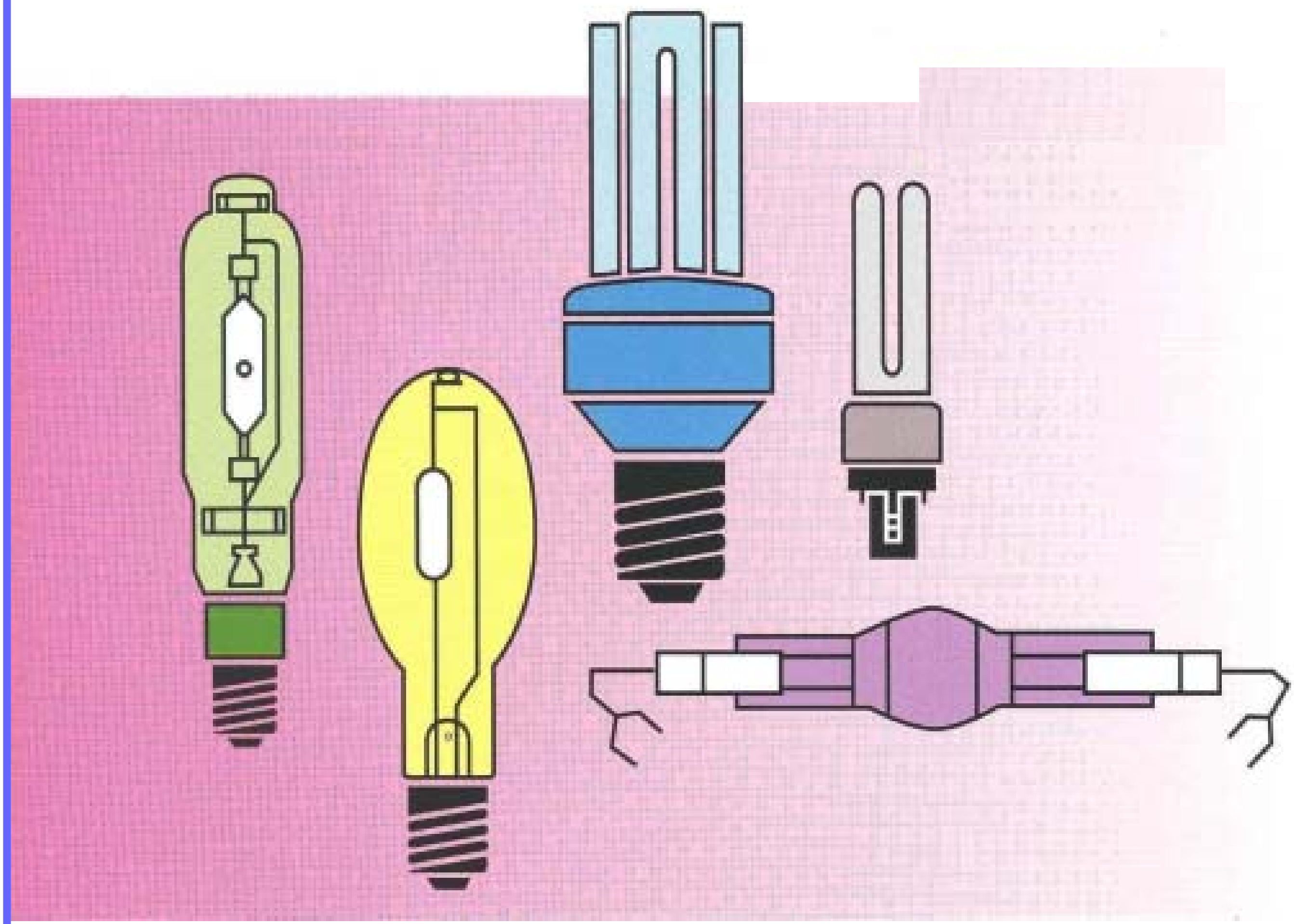
Guidelines on Energy Efficiency of Lighting Installations

2007 EDITION



the Supplement to the ***Code*** document



EMSD

Preface

The Code of Practice for Energy Efficiency of Lighting Installations (Lighting Code) developed by the Electrical & Mechanical Services Department (EMSD) aims to set out the minimum design requirements on energy efficiency of lighting installations. It forms a part of a set of comprehensive ***Building Energy Codes*** **(BEC)** that addresses energy efficiency requirements in building services installations. The set of comprehensive BEC covers the Lighting Code, the Codes of Practice for Energy Efficiency of Air Conditioning Installations, Electrical Installations, and Lift & Escalator Installations, and the Performance-based Building Energy Code.

As a supplement to the Lighting Code, the EMSD has developed this handbook of Guidelines on Energy Efficiency of Lighting Installations (Guidelines). The intention of the Guidelines is to provide guidance notes to compliance with the Lighting Code and draw attention of lighting designers & operators to general recommended practices for energy efficiency and conservation on the design, operation & maintenance of lighting installations. The Guidelines seek to explain the requirements of the Lighting Code in general terms and should be read in conjunction with the Lighting Code. It is hoped that designers will not only design installations that would satisfy the minimum requirements stated in the Lighting Code, but also pursue above the minimum requirements.

The Guidelines were first published in 1998. With the Lighting Code upgraded to its 2005 edition, an addendum for the Guidelines was issued in 2005. The Guidelines are amended in 2007 to suit the 2007 edition of the Lighting Code.

To promote the adoption of the BEC, the Hong Kong Energy Efficiency Registration Scheme for Buildings was also launched. The Registration Scheme provides the certification to a building complying with one or more of the BEC.

The Building Energy Codes, corresponding Guidelines and Registration Scheme documents are available for download at http://www.emsd.gov.hk/emsd/eng/pee/eersb.shtml
Enquiry: hkeersb@emsd.gov.hk

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1. INTRODUCTION

The primary objective of the Code of Practice for Energy Efficiency of Lighting Installations (Lighting Code), published by the Electrical and Mechanical Services Department (EMSD), is to set out the minimum energy-efficient design standards for lighting installations without imposing any adverse constraint on building functions, nor hindrance to comfort or productivity of the building occupants. The Guidelines on Energy Efficiency of Lighting Installations (Guidelines) is a supplement to the Lighting Code. The intention of the Guidelines is to provide guidance notes to compliance with the Lighting Code, and general recommended practices for energy efficiency and conservation on the design, operation & maintenance of lighting installations. Focusing on energy efficiency aspects, the Guidelines are not to provide a comprehensive set of guidance notes in lighting design.

The Lighting Code's requirements are "minimum" performance standards only, and designers should not rely on them but try to exceed these standards in their designs. The Lighting Code's control parameters are adopted based on a simple and easy to follow principle, and the data needed for compliance verification can either be readily obtained from the lighting equipment suppliers or through simple calculations.

The direction to achieve energy efficient lighting depends on both the technological factors and the operational factors of the lighting system. Among them, the operational factors should prevail the technological factors, and should be considered by building owners as first priorities because the effort or cost for implementing good house keeping measures is usually lower than that for implementing the technological measures. On the other hand, the advantages of energy efficient design and equipment may be easily offset by improper operation & maintenance of the original system. For existing installations, new technologies have provided plenty of options to retrofit into more energy efficient installations with attractive payback periods. Decision makers should always discern that money to be spent on improving energy efficiency is an investment rather than a cost.

2. CODE COMPLIANCE

2.1 Code Control Parameters

The Lighting Code has specified the applicable scope of coverage on the types of buildings and the natures of installations, and the types or natures outside the scope are not controlled by the Code. The Code's requirements on luminous efficacy and controlgear loss also apply to outdoor installations (as so extended in the 2007 edition). Having included the communal areas of residential buildings, individual residential units do not come under the Code's control. Having excluded display lighting for exhibit or monument, it should be noted that general purpose lighting such as uplight is also under the Code's control.

The Code stipulates control at both microscopic level and macroscopic level. There is the minimum allowable luminous efficacy and maximum allowable controlgear loss for the former, and the maximum allowable lighting power density for the later.

<u>Minimum Allowable Luminous Efficacy</u>

This controls the choice of lamps. Different lamp manufacturers supply lamps of different efficacy characteristics, and different lamp models of the same manufacturer could also have different efficacy characteristics. Compliance with the Lighting Code requirement will mean the lamp of whatever make or model does have a certain "minimum" efficacy performance, which could also lend to a more readily compliance with the Lighting Power Density (LPD) requirements. To provide flexibility in design, a small percentage of lighting could have efficacies not meeting the requirements though.

For information, various characteristics of major types of lamps are described in Section 3.3 of the Guidelines. Designers should base upon their overall design requirements such as colour rendering, colour temperature as well as energy efficiency to choose the most appropriate type of lamps.

Maximum Allowable Controlgear Loss

A brief description of some major types of control gear is discussed in Section 3.3 of the Guidelines. Tubular fluorescent lamps and compact fluorescent lamps form the most important family of lighting equipment, and the Lighting Code has stipulated relevant maximum allowable controlgear loss requirements. To provide flexibility in design, a small percentage of lighting could have controlgears not meeting the requirements though.

Generally speaking, energy-efficient electromagnetic ballasts and electronic ballasts should have no difficulty in complying with these requirements, while conventional electromagnetic ballasts may fall outside the limits.

The 2007 edition of the Lighting Code has stipulated control on the electronic ballasts for all lamp types such as metal halide lamps and high pressure sodium lamps, which is to follow The Hong Kong Voluntary Energy Efficiency Labelling Scheme for Electronic Ballasts of EMSD.

Maximum Allowable Lighting Power Density (LPD)

This controls the maximum allowable power per square metre in a given space The Code itself does not specify the illumination levels, which should have been taken care of with reference to established illumination standards. The designer can exercise his discretion and manipulate this flexibility in determining the illumination level according to his need, and there may be reiterations in order to arrive at a LPD value meeting the Code requirement.

To add architectural feature to a space, some architects use fixed decorative lights e.g. recessed uplights for the purpose in addition to general lighting, and designers should allow suitable margin in the LPD of the general lighting to make room for the decorative lights.

