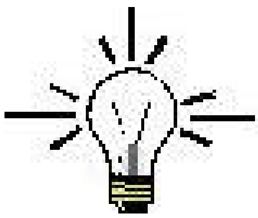
Guidelines on Energy Efficiency of Lighting Installations

1998 Edition



Electrical and Mechanical Services Department
The Government of the Hong Kong Special Administrative Region

Addendum No. 1 to
Guidelines on Energy Efficiency of Lighting Installations

Following the Review in end 2004/05, there are the following amendments:

In the 3rd sentence of the paragraph "Choice of lamp type" in Section 2.2.2 on Page 9, rephrase the sentence as indicated in bold letters as follows:

> *This factor is………………..lamp sources.* **For example, specify T5 fluorescent lamps rather than T8 lamps, use compact fluorescent lamps instead of incandescent lamps etc."**

In the paragraph "Tubular Fluorescent Lamps (MCF)" on Page 12 in Section 3.3.2, rephrase the last sentence as indicated in bold letters as follows:

> *Fluorescent lamps………………..energy efficient.* **While T8 fluorescent tube is more energy efficient than its predecessor the T12 tube, the T5 tube that is more energy efficient than the T8 tube has emerged in the market and is gaining popularity.**

In the paragraph "Ballasts for fluorescent lamps" on Page 30 in Section 5, cancel the 1st sentence "The T8 lamp/electronic……………………..market".

In the paragraph "Fluorescent lamps" in Section 5, replace the last 3 sentences on Page 31 with the following:

> **While T8 lamps play a crucial role in the lighting industry, T5 lamp has emerged in the market and is gaining popularity. As the T5 tube is slightly shorter in length than T8 and is operated by a different controlgear as well, the entire luminaire may need to be replaced in a lighting retrofit from T8 to T5. To avoid the replacement of luminaire, adaptor device complete with controlgear is also available in the market for fixing T5 tube to T8 luminaire.**

Preface

As a supplement to the Code of Practice for Energy Efficiency of Lighting Installations, the Energy Efficiency Office of the Electrical and Mechanical Services Department is developing this handbook of guidelines on recommended practices for energy efficiency and conservation on the design, operation and maintenance of lighting installations. The intention of these guidelines is to provide guidance notes for the lighting code and recommended practices for the designers and operators of lighting systems and installations. The guidelines in this handbook 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 not only design installations that would satisfy the minimum requirements stated in the lighting code, but also adopt equipment, design figures or control methods above the standards of the minimum requirements. It is also the objective of this handbook to enable a better efficiency in energy use of the designed installations and provide some guidelines in other areas not included in the lighting code especially regarding maintenance and operational aspects for facilities management.

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1. Introduction

The primary objective of this Guide is not to provide a comprehensive set of guidelines for lighting design. Instead, the focus will be placed on the energy efficiency aspects of lighting design. This guide will also discuss on the design approach leading to the compliance of the Code of Practice For Energy Efficiency of Lighting Installations.

2. Guidelines for Procedures to Comply with the Code of Practice for Energy Efficiency of Lighting Installations

2.1 General

The Code of Practice for Energy Efficiency of Lighting Installations was published by the Electrical and Mechanical Services Department for designers participated in lighting design. The main objective is to achieve an energy efficient lighting design. *It should be initially checked that the lighting system in concern falls within the scope of control of this Code of Practice(COP).* One should notice that this COP is ***not*** applicable to :

- any indoor space of a hospital, a clinic or an infirmary;
- any indoor space used for utility service such as power stations and sub-stations.

Furthermore, the COP is also ***not*** applicable to the following kinds of lighting systems:

- specialised lighting installations solely used for one of the following functions :
  - academic or industrial research application
  - television broadcasting
  - theatrical production
  - audio-visual presentation
- display lighting for exhibit or monument
- emergency lighting of non-maintained type

The COP mainly control the following aspects in order to achieve its goal:

Minimum Allowable Luminous Efficacy

This controls the choice of lamps as different manufacturers have different efficacy characteristic. The choice of lamp with reasonable energy efficiency can facilitate the compliance to the later Lighting Power Density (LPD) requirements. Various characteristics of major types of lamps will be mentioned in Section 3.3 of this guideline. Designers should base upon their requirements such as colour rendering requirements, colour temperature requirements as well as the energy efficiency requirements to choose the most appropriate type of lamps.

Maximum Allowable Lamp Controlgear Loss

The lamp control gear can consume electrical energy in form of heat dissipation and electromagnetic flux loss. A brief description of some major types of control gear was discussed in Section 3.3. The COP itself only sets out requirements for tubular fluorescent lamps and compact fluorescent lamps, which form the most important family of lighting equipment in indoor lighting. Generally speaking, energy efficient ballast and electronics ballasts should have no difficulty to comply with this requirement while standard ballasts may fall outside the limits.

