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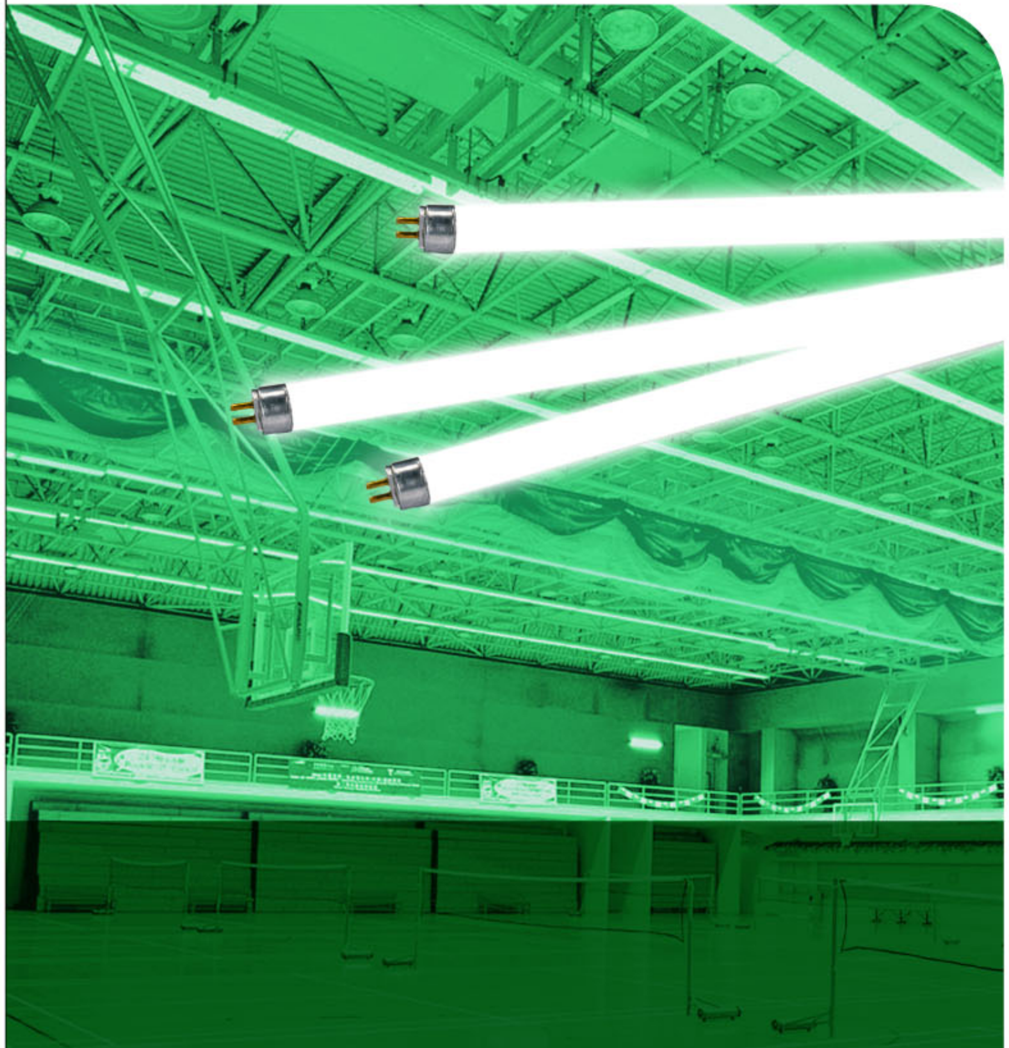

Guidelines on Energy Efficiency Equipment

T5 Fluorescent Lamps

EMSD

Content

Guidelines on Energy Efficiency Equipment

T5 Fluorescent Lamps

Introduction

The aim of this booklet is to provide general guidelines in adopting the new generation T5 (16mm diameter) fluorescent lamps together with appropriate electronic ballasts for use in fluorescent luminaires. The very small dimensions and weight of T5 lamps offer greater opportunities for luminaire design. The guidelines focus on the merits and demerits of luminaires with T5 lamps against those with conventional T8 or T12 lamps. Relevant background information and technical details of the new T5 lamps, T5 electronic ballasts and luminaires design for T5 lamps are covered. The results of some pilot projects using T5 luminaires carried out by Energy Efficiency Office (EEO) have also been included.