The recommended maximum LPD values in the Code are based on an average illumination in the space in question, i.e. different parts in the space have the same average illumination. The LPD values have not taken account of accent or task-oriented lighting. In some designs, there are two lighting systems serving the same space, one to provide the general illumination to the space, and the other to provide the added illumination for the accent or task. An example is the fixed lighting in an office to provide an illumination level of 300 lux and lighting on desks to provide additional illumination, resulting at 500 lux at the working plane, the desk top. In this case, the office will have two levels of illumination, 300 lux at areas away from the desk and 500 lux at the desktop. This approach of general lighting plus separately controlled accent or task lighting is quite common in a number of international standards such as ASHRAE 90.1 in the US, the adoption of which will result in even lower LPD values. When adopting this approach, due consideration shall be given to whether users of the space could accustom to the multi-level illumination.

Another point worth mentioning is the classification of indoor space: discrete space, multi-functional space, and composite space. The LPD calculation for each of these spaces is slightly different. Designers should pay full attention to the usage of the concerned spaces, as a different usage will likely lead to a different LPD requirement.

The 2007 edition of the Lighting Code has extended the control to restaurants, shops and department stores. The 2007 edition also introduces the Lighting Energy Approach to all types of Spaces, and provides further flexibility in lighting design.

Interior Lighting Control

Requiring the lighting control point of a space to be easily accessible to the occupants, clause 4.4.1 in the Code is rather generic. The subsequent clause 4.4.2 however focuses on the number of lighting control points in an office space. Control is not stipulated for the other types of Space.

2.2 Approaches to Comply with Code

2.2.1 Calculations

For compliance with the Code, checking for compliance against the Minimum Allowable Luminous Efficacy values would be straight forward, as the lumen values are normally shown in catalogues or available upon request from lamp suppliers, and the lamp performance in this regard is merely the quotient of dividing lumen by wattage of the lamp.

For compliance with the Maximum Allowable Lamp Controlgear Loss, the ballast loss figure or the sum of lamp & ballast loss figure can be looked up from suppliers' relevant ballast/lamp literatures.

The requirement on Interior Lighting Control is only a matter of placing adequate number of operating switches for the lighting systems.

The Maximum Allowable Lighting Power Density values on the other hand require some calculation. This parameter is a consolidated indication of the lighting equipment's efficacy and the design illumination level, and designers could have a pretty large room to manoeuvre and obtain a balance between the two dimensions. The formulation of a lighting scheme that complies with the Maximum Allowable Lighting Power Density requirements may require reiterations on different alternative lighting designs.

To calculate the Lighting Power Density, there are two approaches:

Forward Approach

This is the most straight forward approach, whereby the lighting designer first layouts the luminaires in a space according to their photometric performances, calculate the total circuit power and divide this by the area of the space, and finally compare the quotient with the values of Maximum Allowable Lighting Power Density given in the Lighting CODE.

Backward Approach

This is the reverse of the Forward Approach. Designers first find the value of the Maximum Allowable Lighting Power Density of the space under consideration and then multiply this by the space area to obtain the maximum allowable installed power for the lighting system. The designer then obtains the number of fittings by dividing this allowable installed power by the power of the luminaires. This value is finally compared with the quantity of luminaires obtained by the basic lumen calculation method to see whether the lighting scheme will work or not.

Forms

The Forms in the Code serve the purpose of step-by-step checking and are meant to be completed by the designer to demonstrate the compliance.

2.2.2 Pre-design Considerations

The Lighting Power Density can be measured directly in-situ by using simple meters for circuit wattage. This parameter is affected by a number of factors:

Choice of Lamp Type & Associated Controlgear :-

A lamp's efficacy basically determines how efficient electrical energy is converted into light output. The higher the luminous efficacy, the lower the wattage will be. Designers should specify energy efficient lamps, for example T5 or T8 fluorescent lamp rather than T12 lamp, compact fluorescent lamp instead of incandescent lamp etc. Another undesirable effect in low efficacy lamp is the amount of heat produced by the lamp as a result of inefficiency will increase the air conditioning load of the space. Thus the air conditioning equipment will consume more electricity to remove the generated heat. Though the electricity consumed by the air conditioning equipment is not to be calculated in the Lighting Power Density, it will increase the overall electricity consumption of the building.

Choice of Lighting System and Luminaires :-

The Utilisation Factor is a characteristic of both the room and the luminaires. It will significantly affect how much light from the lamp(s) can reach the horizontal working plane. It is therefore desirable to choose lighting equipment of higher Utilisation Factor. The computation of Utilisation Factor is fairly tedious as it involves the determination of direct light components and the reflected components from the ceiling, the wall surfaces and the floor. Luminaire manufacturers usually publish pre-calculated table(s) of Utilisation Factors for their products.

The most commonly used lighting equipment for commercial lighting is fluorescent light fitting. These fluorescent light fittings are usually available with standard option of:

- opal panel
- prismatic panel
- general purpose reflector
- low brightness reflector

A comparison of the Utilisation Factor for a typical 300mm x 1200mm recess fitting for mounting in false ceiling is shown in Figure 2.2.2a:

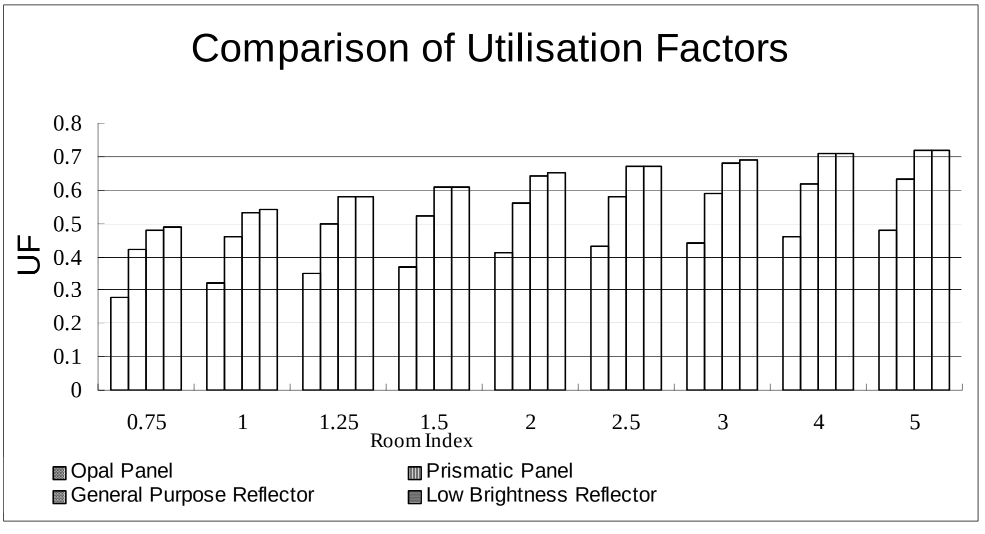


Figure 2.2.2a – Comparison of Utilisation Factors for Different Light Fittings

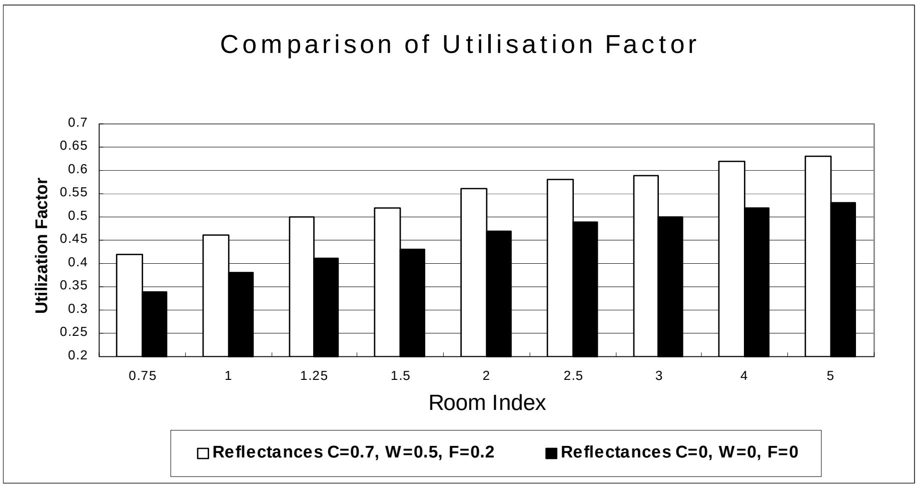
The above diagram indicates the Utilisation Factors for different options of fittings assuming that the reflectance of the ceiling, walls and floor are 0.7, 0.5 and 0.2 respectively. It can be seen that fittings with reflectors have much higher Utilisation Factor then fittings with opal and prismatic diffusers. The different can be as high as 70-80%, which is very significant. Thus in new installations, designers should specify reflector lamps whenever feasible. Furthermore, it can also be noticed that the Utilisation Factor increases with the Room Index (RI), which is defined by:

$$RI = \frac{L \times W}{(L + W) \times H}$$

where L = Length of room
W = Width of Room
H = Height of luminaires above working plane

Higher Room Index merely means high area to perimeter ratio and/or lower mounting height of the luminaires. The high area to perimeter ratio means that the room should be a narrow rectangular corridor shape.

In the contrary the reflectance of the room surfaces have a less significant effect to the Utilisation Factor. Figure 2.2.2b compares the Utilisation Factor of a typical 300mm x 1200mm fluorescent fitting in the normal case of ceiling reflectance=0.7, wall reflectance=0.5 and the floor reflectance=0.2 to an extreme case where the reflectance of ceiling, wall and floor are all equal to zero. The effect to the Utilisation Factor is roughly 20% in this comparison, which is much less significant than the effect of the fitting's physical design. However, adopting a light colour scheme for the room surfaces that will result in higher reflectances always have a positive effect on the Utilisation Factor.



<u>Figure 2.2.2b – Effect of Room Reflectances to Utilisation Factor</u>

Besides the Utilisation Factor, the space to height ratio requirement of the luminaire will also affect the Lighting Power Density of the installation. The space to height ratio determines the number of fittings that will be required to obtain a reasonable uniformity despite of the Utilisation Factor. The values of Utilisation Factor are usually computed base on a nominal space to height ratio. The smaller the nominal space to height ratio, the larger the number of luminaire fittings will be required to maintain uniformity, thus increasing the power requirement of the lighting installation. Fluorescent light fittings usually have lower Utilisation Factors but a higher value of nominal space to height ratio when comparing with down light fittings. Typical figure of nominal space to height ratio for fluorescent fittings are in the range of 1.5 to 2 while that for down light fittings are around 0.5. It means that if down light fittings are to be used for general lighting purpose, the number of fittings required for uniformity reason will be about 3 – 4 times than fluorescent fittings.