Maximum Allowable Values of Lighting Power Density

This controls the maximum allowable power per square meter for lighting installation. The COP itself does not specify the illumination level such that appropriate flexibility can be remained for designers to specify the suitable illumination levels to suit their particular needs. Provided lighting equipment of suitable energy performance are used, the illumination level can be chosen to be on the high side or vice versa. However, the specification for this Lighting Power Density would add complication to designers as they should have to perform calculations before they could confirm that their designs are up to the requirement. Furthermore, there may be reiterations in order to rectify the lighting design in order to match with this requirement. Some architects prefer to use fix decorative lights in addition to general lighting (e.g. recessed uplight) to add features to the space. Thus designers should allow suitable margin in the LPD of the general lighting to make rooms for the installation of these decorative lights. Designers should also notice that this requirement is not applicable to the following indoor spaces:

- indoor space of restaurants;
- indoor space of shops;
- indoor space of department stores.

Another point worth notice for this requirement is the classification of indoor space. In the COP indoor spaces are mainly classified into :

- discrete space;
- multi-functional space;
- composite space.

The LPD calculations for each of these spaces are slightly different. Thus designers should pay full attention to the usage of the concerned indoor space, which may lead to different LPD requirement.

Interior Lighting Control

This requirement mainly specifies the lighting control point requirement for a lighting system. The clause 4.4.1 of the requirement is a rather generic as it only requirement that the lighting control point of a space should be located at positions which are easily accessible to the occupants. The subsequent clauses however, indicated the requirement for the number of control point for the three particular types of space:

- open plan office
- cellular office
- drawing office

2.2 Approach to comply with the Code Of Practice

2.2.1 General

For compliance with the COP, the requirements for the Minimum Allowable Luminous Efficacy and the Maximum Allowable Lamp Controlgear Loss are straight forward as these are only table look up jobs from the manufacturers' data. The requirement for Interior Lighting Control is also simple as it is only a matter of placing the operating switches for the lighting systems. All these requirements can be specified in the contract document and drawings well before tendering. The most difficult part of the COP itself should be the Maximum Allowable Values of Lighting Power Density. This parameter is a consolidated technical indicator of the lighting equipment's efficacy and the design illumination level. Designers can have a pretty large room to maneuver and obtain a balance point between these two dimensions.

The formulation of a lighting scheme that complies with the Maximum Allowable Values of Lighting Power Density may require reiterations on different alternative lighting schemes. This is the most time and effort consuming part of the COP. It is worth considering the use of microcomputer to carry out the tedious reiteration works so as to minimize the time and human effort required. Some CAD softwares in the market have the ability of putting luminaires on architectural layout plans automatically. This will provide a powerful and convenient tool for designers.

The procedures for calculation of the Lighting Power Density have been detailed in the COP. Further to the procedures, there are basically two approaches to ensure compliance to the Lighting Power Density.

The Forward Approach

This is the most straight forward approach. lighting designer first layout the light fittings to be used in according with the photometric performance of the luminaires. Then calculate the total circuit power, divided by the area of the space and compare with the value of Maximum Allowable Lighting Power Density given in the COP.

The 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 area under consideration and then multiply this value by the space area to obtain the maximum allowable installed power for the lighting system. The designer then obtain the maximum allowed number of fittings by dividing the maximum allowable installed power by the power consumption of the luminaires. This value is compared with the numbers of luminaire obtained by the basic lumen calculation method to see whether the lighting scheme will work or not.

2.2.2 Factors That Affect Lighting Power Density

The Lighting Power Density of a lighting system is a major control figure of the Code of Practice. This figure can be measured directly in-situ by using simple measuring equipment. The figure is in fact affected by a number of factors:

Choice of lamp type :-

This factor is one of the dominant factors for the Lighting Power Density as the lamp’s efficacy basically determined how efficient electrical energy is converted into light output. In general, designers should specify energy efficient lamp sources. For example, specify T8 fluorescent lamps rather than T12 lamps, use compact fluorescent lamps instead of incandescence lamps etc. Another side effect of low efficacy lamps is the amount of heat produced by the lamp 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 figures, it will increase the overall electricity consumption of the building.

Choice of lighting system and luminaire equipment :-

The Utilisation Factor is a characteristic of both the room and the luminaire equipment. 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:

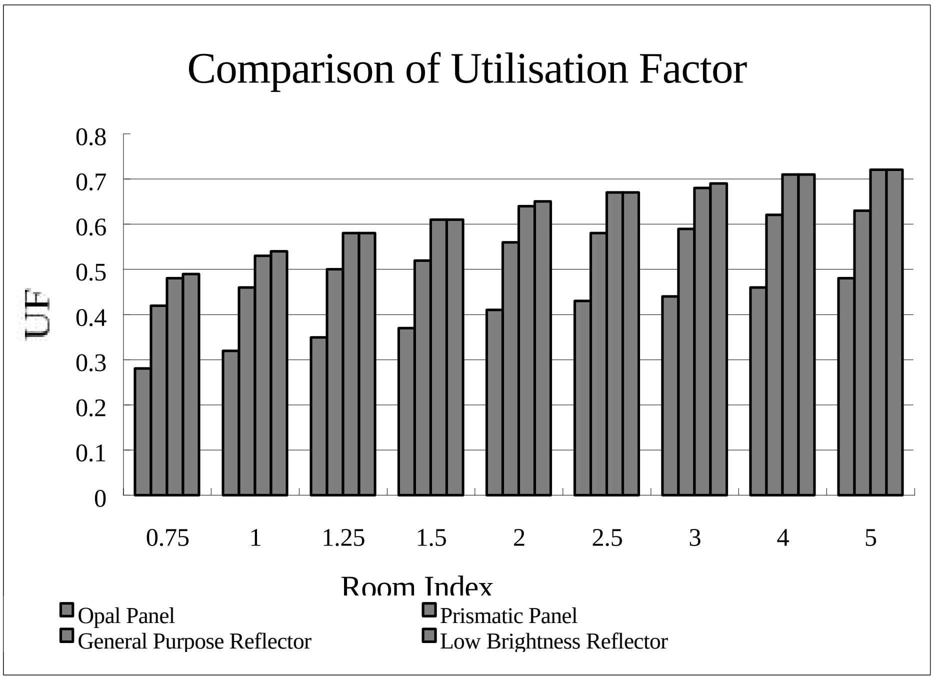


Figure 2.2.2a – Comparison of Utilisation Factor for Different Light Fitting

The above diagram indicated the Utilisation Factor for different option 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.

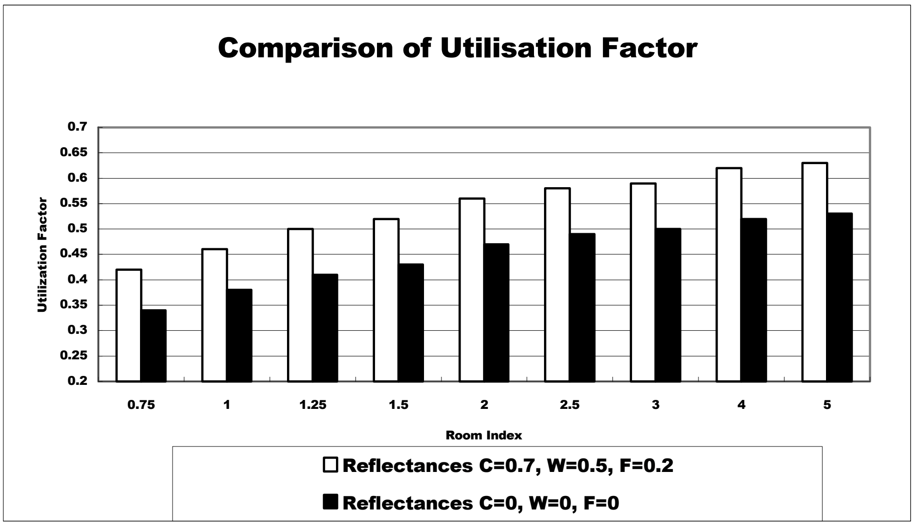


Figure 2.2.2b – Effect of Room Reflectances to Utilisation Factor

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 comparison 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 intended to use lamps of smaller power ratings which make the control gear loss power become a significant “overhead” of the luminaire’s total power consumption.

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 have to estimate 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 luminaire, lumen depreciation of lamp, burnt out of lamp, 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. This margin can be reduced provided there is suitable maintenance programme available. The 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, let’s consider the example in the Figure 2.2.2c:

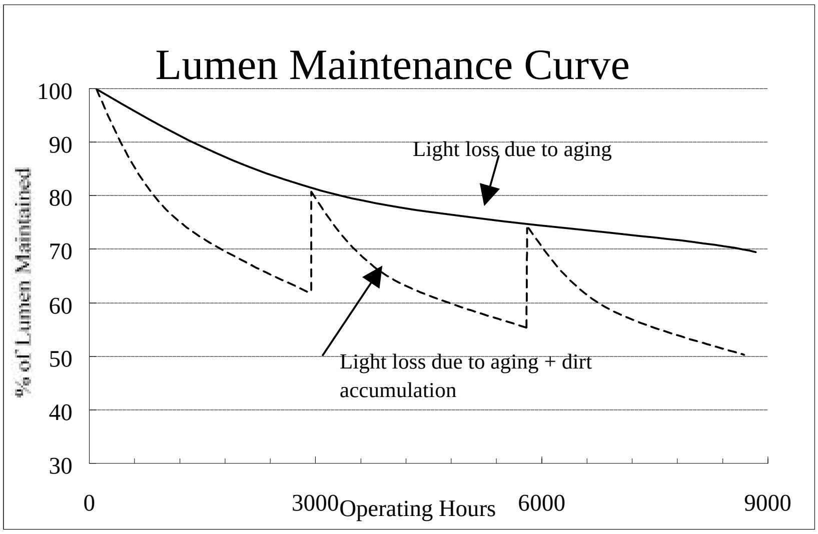
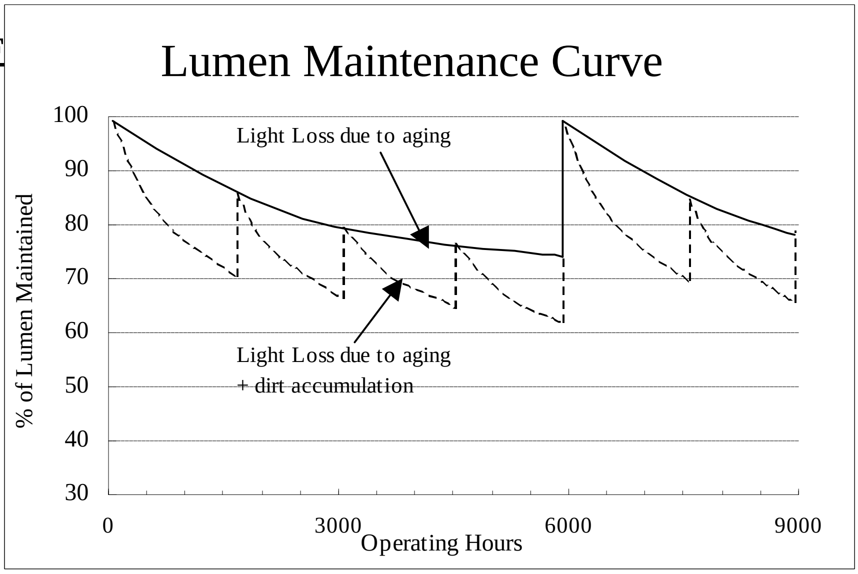


Figure 2.2.2c – Typical Lumen Depreciation Process

This example indicated that a lighting installation has a lamp aging characteristic of illuminance 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 dropped to about 50% of the output when in 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 illuminance depreciation is shown in Figure 2.2.2d.

The diagram indicated that at the end of 9000 operating hours, the maintained illuminance is about 65%, which is significantly higher, then 50% in the first maintenance arrangement. The worst maintained illuminance 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%.



<u>Figure 2.2.2d – Lumen Depreciation Curve with Alternative Maintenance Arrangement</u>

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 depend on the following factors:

- Type of premises:- The type of premises govern the operational needs of the lighting installation. Whether the requirement of maintaining the illumination level is stringent or loose, whether there is specific personnel to be responsible for the utilities management or not etc..
- Location of premises:- The location of the premises affects the rate of dirt accumulation on the light fittings.
- Usage rate of a particular space:- The 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:- The type of luminaire fitting affects the ease of accumulation of dirt, the loss of Utilisation Factor resulted, and the labour efforts required for the cleaning.
- Type of lamp:- Type of lamp govern the characteristic of the lumen depreciation as well as the nominal average lamp life of the installation.
- Electricity cost:- This is one of the key factors in the economic analysis of the maintenance schedule.
- Labour cost:- This is another key factor in the economic analysis.

2.3 Implementation framework of the Lighting Code

The Lighting Code will be implemented to the building industry, in particular the lighting and electrical industry, by the Electrical and Mechanical Services Department of the Government of the HKSAR. The implementation framework will initially be in the form of a voluntary self-certifying building registration scheme, known as "The Hong Kong Energy Efficiency Registration Scheme for Buildings". Details of the scheme including procedures, submission and registration format should be referred to the Practice Note of the Registration Scheme issued separately by the Electrical & Mechanical Services Department from time to time.

3. Guidelines for Energy Efficiency in Design of Lighting Installations

3.1 Factors Affecting Energy Consumption of Lighting Installations

The energy cost of a lighting installation depend on its *connected power (watts or kilowatts)* as well as its *operation time (hours)*. In general, 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.

3.2 General Principles of Achieving Energy Efficient Lighting Installations

Generally, the design criteria for improving energy efficiency of a lighting installation are as follows :

- 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 design criteria. Therefore, trade-offs among various design criteria are necessary.

3.3 Selection of Lighting Equipment

The various lamp types available in the market has a wide range of luminous efficacy (approximately 10 - 180 lm/W). From the standpoint of energy efficiency, it is recommended to choose light sources of the 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 become 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. 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 have the lowest range of lamp efficacies of the commonly used lamps. This would lead to the accepted conclusion that incandescent lamps should, generally, not be used for large area, general lighting systems where a more efficient light source can serve satisfactorily. However, this does not mean that incandescent lamps should never be used. There are many applications where the size, colour rendering, convenience, easy control and relatively low cost of incandescent lamps are suitable for specific applications.

General Service Incandescent (GLS) Lamps 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 its lumen output.

Tungsten Halogen Lamps (TH)

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 retain lumen outputs in excess of 95 % of initial values throughout their lifetime.