Technical Information of T5 Fluorescent Lamps

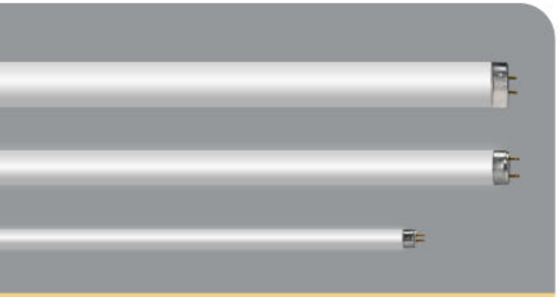

Figure 1 - Physical appearance of T12, T8 and T5 fluorescent lamps

The fluorescent lamp, or low-pressure mercury vapour lamp, is by far the most popular type of discharge lamp used for general lighting nowadays. It is employed almost universally, especially in office lighting. The introduction of compact fluorescent lamp has further led to its application in domestic buildings. The most common type of fluorescent lamp is tubular linear in shape ranged from 600mm (18W) to 1,500mm (58W) in length.

Basically, the linear tubular fluorescent lamp (Figure 1) has undergone three generations so far, which can be sub-divided as follows:

A. The 1st generation is T12 lamp with a diameter of 38mm (1.5") and with a length dictated by the wattage (20W, 30W, 40W and 65W). These so-called 'old' or 'fat/thick' lamps are stabilised by electromagnetic ballasts and have currently been replaced by T8 lamps in most of the cases. Efficacy is about 70 lm/W.

B. The 2nd generation is T8 krypton-filled lamp with a diameter of 26mm (1") and with a length dictated by the wattage (18W to 70W). These so-called 'thin' lamps can be stabilised by both electromagnetic and electronic ballasts with extra benefit of improved efficacy and lumen maintenance. Efficacy is about 80 lm/W. T8 lamps may be used as a direct replacement in T12 switch-start circuit.

C. The 3rd generation is the new T5 lamp with a diameter of 16mm (5/8") and G5 base. T5 lamps have been available in market with outputs of 4W, 6W, 8W and 13W for over 30 years. However, these lamp types were mainly used for furniture, signage and table lighting. A few years ago, however, advanced models of T5 lamps with higher wattage were developed. With their superior luminous efficacy of about 100 lm/W, fierce competition with the classical fluorescent counterparts was witnessed. The standard wattage of the advanced T5 lamps range from 14W, 21W, 28W to 35W. High output versions are also available for some special applications. Operated with high frequency electronic ballasts, these new lamp types fulfil the principle of cost-effectiveness. The slim shape of these T5 lamps contributes to the further reduction in casing dimensions, which paves the way for more innovative luminaire design. In addition, the length of T5 lamps is 50mm shorter than other T12/T8 models, with exact dimensions to be fitted into the usual grids (600mm and 1,200mm) of suspended ceilings.