The choice of appropriate control gear also help to reduce the Lighting Power Density especially when the designer intends to use lamps of lower power ratings which make the control gear loss power a significant "overhead" of a luminaire's total power.

Choice of Power Rating of Lamps :-

For same type of lamp and luminaire model, the choice of appropriate lamp wattage can have significant effect in the Lighting Power Density. Generally, the efficacy of a lamp increases with its power rating. For example, the efficacy of a 7W compact fluorescent lamp is around 57 while that for a 55W one is around 87. Furthermore, the energy loss in control gear will become a significant portion for smaller power rating lamps because the number of fittings required to be installed is much more then other lighting scheme using higher power rating lamps. However, one should always take care of the problem of glare and uniformity when using lamps of high power rating. The two factors together will produce a significant effect on the power density.

Maintenance of the Luminaire and Lamp

In calculating the number of light fittings required for a particular space, designers should also assess the future maintenance condition of the installation. The basic lumen method equation has allowed a margin in the factor LLF to be added to the design to allow for loss in dirt accumulation in the luminaire, lumen depreciation of lamp, burnt out of lamp, and dirt on room surfaces. This add-on margin always results in over design when the luminaires and room surfaces are in good conditions. In some extreme cases, the margin can be as high as 40-50%, which means that the installation is over design for 40-50% at its initial operating period. A reduced margin can reduce the number of luminaires needed to achieve the required illumination level thus lowering down the Lighting Power Density. However, the difficulty lies with the fact that the designer is seldom responsible for the future maintenance of the installation. In a pragmatic way, the maintenance schedule should be reviewed frequently during the initial operating period of an installation so that an optimum frequency for maintenance can be established. In order to illustrate the effects of maintenance schedule on the light output of a lighting installation, consider the example in the Figure 2.2.2c:

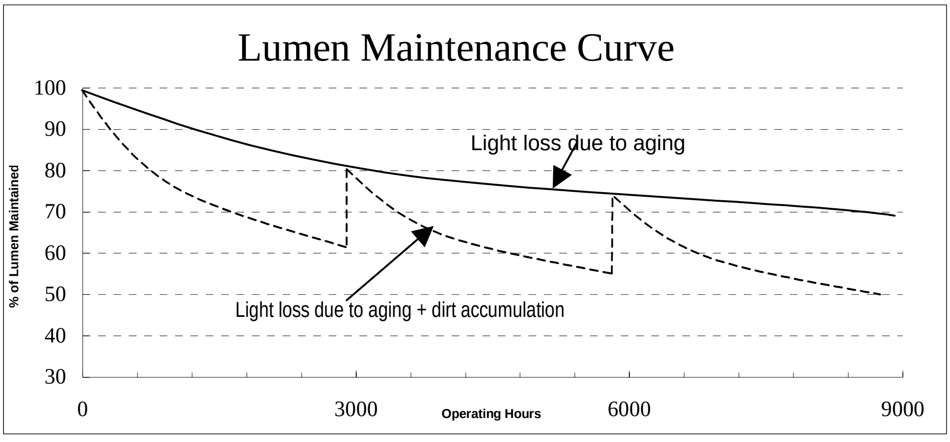


Figure 2.2.2c – Typical Lumen Depreciation Process

This example indicates that a lighting installation has a lamp aging characteristic of luminance output reduction to about 70% after 9000 hours of operation and the cleaning interval for the lighting equipment is 3000 operation hours. At the end of 9000 operating hours, the light output of installation will drop to about 50% of the output at brand new condition.

Now suppose maintenance arrangement can be made such that the cleaning interval is reduced from 3000 hours to 1500 hours and a *bulk re-lamping* is to be carried out at an interval of 6000 hours. The resulting luminance depreciation is shown in Figure 2.2.2d.

The diagram indicates that at the end of 9000 operating hours, the maintained luminance is about 65%, which is significantly higher, than 50% in the first maintenance arrangement. The worst maintained luminance is at the end of 6000 hours before the re-lamping and is about 60%. Compared with the first maintenance arrangement a designer can reduce the number of lighting equipment by about 20%.

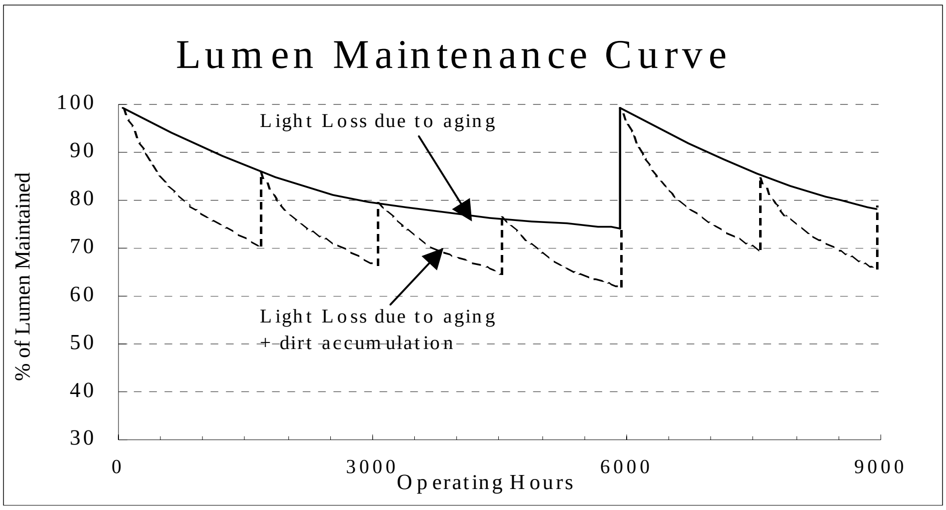


Figure 2.2.2d – Lumen Depreciation Curve with Alternative Maintenance Arrangement

In the example above, it can be seen that the designed maintenance schedule for the installation has a significant effect on the number of light fittings in an installation. The optimum interval for bulk re-lamping and the cleaning depends on the following factors:

- Type of premises:- governs the operational needs of the lighting installation. Whether the requirement of maintaining the illumination level is stringent or loose, whether there are specific personnel to be responsible for the utilities management or not etc.
- Location of premises:- affects the rate of dirt accumulation in fittings;
- Usage rate of a particular space:- affects how long will it take for the illumination of a lamp to depreciate into an unacceptable level;
- Type of luminaire fitting:- affects the ease of accumulation of dirt, the loss in Utilisation Factor resulted, and the labour efforts for cleaning;
- Type of lamp:- governs the characteristic of the lumen depreciation as well as the nominal average lamp life of the installation;
- Electricity cost:- one of the key factors in the economic analysis of the maintenance schedule; and
- Labour cost:- another key factor in the economic analysis.

3. DESIGN CONSIDERATIONS

Energy is the product of power and time. The energy cost of a lighting installation depends on its *connected power (Watts or kilo Watts)* as well as its *operation time (hours)*. The factors related to power or connected load of a lighting system are discussed here, whilst the factors that affect operating time of the system are discussed in Section 4.

3.1 Factors Affecting Energy Consumption of Lighting Installations

The connected power of a lighting installation is affected by the following factors :

(A) Luminous Environment

- illumination levels required for different tasks;
- space area;
- colour rendering;
- visual comfort.

(B) Physical Environment

- physical dimensions;
- room surfaces reflectance;
- furnishing and obstructions.

(C) Lighting Equipment Characteristics

- efficacy, average lamp life, colour characteristics and lumen depreciation of light sources;
- light distribution, efficiency and glare control of luminaires;
- wattage loss and control gear loss of ballasts.

As regards the operation hours of a lighting installation, the following factors need to be considered :

- availability of daylight *(if an automatic lighting control system is installed to allow efficient use of daylight)*;
- occupancy schedule;
- maintenance schedule of a lighting installation.

A multi-illumination level design could be considered to achieve more energy saving.

3.2 General Principles of Achieving Energy Efficient Lighting Installations

Generally, the design criteria are :

- light sources of high luminous efficacies;
- lamp controlgears of low energy losses;
- luminaires of high light output ratios;
- room surfaces of high reflectance;
- optimum mounting height.

However, the energy efficiency criteria interact with other lighting effect criteria, and appropriate trade-offs may be necessary.

3.3 Selection of Lighting Equipment

From energy efficiency point of view, it is recommended to choose light sources with high luminous efficacies. Nevertheless, such energy criterion should be compatible with other lighting design criteria. In many applications, the optical features (e.g. colour temperature, colour rendering index, light distribution curve, etc.) are frequently the lead criteria in choosing lamp types and lamp efficacy may Codeome a secondary consideration.

3.3.1 Selection of Light Sources

Light sources used today in artificial lighting can be divided into two main categories : incandescent and gaseous discharge. The gaseous discharge type of lamp is either low or high pressure. Low-pressure gaseous discharge sources are the fluorescent and low-pressure sodium lamps. Mercury vapour, metal halide and high-pressure sodium lamps are considered to be high-pressure gaseous discharge sources.

In addition to the following major lamp types, there are a number of retrofit lamps that allow usage of higher efficacy sources in the sockets of existing fixtures. Thus, self ballasted mercury lamps or compact fluorescent lamps can replace incandescent lamps. Also, a T5 fluorescent tube in conjunction with a quasi-electronic ballast adaptor assembly could replace a T8 fluorescent tube. These lamps all make some compromises in operating characteristics, average lamp life and/or luminous efficacy.

3.3.2 Major Types of Light Sources

<u>Incandescent Lamps (GLS)</u>

Incandescent Lamps or General Lighting Service Lamps (GLS) have the lowest range of lamp efficacies of the commonly used lamps. Incandescent Lamps should in general not be used for a large area or where a more efficient light source could serve satisfactorily. There are many applications where the size, colour rendering, convenience, easy control and relatively low cost of incandescent lamps are suitable for specific applications.

GLS do not have good lumen maintenance throughout their life. This is the result of the tungsten being evaporated off the filament during heating and being deposited on the bulb wall, thus darkening the bulb wall and reducing the lumen output.

<u>Tungsten Halogen Lamps (TH)</u>

Tungsten Halogen (Quartz) Lamps also work on the same principle of GLS. However they do not suffer from the tungsten evaporation problem of GLS because they use a halogen regenerative cycle so that the tungsten driven off the filament is being deposited back on to the filament rather the bulb wall. Thus, tungsten halogen lamps may retain lumen outputs in excess of 95 % of initial values throughout their lifetime.