Tubular Fluorescent Lamps (MCF)

Fluorescent lamps now ranges from about 30 lm/W to near 90 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 become more and more energy efficient. The series of T8 fluorescent tubes is much more energy efficient than its predecessor the T12 fluorescent tubes while at the moment the more energy efficient T5 fluorescent tubes have already been on the way to the market.

Compact Fluorescent Lamps (CFN, CFG)

The recent 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 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 different in optical performance due to slight different 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 gain quite satisfactory colour rendering by mixed usage of high pressure sodium lamps and metal halide lamps in a 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 type of SON lamps, such as SONDL, SON-R, SON-TD etc. Similar to the case in MBI there is slight different in optical performance for each of these different type.

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.

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 then SON lamps.

3.3.3 Optical Characteristic of Major Types of Light Sources

The main optical characteristics for 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. You may notice that some light sources have appeared in more then one colour temperature range. This is because manufacturers have developed different types of lamp on the light sources that give slight different in colour temperature:

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

As this guide will mainly concentrate on energy performance, the colour rendering performance is briefly discussed in a qualitative manner only. 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

Due to the monochromatic light output of SOX, both colour temperature and colour rendering index are not applicable for this type of lamp.

3.3.4 Energy Characteristic of Major Types of Light Sources

Due to the different in 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 showed 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:

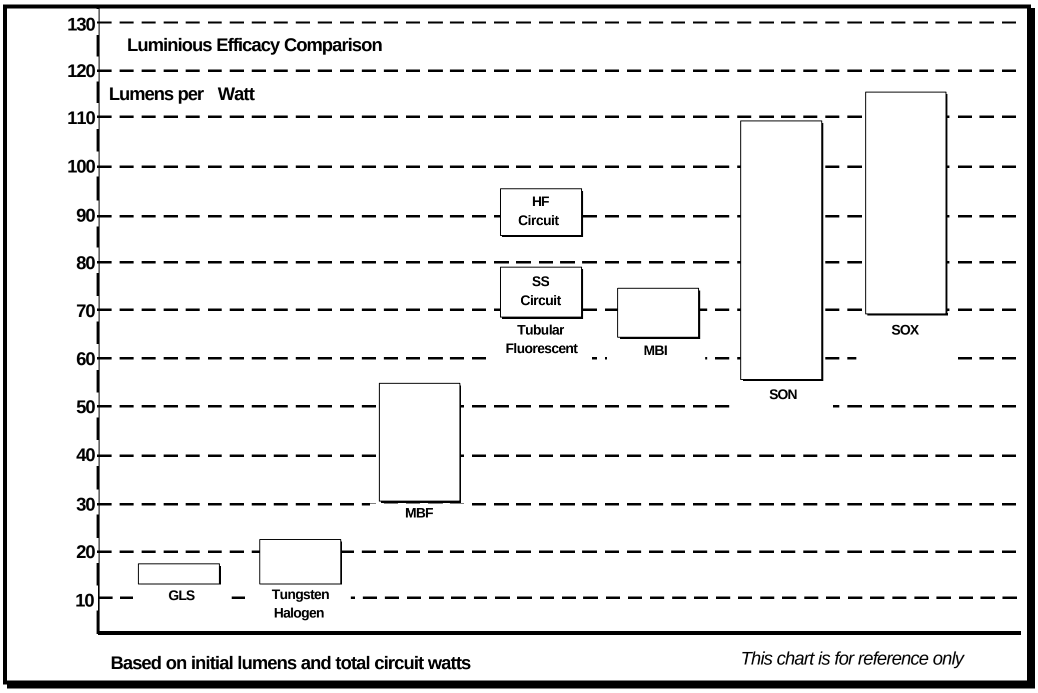


Figure 3.3.4a – Luminous Efficacy Comparison of Light Sources

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 on the actual lumen maintenance characteristic of the lamp source.