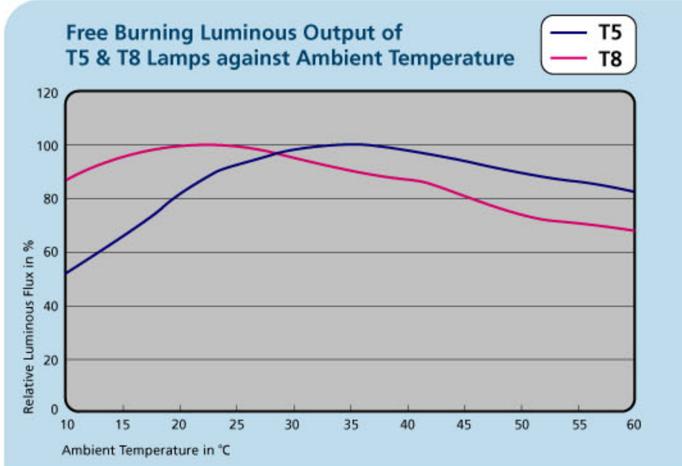

Figure 2 - Luminous flux versus ambient temperature for T8 and T5 lamps

The maximum light output from a fluorescent lamp occurs when the temperature of the coolest part of the lamp is about 40°C. This temperature is usually maintained in T8 lamp when it is operating at free air at an ambient temperature of 25°C. For T5 lamp, the maximum output occurs when its ambient temperature is 35°C. At these temperatures (Figure 2), the mercury vapour pressure is at optimum level for the generation of ultra-violet radiation at 253.7nm.

When a fluorescent lamp is operating inside a luminaire, its ambient temperature will rise. Typical values, as measured in our own offices, are an increase of 15°C and 10°C above room temperature for enclosed and open type luminaires respectively. At a room temperature of 25°C, the T5 lamps installed in a typical recessed modular luminaire with parabolic reflectors will be operating very close to their optimum ambient temperature of 35°C. However, precaution must be taken to avoid direct injection of cool supply air from the room AC system to the luminaires and T5 lamps. Similarly, T5 lamps should not be used in any air-handling luminaires where room return air at about 25°C is drawn through the lamps.

Electronic Ballasts for T5 Fluorescent Lamps

Unlike other T8 lamps, the new T5 lamps are specially designed for operating with electronic ballasts with greater efficiency.

Whether a fluorescent lamp can function at its optimum level or not depends primarily on the properties of the control gear used. It cannot work properly on the mains supply voltage and certain devices have to be incorporated into the lamp circuit. The control gear performs a number of functions:

- To limit and stabilise the lamp current.
- To ensure the lamp operates continuously during zero crossing of voltage at each half cycle.
- To provide ignition voltage for initial lamp starting.
- To supply controlled energy to pre-heat lamp electrodes during ignition.
- To fulfil other requirements such as ensuring high power factor, limiting harmonic distortion, suppressing EMI, limiting short-circuit and starting current, attaining long life, low losses and low noise level, etc.

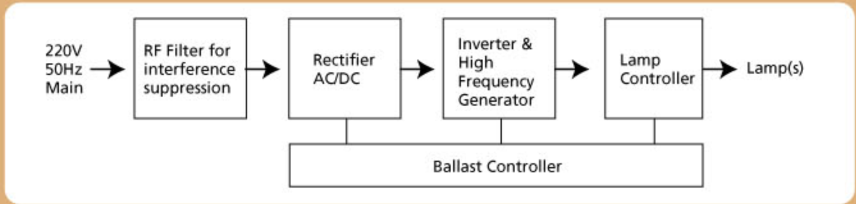

Figure 3 - Block diagram indicating main functions of electronic ballast

The basic construction of a typical electronic ballast involves a low-pass filter, rectifier, buffer capacitor and a high frequency oscillator (Figure 3). Although the electronic ballast system is integrated into one single 'black box', its different functions and requirements can be divided into a number of individual blocks. The basic operation principle is that after passing a low-pass filter, the mains voltage at 50Hz power frequency is rectified in an AC/DC converter. This converter also contains the buffer capacitor, which is charged with a DC voltage. In the HF power generator, this DC voltage is transformed into a HF voltage, which provides the power for the lamp controller. The ballast controller determines all these functions.

The ballast takes advantage of the unique feature of a fluorescent lamp whereby greater efficacy is obtained at high operating frequency of above 20kHz (Figure 4). The overall lighting system efficacy can be increased by 20 to 30 percents due to three main factors:

- Improved lamp efficacy at high frequency operation.
- Reduced circuit power losses.
- Lamp operates closer to optimum performance temperature in most luminaires (i.e. 25°C for T12 and T8, 35°C for T5).

Efficacy due to high frequency operation is increased by about 10% thereby enabling the lamp to be operated at a lower input power than at 50Hz mains power frequency. According to our test results for numerous electronic ballasts samples, a 36W 1,200mm T8 lamp normally consumes a total circuit power of 47W with conventional ballast. But when applying with electronic ballast, only 36W is consumed for the same light output. The net effect proves that in a typical luminaire, the same amount of useful light output is maintained at a comparatively lower input of power.