<u>Tubular Fluorescent Lamps (MCF)</u>

Fluorescent lamps now range from about 30 lm/W to 100 lm/W. The colour spectrum of the light emitted is more complete than other vapour discharge lamps. Lamp manufacturers have recently made significant progress in developing fluorescent tubes that have much more superior colour rendering properties. This has enlarged the areas for application of fluorescent tubes. Besides, manufacturers have also developed tubular fluorescent lamps of different colour temperatures to suit different requirements. On the other hand, new fluorescent tubes have Codeome more and more energy efficient. The series of T8 fluorescent tubes is much more energy efficient than its predecessor the T12 or T10, and T5 more energy efficient than T8.

Compact Fluorescent Lamps (CFN, CFG)

Compact fluorescent lamps open up a whole new market for fluorescent sources. These lamps permit design of much smaller luminaires, which can compete with incandescent and mercury vapour in the market of lighting fixtures having round or square shapes. Products in the market are available with either built in control gear (CFG) or separate control gear (CFN).

Metal Halide Lamps (MBI)

Metal Halide Lamps have a lamp efficacy range of approximately 75-125 lm/W. They are more energy efficient than mercury vapour lamps but less energy efficient than high pressure sodium lamps. However, they normally require a longer re-strike time (around 15-20 minutes at 21 ^{o}C) to restart after being switched off. Manufacturers have developed different type of MBIs such as MBIL, MBIF, MBI-T etc.. They all work in same principles except there is slight difference in optical performance due to slight difference in the lamp components.

High Pressure Sodium Lamp (SON)

High Pressure Sodium Lamps have very high efficacy (up to 140 lm/W). In addition, they have the advantages of good lumen maintenance and long average lamp life that make such lamps ideal sources for industrial and outdoor applications where colour discrimination is not critical. It is possible to attain a quite satisfactory colour rendering by mixed usage of high pressure sodium lamps and metal halide lamps in proper proportions. Since both sources have relatively high efficacies, the loss in energy efficiency is not significant by making this combination. There are also different types of SON lamps, such as SONDL, SON-R, SON-TD etc. Like the MBI, they have slight difference in optical performance.

Low Pressure Sodium Lamp (SOX)

Low Pressure Sodium Lamps provide the highest efficacy of light sources for general lighting with range up to 180 lm/W. It is a good light source for applications where colour rendering is not important, and a high wattage lamp is not required.

Mercury Vapour (MBF)

Mercury Vapour Lamps operate in quartz arc tube. The internal surface of the outer elliptical bulb is coated with a phosphor, which converts ultra-violet radiation from the discharge into light. MBF lamps are usually used in industry for low initial cost where colour rendering is not a major factor. In terms of energy, the efficacy of MBF is less than SON.

Light Emitting Diode (LED)

LED is a semiconductor chip supported by a reflector and encapsulated with an epoxy lens for controlling light distribution. Contrary to conventional lamps, the LED lamp has no filament or breakable glass bulb. Colour of light output depends on the semiconductor materials used in the chip which require different voltages to enable electron flow. Common light colours available are red, red-orange, amber, green cyan, blue and white. LED tends to have a longer service life (50,000 hours). With its versatile colour changing characteristic, robustness and low-voltage operation capability, it is commonly used as decorative lighting, building façade illumination and landscape lighting in particular. It is also widely used in exit signs, advertisement sign boxes and traffic lights. Its luminous efficacy is higher than those of GLS and TH, and is at all the time improving, likely to be compatible to serve as general purpose lighting.

Induction Lamp

The induction lamp operates based on the principle of induction. The lamp has a primary coil. With the passing through of an alternating current in the primary coil, a current will be induced in the mercury vapour inside the lamp, the vapour playing the role of the secondary coil. The induced current circulates through the vapour, causing acceleration of free electrons, which collide with the mercury atoms and bring electrons to a higher orbit. Electrons from these excited atoms fall back from this higher energy state to the lower stable level and consequently emit ultraviolet radiation, which interact with the fluorescent powder coated inside the lamp to convert to visible light. The induction lamp has long operation life, good colour rendering and high efficacy, and is a good candidate for high wattage HID luminaire (80W & above per lamp) that has difficult access such as high bay lighting, sports arena lighting and outdoor lighting. However, care should be taken on the induced electromagnetic interference.

3.3.3 Optical Characteristic of Major Types of Light Sources

The main optical characteristics in choosing the light source are :

- colour temperature of the light source
- colour rendering requirement of light source

Table 3.3.3a gives typical colour temperatures of major types of light source:

Colour Temperature (K)	Type of Light Source
6500	MCF
5200	MBI
4000	MCF
	MBI
3800	MBF
3500	MCF
3300	MBF
3200	MCF
3000	MCF
2900	TH
	MBI
2700	MCF
	GLS
2200	SON
2000	SON

Table 3.3.3a – Colour Temperature of Various Type of Light Source

Table 3.3.3b gives a brief description of the colour rendering performance. The CIBSE/CIE colour rendering classes are ideal for this purpose :

Minimum Class Needed	Description
Class 1A	Excellent colour quality. Where accurate colour matching is required (e.g. colour printing inspection).
Class 1B	Very good colour quality. Where accurate colour judgement or good colour rendering is required for

	reasons of appearance (e.g. merchandising)
Class 2	Good colour quality. Where moderate colour rendering is required, good enough for merchandising.
Class 3	Poor colour quality. Where colour rendering is of little importance. Colour can be distorted but marked distortion is not acceptable.
Class 4	Very poor colour quality. Colour rendering is of no importance and severe distortion of colours is acceptable.

Table 3.3.3b – Colour Rendering Performance Classes

Table 3.3.3c gives a colour rendering guide for each of the major light sources described above :

Class	Type
1A	MCF, GLS, TH
1B	MCF, MBI
2	MCF, MBI, SON
3	MCF, MBF
4	SON

Table 3.3.3c – Colour Rendering Guide

3.3.4 Energy Characteristic of Major Types of Light Sources

With different working principles, different types of light source have different energy performance characteristic. When considering the energy performance of light sources, two aspects should be considered:

- the efficacy of the lamp
- the lumen maintenance of the lamp

Figure 3.3.4a shows the efficacy comparison of some major types of lamps. One should note that the comparison is based on the total circuit watts, which give an overall system efficacy of the lighting. The comparison is also based on initial lumen output as the lumen maintenance characteristic of different type of lamps is different:

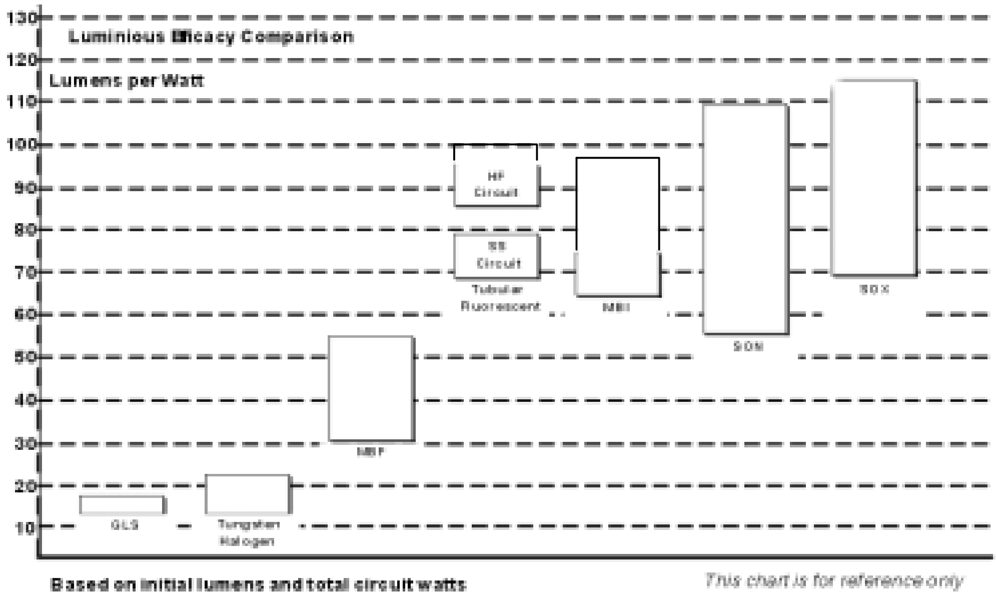


Figure 3.3.4a – Luminous Efficacy Comparison of Light Sources

The lumen maintenance describes the depreciation in lumen output of the lamp throughout the average lamp life of the lamp source. GLS lamps usually fail before there is significant decline of output. Thus it is usually sufficient to indicate the life survival of the GLS lamps. It should be noticed that the dirt would also depreciate the lumen output of the lamp. However, in mentioning the lumen maintenance the dirt effect is not taken into consideration. Figure 3.3.4b is a typical figure of the lumen maintenance curve, and one should aware that there may be slight differences in the depreciation behaviour for same type of lamp from different manufacturers. In designing the lighting system, the designer should check with the manufacturer the actual lumen maintenance characteristic of the lamp source.

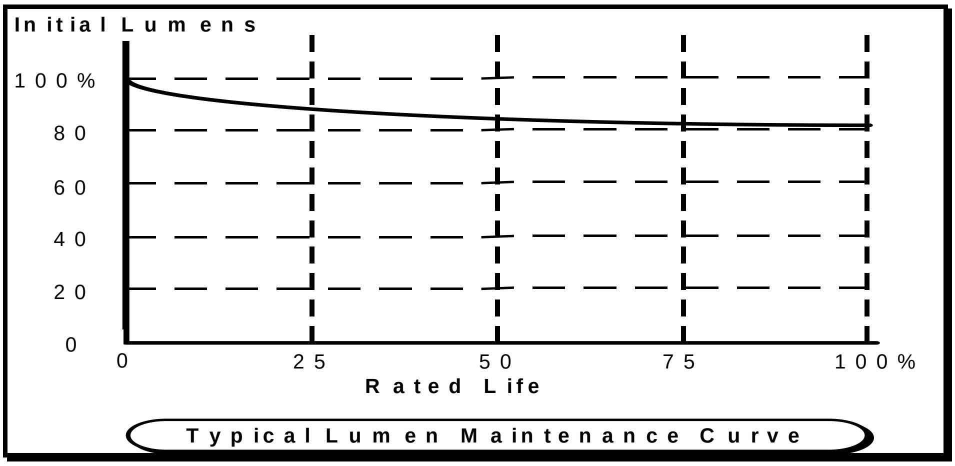


Figure 3.3.4b – Typical Lumen Maintenance Curve

In general at the rated life of operation, SON usually depreciates to about 80%, MBI to about 60%, MBF 50% and MCF 70-80%. Choosing suitable lamp source can avoid the need of extreme over design at the initial lumen in order to compensate for the light depreciation during the operation life span. Over design will affect the compliance to the "Lighting Power Density" requirement of the Code.