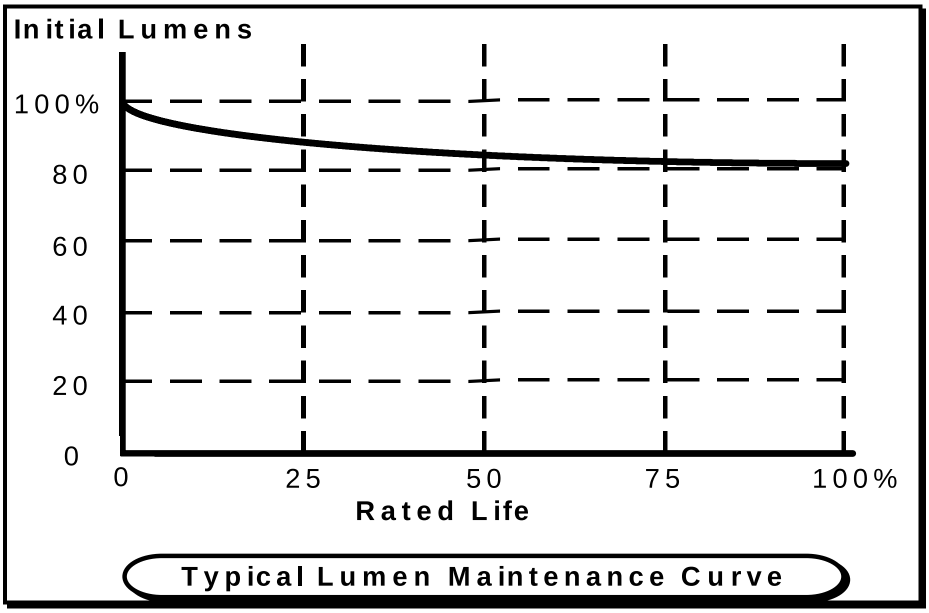


Figure 3.3.4b – Typical Lumen Maintenance Curve

In general the characteristic of some major types of lamp is that at the rated life of operation, SON usually depreciate to about 80%, MBI usually depreciate to about 60% and MBF usually depreciate to about 50% and MCF usually depreciate to 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 of Practice of Energy Efficiency Lighting Installations, which have been discussed in the previous sections of this guideline.

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. Thus, the efficiency of the ballast selected is important from an energy-saving standpoint. Many low loss ballasts are available for fluorescent lamps to provide higher operating efficiencies. Some provide 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 are usually consists 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 is 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 lower than that with electromagnetic ballasts. Another advantage of using electronic ballasts is the overall air conditioning load is reduced due to lower heat generation from the ballasts.

3.3.7 Energy Performance of Ballasts

In general electronics type ballasts have lower ballast loss then traditional electromagnetic ballasts. Most HID lamps use traditional electromagnetic ballasts because the power rating of HID lamps are usually large. In contrary, both electromagnetic ballasts and electronic ballasts are used in fluorescent lamps.

Electromagnetic ballasts used in fluorescent tubes mainly have two major types:

> **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 are often the lowest grade of ballasts that can comply with the requirement in Code of Practice for Energy Efficiency Lighting Installations.

Electronic ballasts usually have lower ballast loss in compare with electromagnetic ballasts. They also give opportunity for operating 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 showed a typical fluorescent lamp's output with respect to the operating frequency:

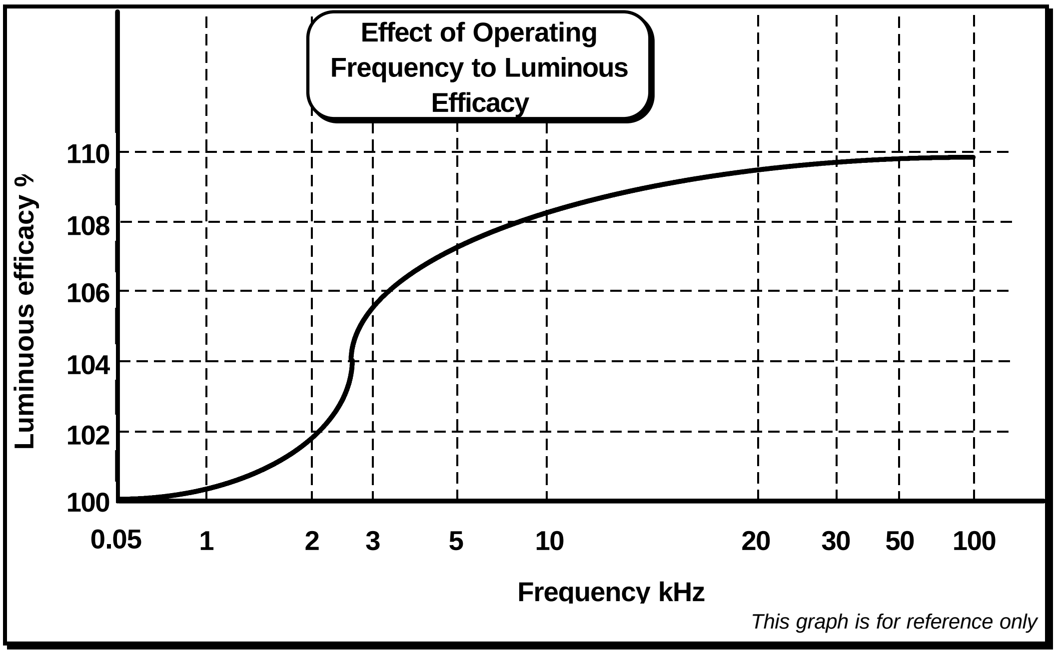


Figure 3.3.7 – Effect of Operating Frequency to Luminous Efficacy

It is worth notice that the efficacy of the lamp can be improved by about 10% when fluorescent lamps are operated at higher frequencies. The graph showed that the gain is less marked at a frequency in excess of 30kHz, thus in real world applications, electronic ballasts are usually operate at a range near this region. The improved efficacy of the lamps implies that the wattage required to produce 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. 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 do lead to higher losses in the whole supply network back to and including the generators. 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

The luminaire selected can have a significant impact on the energy efficacy of the lighting system as a whole. 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);
- lamp failure factor (LFF);

The method of calculating UF is detailed in CIBSE technical memorandum No.5. However, most of the 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 surface;
- the physical design of the luminaires;

Though the Code of Practice for Energy Efficiency of Lighting Installations 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 large number of luminaires required in the lighting system thus exceeding the Lighting Power Density limit.