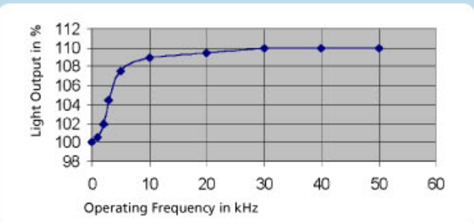

Figure 4 - Luminous flux of fluorescent lamp as a function of operating frequency

When comparing with an electromagnetic ballast, the ballast losses are further reduced as the solid-state circuit contains no conventional copper windings. Our test results reveal that for a single 1,200mm 36W lighting circuit, the losses can be reduced from 12W to a mere 3W. The overall achievement in a suitable luminaire, therefore, is an energy reduction in the region of 20% to 30%. These energy saving features enable the lighting level to be maintained but with a dramatic cut in electricity costs. In addition, with less heat generated, the cooling load on air conditioning equipment will also be reduced.

Luminaires for T5 Lamps

An important element in the design of luminaire is optical control. The purpose of optical design is to redirect the light from a bare source to the area where it is needed, to reduce the light in those zones where it may cause glare, and to provide a housing that is attractive in appearance while, if necessary, protecting the lamp. Opal diffusers, prismatic controllers and parabolic specular reflectors are the most common types of optical control used in fluorescent luminaires. In modern office buildings with intensive computer application, luminaires designed to CIBSE LG3, Cat. II (65° cut-off angle) are normally be specified in order to minimise the problem of reflective glare on computer monitors. Specular parabolic louvres finished in reflection-intensified aluminium are normally used for this purpose.

For fluorescent luminaires with T5 lamps, the most effective means of optical control is parabolic reflection. The parabola is the most commonly used reflector contour --- it is defined by the equation $y^2 = 4ax$ where a is the shortest distance of the focal point to the reflector. The most important optical property of the parabolic reflector is that if a line source is placed at its focus, a parallel beam of light is obtained. Figure 5 shows the beam of reflected light produced by a line source at focus of the parabolic reflector.

Parabolic Reflector

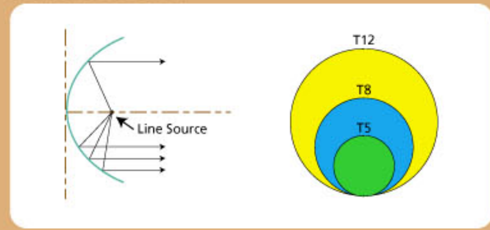

Figure 5 - Parallel beam produced by line source at focus of parabola & relative size of T12, T8 & T5 lamps

In practice the ideal line source is difficult to obtain from fluorescent tube and the shape of the distribution curve depends on the size of the source in relation to the focal length and mouth width of the reflector. As the diameter of T5 tube is much smaller than its T8 and T12 counterparts, and is more closer to a line source, optical control of luminaires with T5 lamps and parabolic reflector can be more precise and efficient.

Pilot T5 Lighting Project at 27/F, Arsenal House

Figure 6 - New 3x14W T5 lighting installation

The pilot project included the replacement of the existing 320 sets 3x18W T8 600mm x 600mm recessed modular fluorescent luminaires in the office areas on 27/F, Arsenal House, with new 3x14W T5 600mm x 600mm recessed modular fluorescent luminaries, completed with electronic ballasts (1 for 3 lamps type) and parabolic reflectors designed to CIBSE LG3, Cat. II. The new T5 luminaires installed in the office areas is shown in Figure 6.