3.3.5 Ballast Selection

All high intensity discharge lamps (HID) and fluorescent lamps need ballasts to perform properly. The ballasts consume power and affect lumen output of discharge lamps. Low loss ballasts are available for fluorescent lamps to provide higher operating efficiencies, with some providing maximum power savings with reduced lamp lumen output.

3.3.6 Major Types of Ballast

Electromagnetic Ballasts

This category represents the more or less traditional, copper-iron control gear for lamps. They usually consist of a choke and a capacitor for power factor correction. The initial cost for installing electromagnetic ballasts is relatively low compared with electronic type ballasts. However, this low capital cost may be at the expense of both inferior energy performance as well as the light output quality. Electromagnetic ballasts can be used with fluorescent lamps as well as high pressure discharge lamps.

Electronic Ballasts

These ballasts have the potential for lowest ballast loss. Using electronic ballasts in fluorescent lamps can enhance significantly system efficiency as well as enhancing light output quality. Economic analysis generally reveals a higher initial cost for systems employing electronic ballasts but a lower operating cost. The total annual owning and operating cost for these systems is usually lower than that with electromagnetic ballasts. Another advantage of using electronic ballasts is the overall air conditioning load that is reduced due to lower heat generation from the ballasts.

3.3.7 Energy Performance of Ballasts

Electromagnetic Ballasts

Electromagnetic ballasts in fluorescent tubes can be classified into:

Standard Ballasts: they have high loss steel cores. Typically, the ballast loss of standard ballast comprises about 17% of fluorescent system power. They are not recommended for new lighting installations or even to replace broken down ballasts individually.

Energy Efficient Ballasts: also named as low loss ballast in the market. These ballasts use a better grade of steel in the cores and the ballast loss is around 75% that of standard ballasts. Lower loss also resulted in lower luminaire temperature. These barely comply with the ballast loss requirements in the Code.

Electronic Ballasts

Electronic ballasts usually have lower ballast loss when comparing with electromagnetic ballasts. They normally operate the fluorescent lamps at a much higher frequency then the main 50Hz frequency. The result of operating the fluorescent lamps at higher frequencies can significantly enhance the lumen/Watt of the lamp output as fluorescent lamps are sensitive to the operating frequency. Figure 3.3.7 shows a typical fluorescent lamp's output with respect to the operating frequency:

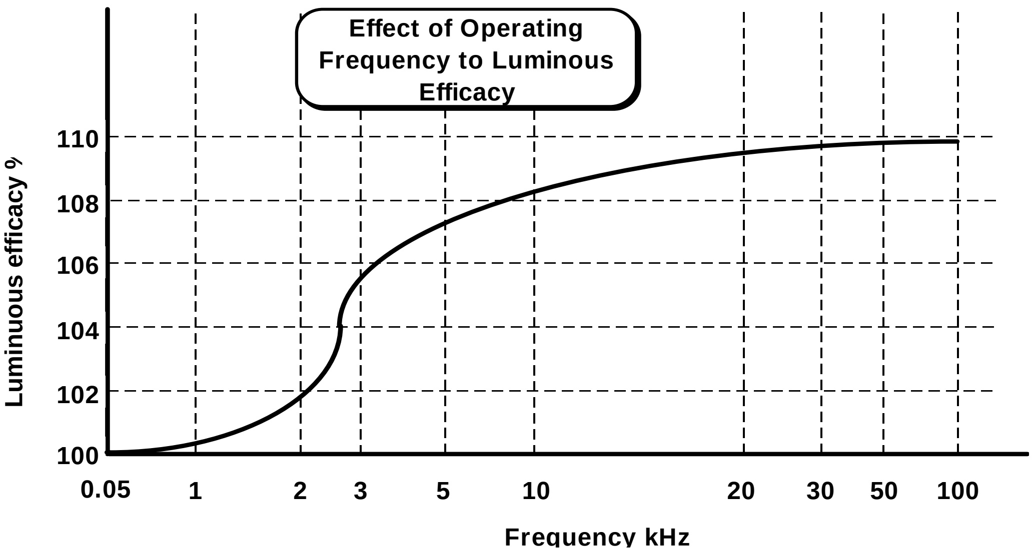


Figure 3.3.7 – Effect of Operating Frequency to Luminous Efficacy

It is worth noticing that the efficacy of the lamp can be improved by about 10% when fluorescent lamps are operated at higher frequencies. The graph shows that the gain is less marked at a frequency in excess of 30kHz, thus in real world applications, electronic ballasts usually operate at a range near this region. The improved efficacy of the lamps implies that the wattage required to produce the same lumen output is reduced. An energy saving of up to 25%

can be achieved when all the benefits are taken into consideration.

3.3.8 Power Factor of Ballasts

From energy point of view, the measured wattage does not represent the true electricity consumption. A low power factor will result in considerably larger currents being required as indicated in the VA figures. These larger currents have a considerable "wattless" component but may lead to higher losses in the whole supply network. With power factors as low as 0.4 this current ratio can be 2.5 (VA/W) and the wasted power would then be an additional 44% above the measured power.

3.3.9 Selection of Luminaire

By selecting an appropriate luminaire that results in a reasonable illuminance, minimum direct glare, reflected glare and veiling reflections, both of the task visibility and productivity can be improved.

An important consideration of lighting efficiency is the Utilisation Factor (UF). This is a measure of the efficiency with which the luminaire distributes the lumens generated by the light source to the working plane.

Other factors that affect the efficiency that light can reach a particular surface are :

- luminaire dirt depreciation (LDD),
- room surface dirt depreciation (RDD),
- lamp lumen depreciation (LLD), and
- lamp failure factor (LFF).

The method of calculating UF is detailed in CIBSE technical memorandum No.5. Also, most lighting manufacturers publish tables of UF for their own luminaires. Basically, the UF for a luminaire depends on:

- the geometric shape of the room space,
- the reflectance of the room services,
- the orientation of the surfaces, and
- the physical design of the luminaires.

Though the Lighting CODE does not specify the minimum UF, the Power Density itself does however control the choice of luminaire. Using a luminaire with a low UF will result in requiring a large number of luminaires in the lighting system that thus exceed the Lighting Power Density limit.

Basic Lumen Method Equation

The following equation can obtain the number of luminaire required to produce an average illuminance E_s on a particular surface:

$$N = (E_s \times \text{Area of surface}) \div (F \times n \times LLF \times UF)$$

and $LLF = LLD \times LFF \times LDD \times RDD$

where N is the number of luminaires
n is the number of lamps per luminaire
F is the initial bare lamp flux
LLF is the total light loss factor
UF is the utilisation factor for the reference surface s
LLD is the lamp lumen depreciation

LDD is the luminaire dirt depreciation
LFF is the lamp failure factor
RDD is the room surface dirt depreciation

This equation is the basic lumen method equation. In addition to this equation, designer should also check the **Space to Height Ratio (SHR)** of the luminaire to ensure the calculated system has an acceptable uniformity :

$$SHR_{AX} \times SHR_{TR} \leq (SHR_{MAX})^2$$
$$SHR_{AX} \leq SHR_{MAX}$$
$$SHR_{TR} \leq SHR_{MAX\ TR}$$
$$SWT \leq SHR_{TR}/2$$
$$SWA \leq SHR_{AX}/2$$

where SHR AX is the SHR at the axis of the luminaire
SHR TR is the SHR along the transverse direction
SWT is the SHR along transverse direction for fitting next to a wall
SWA is the SHR along the axis of the luminaire next to a wall
SHR MAX is the maximum allowable SHR

The maintainability of the luminaires must be considered as it relates to power and energy efficiency. A luminaire is only cleaned when it is being re-lamped. With the introduction of longer life lamps, many up to 24,000 hours rated life, re-lamping may not occur for several years. Without maintenance, dirt accumulates on the luminaire, greatly reducing the illuminance. In the above equation, the LLF mainly concerns the maintenance of the luminaire as well as the room surfaces. Thus a comprehensive and effective maintenance and cleaning programme can reduce the number of luminaires required to achieve the required illuminance.

3.3.10 Power Quality of Lighting Equipment

The Power Quality in a lighting system affects the efficient usage of electrical energy. With the increasing usage of more sophisticated lamp equipment that incorporate electronics switching devices, the power quality consideration should be paid more attention in a lighting design. In an alternating current circuit, the direction of current flow reverses every half of the cycle. For example, the direction of current flow changes 100 times every second for a 50Hz main supply. A device with ideal power quality characteristics should neither distort the supply voltage nor affects the voltage-current phase relationship. Most incandescent lighting systems, which can be considered as a pure resistive load, do not reduce the power quality of a distribution system because they have sinusoidal current waveforms that are in phase with the voltage waveform (i.e. the current and voltage both increase and decrease at the same time). Other lamp sources such as fluorescent, HID and low voltage incandescent lighting system that use ballasts or transformers, may have distorted current waveforms. Especially for electronic ballasts that are worked on electronics switching devices. These electronics switching devices will draw current in short bursts (see Figure 3.3.10a), which creates distortion in the voltage. These devices' current waveforms may also be out of phase with the voltage waveform due to their inductive/capacitive

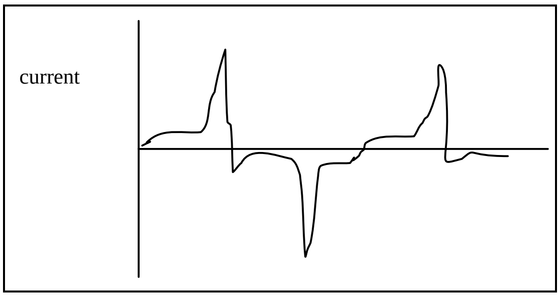


Figure 3.3.10a – Short Burst Current

loading characteristics. Such a phase displacement can reduce the efficiency of the alternating current circuit by generating excessive reactive powers that derate the capacity of the distribution circuitry.