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

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

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 the above equation, designer should also check the Space to Height Ratio of the luminaire to ensure the calculated system has an acceptable uniformity :

SHR AX x SHR TR	≤	$(\text{SHR MAX})^2$
SHR AX	≤	SHR MAX
SHR TR	≤	SHR MAX TR
SWT	≤	SHR TR/2
SWA	≤	SHR AX/2

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

The maintainability of the luminaries must be considered as it relates to power and energy efficiency. Generally, a luminaire is cleaned only when it is 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, dirts accumulate on the luminaire and the illuminance of luminaires will be greatly reduced. In the above equation, the LLF is mainly concerning 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

Power Quality will also affect the efficient usage of electrical energy. This factor received much lower attention in the past as the major source of illumination is incandescent lamps. With the increasing usage of more sophisticated lamp equipment that incorporate electronics switching devices, the power quality consideration should bear more consideration in a lighting system. In an alternating current circuit, the direction of current flow changes every half of the cycle. For example, the direction of current flow changes direction 100 times every second for a 50Hz main supply.

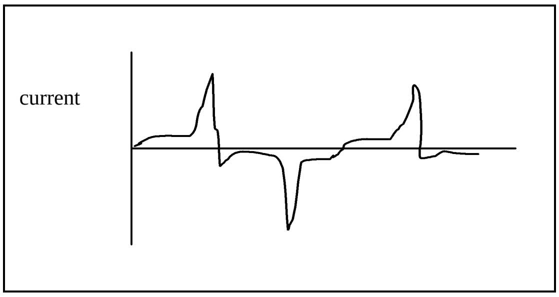


Figure 3.3.10a – Short Burst Current

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 also may be out of phase with the voltage waveform due to their inductive/capacitive 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.

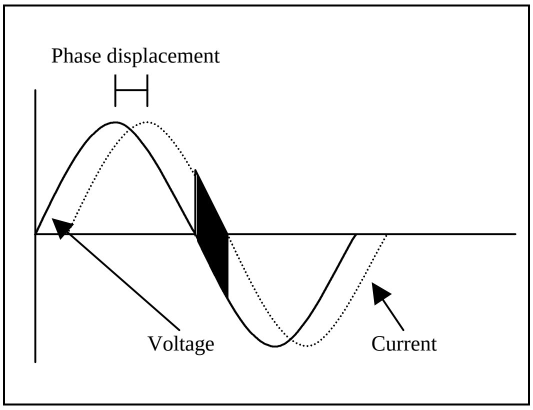


Figure 3.3.10b – Typical Lagging Current Waveform

Figure 3.3.10b on the left shows a typical case for a current waveform lags 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 call reactive power. The device produce 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 beyond 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.

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 harmonics filters to reduce harmonics and capacitors to correct power factors.

Poor power quality can damage the distribution system as well as the devices operating on 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 results 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%.

4. Guidelines for Energy Efficiency in Operation and Maintenance of Lighting Installations

Energy is the product of power and time. The factors that related to power or connected load of a lighting system has been 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 augment day lighting 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 is 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

The efficiency of a lighting system changes as the lamps get older and the luminaires become dirty. As time passes, it takes more energy to provide the required lighting level than when all lamps are new and the luminaires are clean. Poor maintenance will render the total light loss factor LLF as mentioned in Section 3 above. 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 when the lamp burnt out since it is labour consuming and the burnt out of lamp is more or less occurred in 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 noticed 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 be follows procedures and recommendations as recommended by relevant technical document.

4.4 Cleaning

Lighting energy is often wasted during the cleaning operations of commercial buildings. As there is large difference in the design illumination levels for office operations (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 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 cost. 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.

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;
- 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, 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 consist 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 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 exterior applications, it is necessary that timing of operation adjust 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 schedules. This technology does not reduce energy wasted during normal operating hours, so occupancy sensors can improve saving further.