Table 1 and Figure 7 show the test data of the existing 3x18W T8 luminaire removed from site

			Voltage	Current
Frequency	50Hz	RMS	223.4 V	0.754 A
Power:		Peak	312.7 V	1.095 A
Active (P)	90W	DC Offset	0.2 V	-0.02 A
Apparent (Q)	168 VA	Crest Factor	1.4	1.45
Reactive (R)	142 var	THD Rms	2.23%	8.80 %
Peak W	244 W	THD Fund	2.23%	8.84 %
Phase	58° lag	HRMS	5.0 V	0.66 A
Total PF	0.53	KFactor		1.51
DPE	0.53			

Table 1 - Electrical parameters of the old 3x18W T8 luminaire

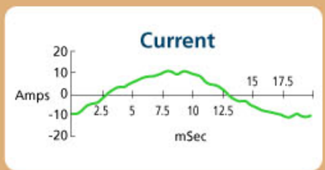

Figure 7 - Current waveform of the old 3x18W T8 luminaire

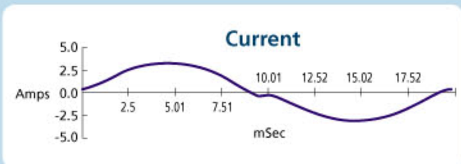

Figure 8 - Current waveform of the new T5 luminaire

Table 2 and Figure 8 show the test data of the new 3x14W T5 luminaire used in the project.

			Voltage	Current
Frequency	50Hz	RMS	221.8 V	0.22 A
Power:		Peak	308.5 V	0.316 A
Active (P)	48 W	DC Offset	0.0 V	-0.03 A
Apparent (Q)	49 VA	Crest Factor	1.39	1.44
Reactive (R)	7 var	THD Rms	2.30%	8.60 %
Peak W	98 W	THD Fund	2.30%	8.63 %
Phase	8° lead	HRMS	5.1 V	0.19 A
Total PF	0.99	KFactor		1.19
DPE	0.99			

Table 2 Electrical parameters of the new 3x14W T5 luminaire

Measurement on site before the lighting retrofit indicated that the floor had a total lighting load of 28kW and an average daily energy consumption of 470kWh. Each of the existing 3x18W T8 luminaire consumed 90W at a power factor of 0.53. Table 3 summarises the performance of the new T5 lighting installation as compared with the old lighting system.

	Existing T8 Lighting System	New T5 Lighting System	% Difference
Active Power (kW)	28 kW	16 kW	- 42 %
Power Factor	0.53	0.99	+ 87 %
T. H. D.	11 %	8.6 %	- 21.8 %
Apparent Power (kVA)	52.8 kVA	16.2 kVA	- 69 %
Reactive Power (kvar)	23.7 kvar	2.3 kvar	- 90 %
Average Illuminance	450 lux	500 lux	+ 11 %
Lighting Power Density	30 W/m^2	18 W/m^2	- 40%

Table 3 - Summary table for the lighting retrofit at 27/F Arsenal House

Based on the measurement results, the following remarks could be drawn for this pilot T5 lighting retrofit project:

- The average daily lighting energy consumption measured on site before retrofit was 470kWh. The average measured daily lighting energy consumption after retrofit was 270kWh. An annual energy saving of 55,000 kWh is anticipated per floor.
- The power factor of the lighting circuits was greatly improved from 0.53 to 0.99, resulting in lower circuit current, less reactive power, smaller distribution loss and possible saving in demand charge under bulk tariff.
- The reduction in reactive power of the lighting load in this floor is 21.4 kvar. The reduction of reactive power for the whole building will be 642 kvar if all 30 storeys of offices/workshops are retrofitted with new T5 luminaires. This would eliminate the requirement to add extra capacitor banks at the main distribution board for power factor correction.
- The average lighting power density before retrofit was 30 W/m^2, which has exceeded the maximum 25 W/m^2 as stipulated in the Lighting Code. The new lighting power density after retrofit was 18 W/m^2.
- There was also a slight reduction in Total Harmonic Distortion (THD) of current, causing fewer problems to the power quality of the building.
- Due to the improvement in the design of parabolic reflector and the more linear T5 light source, the utilisation factors of the new luminaire is higher. The average illuminance measured after retrofit was 500 lux, which was 11% brighter than that of the original lighting installation.