Reactive Power

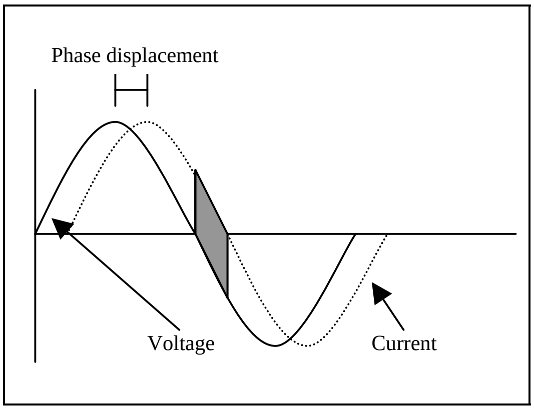


Figure 3.3.10b – Typical Lagging Current Waveform

Figure 3.3.10b on the left shows a typical case for a current waveform lagging behind the voltage waveform (a typical case for inductive load). During part of the cycle the current is positive while the voltage is negative (or vice versa), as shown in the shaded areas; the current and voltage during this period work against each other, creating the so called reactive power. The device produces useful work only during the time represented by the non-shaded parts of the cycle, which represent the circuit's active power. Reactive power does not distort the voltage. However, it is an important power quality concern because utilities' distribution systems must have the capacity to carry reactive power even though it accomplishes no useful work. Therefore, there is always a requirement in the supply rules of the power companies that request the connected load to maintain a power factor not less than 0.85. Most electronic ballasts for full-size fluorescent lamps are equipped with filters to reduce current distortion. Some electronic ballasts for compact fluorescent lamps have high current distortion, but contribute little to voltage distortion because of their relatively low power consumption in a distribution system. Traditional magnetic ballasts for fluorescent and HID lamps typically have lagging current due to their inductive nature. In order to meet the power factor requirement, some magnetic ballasts are fitted with capacitors that reduce the lag displacement between current and voltage, which eliminates excessive reactive power.

Harmonics

Another power quality concern is the harmonics. A harmonic is a wave with a frequency that is an integer multiple of the fundamental, or main wave. All distorted waveform can be described by the fundamental wave plus one or more harmonic components. Highly distorted current waveforms contain numerous harmonic components. The even harmonic components (second-order, fourth-order, etc.) tend to cancel out each other's effects, but the odd harmonics tend to add in a way that rapidly increase distortion because the peaks and troughs of their waveforms often coincide. The measurement of harmonics is most commonly in terms of total harmonics distortion (THD). Devices with high current THD contribute to voltage THD in proportion to their percentage of a building's total load. Thus, high wattage devices can increase voltage THD more than low wattage devices. It is recommended that designers should include filters to minimize THD when specifying electronic ballasts.

Power factor is a measure of how effectively a device converts input current and voltage into useful electric power. It describes the combined effects of current THD and reactive power from phase displacement. A device with a power factor of unity has 0% current THD and a drawn current that is perfectly in phase with the voltage. Resistive loads such as incandescent lamps have power factors of unity. Magnetic and electronic ballasts for fluorescent lamps usually have integral provisions to reduce harmonics and correct power factors.

Poor power quality can damage the distribution system as well as the devices operating in the system. It is not uncommon to experience neutral conductor heating or even nuisance circuit breakers tripping due to poor power quality in high rise buildings. In a system with no THD, the neutral wire should carry no current. High current THD devices can send odd harmonics onto the voltage supply, which do not cancel each other out. They add up on the neutral conductor, and if the current exceeds the conductor's rating, the neutral conductor can overheat and may result to the extreme in a fire hazard. Voltage distortion can also shorten the life of utilities' transformers and cause capacitor banks to fail. Reactive power derates capacity of the distribution system, which limits the amount of active power that a utility can deliver. This may be a problem during periods of peak demand.

Designers should specify high power factor ballasts (power factor > 0.9) for buildings with sensitive equipment, such as hospitals. Almost all of the electronic ballasts currently available are high power factor with current THD less than 20%.

The 2007 edition of the Lighting CODE has stipulated the use of electronic ballasts in compliance with The Hong Kong Voluntary Energy Efficiency Labelling Scheme for Electronic Ballasts and compact fluorescent lamps in compliance with The Hong Kong Voluntary Energy Efficiency Labelling Scheme for Compact Fluorescent Lamps of EMSD. This reduces the problem of undesirable power quality to a minimum.

3.4 Holistic Approach in Design

Lighting design is an iterative process. Designers should always go back to the design basics to ensure the achievement of energy efficiency and the meeting of demands from users on a suitable and comfortable lighting environment. In many circumstances, the lighting design should be integrated with the overall building design, and the lighting requirements re-think from time to time with the other fundamental aspects in the overall building design embracing building fabric, various building services, objectives of the building & the different spaces, human factors, requirements on operation & maintenance etc.

4. OPERATION & MAINTENANCE CONSIDERATIONS

Energy is the product of power and time. The factors related to power or connected load of a lighting system are considered in Section 3. This section presents the design factors that affect operating time of a lighting system.

Energy consumption can be reduced by controlling the number of operating hours. Turning off the light when it is not needed will reduce energy consumption. The lighting system, should, whenever practical, be designed to provide a reduced light level during cleaning periods, and a mean for turning off lights by room or floor as the cleaning staff moves through the building. All spaces that are not used continuously should have local or automatic switching, allowing lights to be turned off when the space is not in use.

4.1 Occupancy

Energy is wasted when lights are left on in unoccupied rooms. By employing proper lighting management systems or devices, the energy use can be optimised.

4.1.1 Automatic Switching

Automatic on/off systems, occupancy sensors, time clocks or energy management systems, save energy by preventing light from being left on when not needed. The automatic on/off controls can be designed according to the occupancy schedule. Additional energy can be saved through the use of Manual On/Automatic Off Systems, by which occupants turns lights ON in his work space at the beginning of the day, or when needed. At the end of the day, all lights can be turned off using a central control switch.

Occupancy sensors can be used to save energy in areas where employees are not present for a portion of a day. Such sensors should not be activated to turn lights ON in a space where daylight is sufficient for part of the occupied hours.

4.1.2 Occupancy Scheduling

One way to save lighting energy, based on building or room occupancy, is to alter the occupancy schedule. This design consideration does not involve any automatic controls, but a commitment by the building owner/occupants.

The lighting designer can suggest some scheduling alternatives that would optimise the use of lighting energy. For instance, if all employees have common lunch hours, the lights in the work area can be reduced and only the lights in the lunch area are in full operation during that period.

In the early stage of office layout design, employees or divisions that frequently work overtime can be identified and grouped in the same area. By this way, night time operation of the lighting systems can be limited to only one area of the building.

4.2 Daylight Utilisation

The introduction of daylight into an interior space will not, by itself, save energy. Lighting control devices should be used to enable the substitution of daylight for artificial lighting when adequate daylighting is available. Either dimming or switching controls can be effective in maintaining suitable interior illumination levels.

The effective use of daylighting requires the proper design of building fenestration that can capture day light penetration.

The correct placement of sensors to control electric lights is critical to balancing lighting quality and energy saving. Automatic sensors should be located in a manner such that the portion of the lighting zone being controlled experiences fairly uniform daylight illuminance levels. Also, the electric light levels nearer to the fenestration elements are lower than the levels at interior core locations.

Electric lighting systems should be designed to be compatible with the daylighting system in respect of luminance ratios, controls and colour rendition. This co-ordination helps to enhance the daylight quality and improve user acceptance of the energy saving features.

4.3 Lighting System Maintenance

Design of lighting systems to compensate for lack of system maintenance can waste lighting energy since more light is provided initially than is necessary. The use of maintenance compensating controls can reduce energy consumption by only providing the required amount of light. Typical compensation control systems involve a sensor that measures the lighting level in a space and a control device, which adjusts the light output to maintain the required lighting level.

From maintenance point of view, it may not be cost effective to replace the lamp at a time when the lamp burns out, because it is labour consuming and the burnt out of lamps occurs more or less at a random manner. It is therefore more cost effective to carryout group replacement at the economic lamp life. This strategy can also uphold the energy performance of the lamp as you can recall the concept of lumen maintenance depreciation in Section 3. There is no official definition of economic lamp life however, it can be regarded as the number of operating hours after which the cost of group replacement equals the electricity cost of the depreciated illuminance plus the cost of changing early failures. It is worth noticing that with group replacement, the labour demand for maintenance is actually reduced because the demand for replacing burnt out lamp in a "put out fire" style is decreased.

For lighting system installed with automatic control sensors such as occupancy sensors, daylight sensors etc., maintenance staff should not change the settings without proper knowledge on how they are calibrated. All calibration and adjustment should follow documented procedures and recommendations.

4.4 Cleaning

Lighting energy is often wasted during the cleaning operations of commercial buildings. As there is a large difference in the design illumination levels for office operation (around 500-600 lux) and cleaning (100 - 200 lux), control devices can be used to reduce the lighting for night cleaning operations. Manual or automatic dimming or two-level switching may be appropriate methods of reducing the light levels. Where night-time cleaning is required, the night-time cleaning activities can be scheduled for just one or two floors or one or two areas of a single floor, at a time. By this way, the lighting on the remaining floors or floor area can be left OFF until scheduled to be cleaned, and then turned off when the cleaning is finished. Manual or automatic controls can be used to facilitate light switching for cleaning purpose.

4.5 Multiple Visual Task

Some lighting systems are designed for the most critical task performed in the space. However, the task may be performed only a few hours per day or only by a limited number of workers. Energy is wasted if the lighting system remains at the critical level all the time or in every area. Task-ambient lighting is a feasible design solution for a multiple task environment. The ambient lighting system provides sufficient light for the general space or for the less critical task. On the other hand, a task light supplements the ambient light for more critical tasks. Often, task lights are left ON during the night. To avoid this type of energy waste, the task-ambient system should be wired and controlled so that individual task lights must be physically switched ON by occupants as needed, but can be turned off manually or automatically at the end of the day.

It is recommended to adopt a lower ambient illumination level with higher task illumination levels for different task locations.