Photocells

The use of photocells is popular for 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 now 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 have the following advantages:-

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

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 Microcomputer Control

A microcomputer-controlled lighting system can be a standalone system or part of the building automation system. It offers great flexibility of lighting controls. The typical control functions includes :

a. automatic daylights compensation control
b. automatic compensation for lamp lumen depreciation and luminaire dirt depreciation
c. scheduling of lighting operations to minimise the operating hours
d. fine tuning of lighting level to suit actual requirements

5 Guidelines for Energy Efficiency Retrofit Opportunities for Existing Lighting System

From economical point of view, retrofitting old 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:-
  - Reduce visual fatigue and absenteeism.
  - Reduces errors and improves work performance
  - Save time spent on redoing work.
- Better Quality Control:-
  - Decrease waste of source materials and energy due to lower error rate.
  - Increase 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
  - Reduce 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 ambiance for a given display.
  - Bring out colour and texture of fashions
  - Lends sparkle to crystal and jewelry
  - Reveals features, details, colours and wholesomeness of the display products.
  - Motivates larger quantity, higher-priced purchases.
  - Prompts confident buying decisions and reduces returns.
- Improved Visual Environment
  - Creates lively visual environment.
  - Improves working conditions.
  - Make image statement.
  - Establishes brightness variations that match merchandising objectives.
  - Lets customers enjoy and extend stay in stores.
  - Instills 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 kind of 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.

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:

- Ballasts for fluorescent lamps

  The T8 lamp/electronic ballast combination is practically the most popular choice available in market. Electronic ballasts are more 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. Three- and four-lamp ballasts reduce material and energy costs, as compared to two-lamp ballasts, because less units will be required. Less ballasts can also increase the overall system efficiency as the gear loss for a four-lamps electronic ballasts is typically less than the sum of the gear loss of four one-lamp electronic ballasts.

- Fluorescent lamps

  The T8/electronic ballast combination provides light levels comparable to the T12/magnetic ballast system while consuming up to 40% less electrical energy. Tri-phosphor coatings improve T8s' colour rend ering characteristics. Because T8s operate at a reduced current, they require a ballast that is designed for T8 lamp. 1.2m, 1.5m, 1.8m high-output T8 lamps offer 50% longer lamp life then the 1.2m T12 as well as greater efficacy.

  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 will soon be 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 less over a 10-year period. 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, the some may consider the use of halogen lamps, which are more efficient and last longer than standard incandescent.

While the T8 lamps are expected to play a crucial role in the coming future of the lighting industry, the new T5 lamps, which are more efficient, have started their way to the market place. However, retrofit of existing lighting to use the new T5 lamps will require the replacement of the luminaires also. Thus, it results in higher cost of retrofit and adds complication to the retrofitting work.

- Fluorescent luminaires accessories

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.

- High-intensity Discharge Systems

Metal halide and high pressure sodium 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. At the moment, nearly all high intensity discharge lamp ballasts are electromagnetic type, electronic ballasts are available but not very common in the market. They are smaller, weight less, and can improve colour control, improve average lamp life, but do not significantly increase system efficacy.

High-performance metal halide systems use a new kind of metal halide lamp and a dedicated magnetic ballast with a built-in starter. They offer up to 25% efficiency increase over standard 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 they have longer warm-up and restrike times as well as dimming limitations. However, they are usually not the most economical choice for retrofit.

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 now 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.

- Lighting Control

The simplest retrofit for lighting control is to provide lighting control switches at appropriate locations. For example, lighting control switches located to suit the layout of the office such that occupants can easily access and operate these switches.

Dimming and switching systems are highly recommended for the right applications. Though frequent switching decrease the hours of lamp operating life, effectively applied controls can increase the years of lamp calendar life, which is in fact what the owner have to pay for. Occupancy, or motion sensors are generally accepted as an effective energy-saving devices despite earlier problems caused by improper settings, placement or selection. Those factors are keys to occupancy sensor applications. 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, are not quite suitable. 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.

Wall-mounted units should be specified for smaller 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 sensors are also available. Another option is to provide personal control of fluorescent lighting with an infrared remote control that dims fixtures individually or in groups.

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 site 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.

6 Epilogue

The Code of Practice for Energy Efficiency Lighting Installation is the first Code of Practice concerning energy efficiency in Hong Kong. The requirements in the Code of Practice are basically simple and easy to follow even during the design stage of the installation. Data need for carrying out calculations and verifications can be readily found from the lighting equipment suppliers. The Code of Practice also features a flexible approach in controlling design aspects of the lighting installation by specifying only the Lighting Power Density. This allows room for designers to consolidate different design requirements in their system.

The direction to achieve energy efficiency lighting depends on both the technological factors and the operational factors of the system. Among these two factors, the operational factors should prevail the technological factors and being considered by building owners in first priority because efficient operation of the lighting system always improves energy efficiency and the cost for implementing good house keeping measures is usually lower then that for implementation of most of the technological measures. Although technologies are advancing at a rapid pace, it will require breakthroughs in lighting equipment in order to achieve a progressive improvement in equipment's energy efficiency performance. On the other hand, the advantage of energy efficient equipment may be offset by improper operation/maintenance or over design of the original system. For existing installations, new technologies have provided plenty of options to retrofit the installations into a more energy efficient installations with attractive payback period. Decision makers should always discern that money to be spent on improving energy efficiency is an investment rather than a cost.