T5 Lighting Retrofit at Government Offices, Citibank Plaza

The new retrofit government offices on 9th to 10th floor at Citibank Plaza were selected as the second pilot T5 lighting project. The adoption of the new generation of T5 fluorescent lamps together with appropriate T5 electronic ballasts in the specially designed air-handling fluorescent luminaires provided many energy efficiency features. The new lighting installations increased illumination at the working plane from 500 lux to 700 lux and at the same time consumed 38% less energy than their T8 counterparts with conventional lamps and electromagnetic ballasts. Intelligent lighting control was also included in some offices along the perimeter with digital control technology for dimming and occupancy sensing. The scope of work consisted of the following:

- Retrofitting of about 600 sets of 2x28W T5 luminaires (designed to CIBSE LG3, Cat. II) with 2x28W T5 electronic ballasts for office lighting.
- Installation of 70 sets of T5 batten luminaires for indirect ceiling and cabinet lighting.
- Installation of 50 sets of compact fluorescent down-lighters with electronic ballasts in meeting rooms.
- Installation of intelligent lighting control system at five senior staff offices.

Tests were carried out on the existing 2x36W T8 luminaire removed from site. The luminaire was controlled by conventional ballasts and electronic starters with 8uF power factor correction capacitor. The test results are indicated in Table 4 and Figure 9.

			Voltage	Current
Frequency	50Hz	RMS	225.6 V	0.488 A
Power:		Peak	314.0 V	0.686 A
Active (P)	98 W	DC Offset	0.0 V	-0.03 A
Apparent (Q)	110 VA	Crest Factor	1.39	1.41
Reactive (R)	46 var	THD Rms	2.67%	22.46 %
Peak W	213 W	THD Fund	2.67%	23.04 %
Phase	25°lag	HRMS	6.0 V	1.10 A
Total PF	0.89	KFactor		3.53
DPE	0.90			

Table 4 - Test results of the existing 2x36W T8 luminaire

Figure 9 - Current waveform of the existing luminaire

The new 2x28W T5 luminaire completed with single electronic ballast has also been tested. The test results are shown in Table 5 and Figure 10 below.

			Voltage	Current
Frequency	50Hz	RMS	225.8 V	0.284 A
Power:		Peak	316.0 V	0.434 A
Active (P)	60 W	DC Offset	-0.1 V	-0.03 A
Apparent (Q)	64 VA	Crest Factor	1.4	1.53
Reactive (R)	20 var	THD Rms	2.71%	13.70 %
Peak W	134 W	THD Fund	2.71 %	13.83 %
Phase	18° lead	HRMS	6.1 V	0.19 A
Total PF	0.95	KFactor		1.52
DPE	0.95			

Table 5 - Test results of the new luminaire

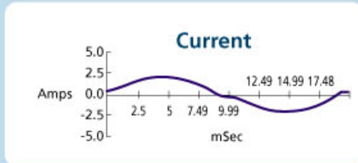

Figure 10 - Current waveform of the new T5 luminaire

	Existing T8 Lighting System	New T5 Lighting System	% Difference
Active Power (kW)	34 kW	23 kW	- 32 %
Power Factor	0.89	0.99	+ 11 %
T. H. D.	23 %	10 %	- 53 %
Apparent Power (kVA)	38 kVA	23 kVA	- 39 %
Reactive Power (kvar)	17 kvar	3.2 kvar	- 81 %
Average Illuminance	500 lux	700 lux	+ 40 %
Lighting Power Density	27 W/m^2	17 W/m^2	- 37%

Table 6 - Summary table for the lighting retrofit at the new Government Offices

Table 6 highlights the performance of the new T5 lighting system as compared with the existing T8 lighting system installed in the new Government offices. The energy saving potential as well as improvement in other electrical parameters of T5 lamps are very obvious.

Design Considerations for T5 Lighting

A. The new range of T5 lamps were developed for higher system efficiency and miniaturisation. With appropriate luminaire and parabolic reflector design, the T5 lamp offers higher utilisation of the available light on the working plane. As far as energy saving is concerned, the 28W T5 luminaire consumed only 30W circuit power and achieved a saving of 36% as compared with 36W T8 luminaire with conventional ballast.