4.6. Lighting Control Strategies

Energy used for electric lighting depends upon the degree to which the lighting controls reduce or turn off the lights in response to:

- availability of daylight
- changes in visual tasks
- occupancy schedules
- cleaning practices

Lighting designers are faced with three types of applications choices (retrofit, renovation or new construction) for a lighting control system. The primary objective of a retrofit is to reduce operating costs. It is unlikely that a retrofit application would be economically sound if the supply circuit layout or the building design would have to be altered. The ideal retrofit should require no wiring work to the supply circuits. For renovation applications, the lighting control system can employ more control strategies to optimise the initial, operating and maintenance costs. In new construction, designer should work closely with the architect and provide input to optimise the utilisation of day light.

Automatic controls can conserve energy, but they should be designed to avoid annoying the occupants. Occupants should be advised about the performance and functions of the lighting control system. Use of local controls and manual overrides can facilitate users' acceptance of the system. Training should be provided to the local occupants wherever required.

Abrupt changes in the illuminance, as in timing controls and switches, will be annoying in critical task areas and may reduce workers' productivity. However, such methods can be used effectively in non-critical task areas, such as corridors or warehouses.

4.6.1 Types of Control :

Generally, there are two major types of lighting control :

- ON/OFF Control, and
- Level Control.

4.6.1.1 On/Off Control

The basic ON/OFF control equipment is the switch, which is available in the following configurations :

AC Snap Switches

Normally, a large space is divided into several zones, each of which is controlled by one or more than one switches. In addition, the switches should be circuited in a way to suit specific functions of the space. For a space with more than one entrance, 2-way, 3-way or 4-way switches should be used to provide control at each entrance. Separate controls should be provided for task lighting at each luminaire locations.

Low-Voltage Remote Control Switching

A low-voltage switching system consists of a magnetic relay, a transformer and switches. The relay switches a line-voltage lighting load by a low-voltage switch in the space. This provides the advantages of controlling loads from great distances, controlling a number of different loads from one location, and controlling one load from multiple locations. Since all switch leagues are on low current and carry 24 volts or less, copper loss in electrical wiring is reduced. Moreover, each luminaire or any group of luminaires up to branch circuit capacity can be grouped on a relay. The switching pattern can then be put together by connecting the low-voltage wiring and switches as needed.

Time Switches

For near-window or exterior applications, it is necessary that timing of operation adjusts with the season. There are some other applications, such as storerooms, where people enter the space for short periods of time and forget to turn off the lights. The prerequisite for such a system to work is to have a predictable operating schedule.

Photocells

The use of photocells is popular for near-window or outdoor lighting. Photocells can also be used for automatic lighting control of an indoor space. When crucially mounted at a proper location, a photocell will read the level of lighting, incorporating daylight influence, and automatically adjust the artificial lighting level of a single or a group of luminaires. Lighting system must be installed with dimmers in order not to induce abrupt change of lighting level. Under certain circumstances, manual overriding switches may be necessary when space functions or personal requirements change. A properly designed and commissioned daylight system can cut lighting operating hours up to 50% and reduce electricity use. Daylight dimming success relies on photocells placement and the amount of window area and ambient light available. Individual zone conditions, including building orientation, window coverings and other obstacles that prevent daylight from entering, must be considered. Daylight systems can be installed with occupancy sensors or timer control.

Occupancy Sensors

Occupancy sensors can reduce a building's lighting energy by turning lights off in unoccupied spaces. Energy savings may not be realised if the sensors are improperly installed or are disabled by dissatisfied occupants. These sensors are typically infrared type or ultrasonic sensors. Infrared sensors detect motion when the heat source moves from one zone to another. The sensor must have a direct line of sight to the occupants to detect motion. Relatively small movements, such as typing on a keyboard, may not be sufficient to cross a zone and trigger the sensor. Ultrasonic sensors emit high-frequency waves in the range of 25-40kHz. These waves bounce off objects in the room and return to the sensors. Objects moving in the space shift the frequency of the returning signals and this shift is detected by the sensors. Ultrasonic sensors can detect small movements and do not require a direct line of sight to occupants, but wind-blown curtains or papers can trigger the sensor incorrectly. New generation of occupancy sensors utilise dual technology to solve this 'drapery problem'. For instance, while an ultrasonic sensor would sense the movement of drapery and want to turn the lights on, the infrared sensor would not sense a movement of heat and would override the ultrasonic signal. Another dual technology control incorporates a microphonic sensor, which 'listens' for minute sounds, such as the turning of pages, even though an occupant would not show any appreciable movement in the room.

4.6.1.2 Level Control

Dimmers

Solid-state dimmers are available for incandescent, fluorescent and HID lamps. Generally, solid-state, high frequency ballasts are used for fluorescent and HID lamps to facilitate the dimming operation. The dimmer modules used in the high-power lighting systems are suitable for interfacing with time clocks, photocells or computers.

When the dimmers are connected with an automatic energy-control system, substantial energy saving can be made. Such automatic dimming system has the following advantages:-

- compensate for the wasted power due to lamp lumen depreciation and luminaire dirt depreciation
- use of daylight

Normally, dimmable lighting systems are expensive and, may not be applicable for every installation. It is recommended to use dimmers only where it is anticipated that lighting level control is needed.

4.6.2 Micro-processor Control

Micro-processor control can be applied to a lighting system, from a standalone system in a single space to the entire system in a building. It is usually connected with controlling devices such as timers, photo-sensors etc. to provide the desired lighting group/system performance. It offers great flexibility to lighting control. The typical control functions include :

a. automatic daylight compensation control,

b. automatic compensation for lamp lumen depreciation and luminaire dirt depreciation,

c. scheduling of lighting operations to minimise the operating hours, and

d. fine tuning of lighting level to suit actual requirements.

<u>DALI Control</u>

Digital Addressable Lighting Interface (DALI) is an international standard under IEC 60929 that guarantees the exchangeability of dimmable electronic ballast from different manufacturers. The DALI was developed to overcome the problems associated with the analogue 1-10V control interface for dimming of electronic ballasts. It provides a simple and digital way of communication among intelligent components in a local system. The DALI does not centralize the intelligence of DALI-interface control devices, meaning that many of the set points and lighting values, such as individual address, group assignment, light scene values, fading times etc are stored with the individual ballast, and each luminaire could be individually addressed and programmed to its designated lighting group, scene and switch settings.

There are control standards other than the DALI in providing the interface platform, in particular for equipment and devices of the same manufacturer.

5. OPPORTUNITIES FOR RETROFITS IN EXISTING LIGHTING SYSTEMS

5.1 Energy Efficiency Plus Side Benefits

From economical point of view, retrofitting existing lighting system of less energy efficient equipment into new energy efficient equipment does not only reduce its operating costs. As some of the retrofitting options also improve the light quality, the side benefits can lie beyond the saving in electricity costs alone. Usage of more energy efficient equipment also means that the illumination level can be increased with the same electricity consumption. Some other side benefits may be:

- Reduced Operating Costs:-
  - Reduces energy and demand costs because of improvement in energy efficiency,
  - Reduces air-conditioning costs, depending on lamp type, &
  - Lowers insurance costs due to risk reduction;
- Increase Productivity:-
  - Reduces visual fatigue and absenteeism,

- Reduces errors and improves work performance, &
- Saves time spent on redoing work;

- Better Quality Control:-
  - Decreases waste of source materials and energy due to lower error rate, &
  - Increases effectiveness of visually oriented quality control procedures;

- Enhance Business Image:-
  - Improves appearance of first impression lobby areas, &
  - Highlights paintings, sculpture, and other art objects;

- Heightened Safety and Security
  - Reduces safe harbours for vandals, muggers, and other lawbreakers,
  - Eliminates shadows that can mask hazards, &
  - Highlights particular hazards or provides more illumination where people must work with sharp or heavy objects, near exposed moving equipment, or in areas subject to liquid spills;

- Increased Retail Sales
  - Creates the proper ambience for a given display,
  - Brings out colour and texture of fashions,
  - Lends sparkle to crystal and jewellery,
  - Reveals features, details, colours and wholesomeness of the display products,
  - Motivates larger quantity, higher-priced purchases, &
  - Prompts confident buying decisions and reduces returns; and

- Improved Visual Environment
  - Creates lively visual environment,
  - Improves working conditions,
  - Makes image statement,
  - Establishes brightness variations that match merchandising objectives,
  - Lets customers enjoy and extend stay in stores, and
  - Instils confidence in store's fashion or quality awareness.

Optimally designed retrofits will typically exceed reasonable rates of return. Decision-makers should discern the difference between costs and investments in dealing with these retrofitting works. That is, to treat lighting retrofit as an investment rather than a cost of expenditure. If lighting retrofit is treated as a cost of expenditure, decision-makers will easily fall into the trap of which-option-is-cheapest logic in making retrofit decision that may sometimes hinder designers to use energy efficient equipment of a higher cost. Lighting retrofit when treated as an investment will shift decision-makers' logic from focusing on which-option-is-cheapest to which-option-is-the-best. The added benefit is an image of being "politically correct" as well because of their positive environmental impact.

5.2 Retrofit Options

Evaluation of various retrofit options can be made in terms of their payback periods. Some of the retrofit options that worth to be considered by decision-makers and designers are:

5.2.1 Ballasts for Fluorescent Lamp

The T5/T8 lamp with electronic ballast combination is practically the most popular choice. Electronic ballasts are energy efficient, produce less heat load for the air conditioning system, and eliminate flicker and hum. Products are available for compact fluorescent and full-size lamps, connecting up to four lamps at a time. 3-lamp and 4-lamp ballasts reduce material and energy costs, as compared to 2-lamp ballasts, because fewer units will be required. Fewer ballasts can also increase the overall system efficiency as the gear loss for a 4-lamp electronic ballast is typically less than the sum of the gear loss of four 1-lamp electronic ballasts. However, as the cabling between the ballast and the lamps shall be well screened for electrical safety as well as to restrict the electromagnetic interference to acceptable limit, the multiple lamp on single ballast arrangement are usually applied to lamps in the same luminaire.

5.2.2 Fluorescent Lamp & Luminaire

The T8 lamp with electronic ballast combination provide a light level comparable to the T12 with electromagnetic ballast system, and has the benefit of consuming up to 40% less electrical energy. The tri-phosphor coating improves the T8's colour rendering characteristic as well as its efficacy. Also, the T8 lamp has some 50% longer lamp life then the T12. With the advantage of T8, the T5 has even an efficacy of some 10% higher.

Most T8 lamps can operate on conventional electromagnetic ballast, and can be used to directly replace T12 lamps to capture the T8's higher efficacy of some 10%. It is however worth noticing that not all electromagnetic ballasts and T8 could harmoniously work together, and a trial of a few selected luminaire should be conducted before large scale replacement of the same luminaire models. Should the simple replacement does not work out, the ballast in the luminaire will have to be replaced with one suiting T8 as well.

Whilst T8 lamp could replace T12, T5 can normally not replace T8, as the T5 requires its own high frequency ballast that is different from that of a conventional T8. Also, the T5 tube is slightly shorter in length than the T8, and the holding end-caps on the luminaire have to be spaced differently. As such, a retrofit of existing lighting of T8 or T12 to use the new T5 will require the replacement of the ballast and likely the entire luminaire as well, thus resulting in higher cost of retrofit.

To avoid retrofitting the luminaire when switching from T8 or T12 on electromagnetic ballast to T5 on electronic ballast, there is the Plug & Enhance (PnE) technology. The PnE technology introduces a quasi-electronic ballast (QEB) in the tube replacement. The QEB is an electronic device that is attached as an end cap or inside a fitting, which works with the original electromagnetic ballast to light up the fluorescent tube. With the QEB, a T5 can be fitted direct in place of the T8 or T12, and the overall efficiency after replacement is similar to a simple T5 on electronic ballast arrangement. A short circuit component is required to replace the original starter for some system though.

5.2.3 Compact Fluorescent Lamp

Compact fluorescent lamps are an excellent replacement to incandescent lamps; they are more efficient, have longer average lamp life and provide good colour rendering. Smaller models and additional improvements in technology have significantly increased their applications – from downlights to floodlights to task light and even to exit signs. Compact fluorescent lamps are available as either equipped with integral ballast or separate lamp and ballast units, in combination with common screw-in adapters (e.g. E27 adapters) for incandescent retrofits.

Although compact fluorescent lamps emit light in a diffuse manner and require special devices for dimming, high-bay compact fluorescent lamps systems can be good alternatives to high intensity discharge systems in applications with mounting heights up to 9m. The advantages of using compact fluorescent lamps include: instant-on (minimal warm-up time require), instant-restrike, high colour rendering index, high efficacy and multiple light-level capabilities. Six to nine high-bay compact fluorescent lamps are typically housed in one luminaire, the two- or three-lamp ballasts can provide separate switching for multiple light-level control. This is an alternative arrangement if dimming is required.

Screw-in compact fluorescent lamps that can be dimmed with conventional incandescent dimmers are also available. THD from electronically ballasted compact fluorescent lamps can exceed 30%, though low-harmonic units are available. Compact fluorescent lamps with magnetic ballast typically produce THD of 15 to 25%, which is acceptable in most applications. Technological improvements and cost reductions in compact fluorescent lamp electronic ballasts make them economically viable, providing instant starting; three-lamp capabilities; reduce flickers, hum, size and weight; and efficacy increases of 20%. Though the electronic compact fluorescent lamp system costs several times what a comparable incandescent costs, the lift-cycle cost is usually worthy of consideration.

Applications requiring incandescent performance, such as tight beam control, dimming, or optimal colour rendering, may not be a good candidate for compact fluorescent lamps retrofit. Instead, some may consider the use of halogen lamps, which are more efficient and last longer than standard incandescent.

5.2.4 Fluorescent Luminaire Reflector

Sometimes replacing rather than retrofitting the luminaires can be more economical and cost effective, especially where there is a change of the lighting system requirements. New luminaires can optimise efficiency, visual performance, technology compatibility and aesthetics. If it is decided to go for retrofitting, reflectors can be a very simple and cost effective option. Luminaire efficiency is increased because less light is trapped and wasted within the luminaire fitting. The effectiveness of the reflector depends on its geometrical shape, coating material and the efficiency of the luminaire. **Reflector installation can usually reduce the number of fluorescent lamps** in three- and four-lamp luminaires for the same light output levels. The remaining lamps in a typical , say 300x600mm, luminaire may need to be relocated to maximize light output and uniformity. In combination with higher output fluorescent lamps and electronic ballasts, light output may be increased significantly with suitable reflectors.

Old and degraded luminaires that cannot be rectified by cleaning alone are generally excellent reflector retrofit candidates. To determine if reflectors are appropriate, prepare a reflector trial mock up. Begin by cleaning a few luminaires, install reflectors in half of the cleaned luminaires and compare light levels with clean luminaires where reflectors were not installed. Shielding devices are usually installed in luminaires to control uncomfortable glares. Inefficient shielding devices will degrade even the most efficient lamps and ballasts. Balancing visual comfort (glare control) and luminaire efficiency should be the key to achieve success in reflector retrofit. Deep-cell parabolic louvers provide good glare shielding and an efficient distribution of light. Low-glare clear lens optimise photometric efficiency while providing sufficient glare control. Opal diffusers and small-cell louvers are generally considered not efficient shielding devices.

5.2.5 High-intensity Discharge Lamp

Metal halide and high pressure sodium lighting systems offer high-quality lighting and among the highest efficacies of all lighting systems. Besides outdoor and industrial applications, metal halide and high pressure sodium systems are now commonly found in indoor applications such as office, retail and other commercial spaces. Both systems offer low to moderate life-cycle costs and different range of wattages, good average lamp life, good colour rendering index and superb system efficacies. In general, higher wattage systems provide better efficacies. However, higher wattage systems require higher mounting height to control the uncomfortable glare and the uniformity of the light output.

High-intensity discharge lamp ballasts are designed to operate only the specific type of lamps and range of wattages. Specially designed metal halide and high pressure sodium lamps may be operated from mercury-vapour ballasts. Whilst many new high intensity discharge luminaires are incorporated with electronic ballasts, the ballasts of many installed luminaires are electromagnetic type. Electronic ballasts are smaller, lighter, and can improve colour control and improve lamp life, but may not significantly increase the luminaire efficacy.

High-performance metal halide systems use a new kind of metal halide lamp and a dedicated magnetic ballast with a built-in starter or an electronic ballast. They offer up to 25% efficiency increase over conventional metal halide systems, extended lamp life, stabilise colour and reduce restrike time. New, low-wattage, high colour rendering index compact metal halide lamps offer light quality comparable to incandescent lamps, though having longer warm-up and restrike times as well as dimming limitations.

Instant-restrike model of standard high pressure sodium lamp are suggested for use with occupancy sensors. Where improved colour rendering is desirable, deluxe and white high pressure sodium lamps provide a broad range of performance alternatives. Efficacy is sacrificed for quality with the deluxe and white high pressure sodium lamps. Deluxe model offer efficacies comparable to standard metal halides lamps. White high pressure sodium lamps with integral reflectors are also available; they are less efficient than a compact metal halide but better than a halogen lamp. Its warm, incandescent like light quality and wide range of beam spreads make this technology a good, efficient alternative for retail display lighting application.

5.2.6 Lighting Control

<u>Switching</u>

The simplest retrofit for lighting control is to provide lighting control switches at appropriate locations. An example is lighting control switches located suiting the layout of the office such that occupants can easily access and operate these switches. Though frequent switching shortens the lamp operating life, effectively applied controls can increase the years of lamp calendar life, which is in fact what the owner has to pay for.

The Lighting CODE provides a guideline on the area per switch in an office space, so that the number of switches could be determined easily in a lighting design.

<u>Timer</u>

Typical operation is on at night time and off at day time. A timer set to ON from 7:30pm to 5:30am, however, cannot turn off the lighting system on a summer day at 7:00pm, a time that is still fine without artificial lighting. Under the circumstance, the timer should be re-set at least two times annually to suit the sun summer/winter set/rise times, or consideration should be given to introduce a photo sensor control.

<u>Photocell</u>

Upon falling below the design illumination level, the photocell turns on the luminaire to serve the space. A photocell, however, will still unnecessarily turn on the lighting that is meant only for people working in the space. Under the circumstance, consideration could be given to introduce occupancy control.

<u>Occupancy Sensor</u>

Occupancy, or motion sensors are generally accepted as an effective energy-saving device, which however must accompany with proper setting, placement & selection. The sensors should have adjustable sensitivity setting to ensure detection of normal activities without picking up false signals. It should also be equipped with time-delay setting to control the length of time for luminaires to remain on without motion being detected. Manual-on or two-level options can also be considered. Trial and mock up installations are a good idea. Intermittently occupied spaces – such as offices, restrooms and conference rooms – are good candidates while common space, such as reception areas or main hallways, might be less suitable.

Wall-mounted units might be specified for small spaces that do not have obstacles to signal detection. Ceiling-mounted units are recommended for larger spaces, irregularly shaped rooms and those with partitions. Infrared units are most sensitive to lateral motion while ultrasonic units detect motions directly toward or away from the unit. Dual-technology modules are sensitive to both type of motion. System using microphonic sensor is also available. Another option is to provide personal control of fluorescent lighting with an infrared remote control that dims fixtures individually or in groups.

Dimming

A typical application is for spaces at building perimeter with fenestration, whereby the lamp output could be adjusted based on the brightness of available daylight. For some energy-conscious spaces, the minimum illumination levels required at different times of the day may be different, and dimming could be applied for the purpose to adjust the lighting levels in accordance to the activity levels. An example is the higher level at commencing of work at 8:30am & 2:00pm, reduced level at 10:30am to 12:30pm & 3:30pm to 5:30pm, and low level at 12:30pm to 2:30pm.

Panel-level dimming systems are designed for high-intensity discharge and fluorescent systems. Panel-level dimming uniformly dims circuits of luminaires by modifying current or voltage waveform. Bi-level switching systems, or capacitive switching, render full or partial light output to fluorescent and high-intensity discharge systems according to input from sensors, switches or timers. Tri-level systems may also be considered.

Daylight dimming provides energy savings of up to 40% while dimming down to as low as 20% of full output. Daylight dimming can enhance lighting quality by maintaining a constant, uniform light level and providing greater light-level flexibility to the occupant. Generally, the periphery area within 4m of a window has good potential for daylight utilisation but it also depends on the building's surrounding environment. An assessment on the amount of daylight available from the window can determine its feasibility and its effectiveness. Furthermore, these systems can automatically compensate for lumen depreciation. Daylight systems must be fully commissioned before handover to the building users for correct functioning.

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