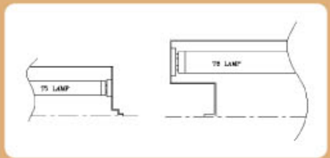

Figure 11 - Recessed 50mm modular T5 luminaire (left) and100mmT8 luminaire with extruded endbox (right)

B. The T5 lamps are specially designed for high frequency operation with electronic ballasts for higher efficiency and longer life (15,000 hrs.). Their shorter lamp length and thinner diameter (closer to a line source) give more luminaire design possibilities and they can be easily fitted into the common ceiling module systems (e.g. 600mm x 600mm, 600 x 1200mm, etc) without protruding into the adjacent ceiling grid. Figure 11 shows the differences in length and depth between a typical T5 luminaire and T8 luminaire with and without an extruded endbox recessed into the suspended ceiling.

C. Physically, T5 recessed modular luminaires is much slimmer and can fit exactly into the standard ceiling grid without occupying additional adjacent space. Co-ordination of services at the suspended ceiling is easier where air grilles could be mounted directly at the end of the luminaire or luminaires can be run in a continuous row.

D. Harmonic distortion is a major concern of T5 tube application. As special electronic ballasts with non-linear electronic converters and high frequency oscillator are used for T5 lamp operation, harmonic filtering must be incorporated in the ballast to reduce the current harmonic distortion, especially third harmonic, in order not to affect the power quality of the existing distribution system. All T5 electronic ballasts specified should meet the minimum requirements as stipulated in IEC1000-3-2 "Limits for harmonic current emission (equipment input current < 16A per phase)".

E. The current that flows during the first few milliseconds when switching on a luminaire or an entire lighting installation is called the inrush current. For the same lamp wattage the inrush current of electronic ballast is in principle higher than that of conventional ballast. Provided that no more than 10 luminaires with electronic ballasts are controlled by a 10A lighting switch and a 10A type C MCB, no special provision is required to be made for inrush current at starting.

F. The power factor of conventional and low loss ballasts can be as low as 0.4 without capacitor for reactive power compensation. Most electronic ballasts nowadays have a displacement power factor approaching unity and a total power factor above 0.95.

G. The adoption of T5 tubes in fluorescent luminaires for new projects could have instant effect of reduction in energy and demand charge in electricity bill. It could also meet the requirements for participation in the power companies' Demand Side Management (DSM) programmes for non-residential sector and support the global issue of reducing green house gas emission in electrical power generation.

H. From the economic point of view, the material cost of T5 luminaires is about 15% more expensive than the conventional T8 luminaires for new projects. The higher initial cost of the T5 luminaires could easily be compensated via enhanced performance such as high efficacy, high utilisation factor, long lamp life, less heat dissipation, reduced energy and demand charge, etc.

I. The reliability of electronic ballasts might be the major concern for the project engineers specifying T5 luminaires. From the technical point of view, it is advisable to specify electronic ballasts in accordance with the relevant particular specifications to ensure quality of the products.

J. For T5 luminaires operating on electronic ballasts, the electromagnetic compatibility (EMC) problem is basically determined by the characteristics of electronic ballast in combination with the luminaire design. As far as EMC is concerned, the following technical aspects and basic rules have to be considered when incorporating electronic ballasts in luminaires:

- Effective protective earth must be provided for all exposed conductive parts of the metal luminaire.
- Functional earth is required to fulfil certain EMC requirements or to guarantee proper operation of the system.
- Ensure a firm electrical connection between the electronic ballast and the metal luminaire.
- Mains power wiring and lamp wiring inside luminaire must be as short as possible, firmly mounted on spacers and far away from each other to minimise stray capacitance.
- Provide good electrical contact between metal luminaire and reflector and/or louvre. Reflector and louvre serve as a shielding around the lamp.

K. Similar to T8 luminaires, various designs of T5 luminaires with different optical control and IP ratings are also available in the market. They could be selected to suit various applications and lighting environment of any new lighting projects.

L. For those lighting installation using low brightness T5 luminaires designed to CIBSE LG3, Cat. II (for use in room with visual display units or computer monitors), the ceiling and walls might appear darker and consideration might be required to include some down-lighters with CFL lamps for wall washing purpose.