Induction Lamps Installations at Kowloon Bay Indoor Games Hall

Ir. Martin WU Kwok-tin

Energy Efficiency Office, Electrical & Mechanical Services Department

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Executive Summary

As part of the Pilot Energy Management Opportunity (EMO) Implementation Programme using innovative energy efficient equipment, Energy Efficiency Office (EEO) of Electrical and Mechanical Services Department (EMSD) has completed a pilot project in March 2003 using the latest induction lighting technology in Squash Court No. 2 at Kowloon Bay Indoor Games Hall. The work covered the supply and installation of four new high-bay luminaries, completed with 2 nos. 150W induction lamps and electronic ballasts, to replace the existing six 250W metal halide high-bay luminaries in the squash court. The new induction lamps are actually fluorescent lamps without any electrodes for electrons emission. Because of the electrodeless property, induction lamps have extreme long life and the lifetime of the system is determined primarily by the lifetime of the ballast (i.e. 60,000 hours). Preliminary test results indicated that the power consumption of the squash court reduced from 1.65 kW to 1.25 kW and the average illumination increased from 470 lux to 710 lux. Other advantages of the new induction lighting system include instant flicker-free starting and restrict, higher colour rendering index (>80), lower luminous depreciation and less maintenance requirements due to a much longer lamp and equipment life. The estimated payback period lies within 5 to 8 years.

1 Introduction to Induction Lamps

Induction lamps are high frequency (HF) light sources, which follow the same basic principles of converting electrical power into visible radiation as conventional fluorescent lamps. Fig. 1 below shows the operating principle of a fluorescent lamp.

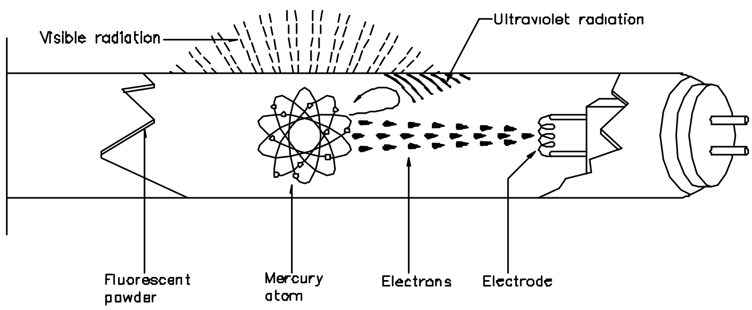

Fig. 1: Basic operating principle of conventional fluorescent lamp

The fundamental difference between induction lamps and conventional lamps is that the former operate without electrodes. Conventional fluorescent lamps require electrodes to connect the discharge plasma to an electrical circuit and inject electrons into the plasma. Fluorescent lamps normally operate on ac current at a frequency of 50 Hz or at HF of 40 to 100 kHz when driven by electronic ballasts. Thus, each electrode operates for one-half period as a cathode and the other half period as an anode. The production of electrons from electrodes is due to thermionic emission. The presence of electrodes in fluorescent lamps has imposed many restrictions on lamp design and performance and is a major factor limiting lamp life.

Induction lighting is based on the well-known principles of induction and light generation via a gas discharge. Induction is the energy transportation through magnetism. Practical examples are transformers, which consist of ferrite cores or rings with primary coils and secondary rings via the mercury vapour inside the lamps. Fig. 2 and Fig. 3 show two typical induction lamp types, and their principle of operation, which are commercially available nowadays. An alternative current I_p through the primary coil induces an alternative magnetic field in the ferrite core or coil. The alternative magnetic field in turn induces an alternative secondary current in the secondary coil or ring (I_s). The efficiency of the lamp is proportional to the operating frequency of the driving alternative current.

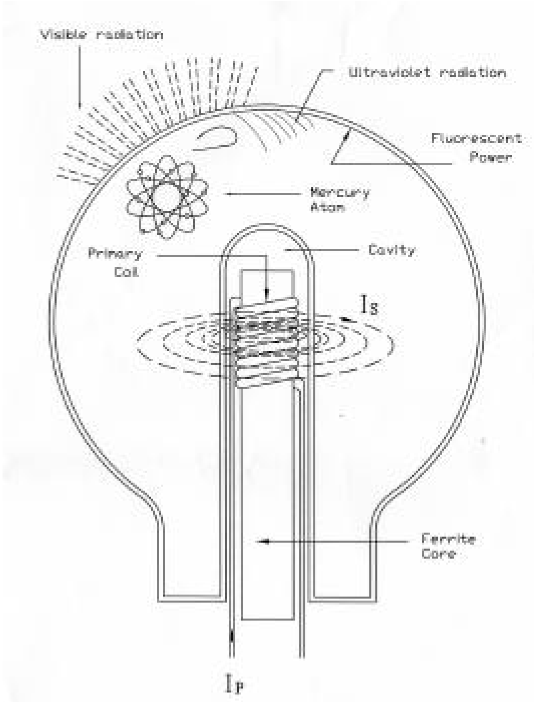

Fig. 2: Cavity Type Induction Lamp

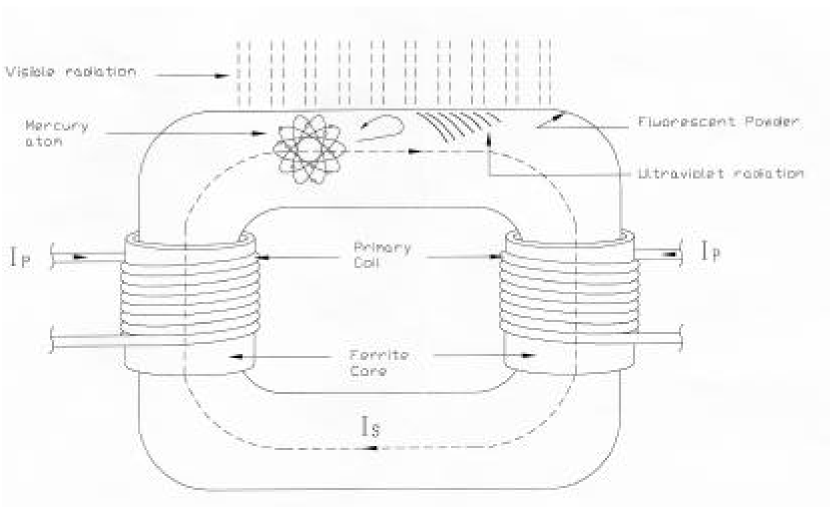

Fig. 3: External-coil Type Induction Lamp

The mercury vapour inside the induction lamp can be regarded as the secondary coil of the system and the induced current circulate through the vapour causing acceleration of free electrons, which collide with the mercury atoms and bring electrons to a higher orbit. Electrons from these excited atoms fall back from this higher energy state to the lower stable level and consequently emit ultraviolet radiations. The UV radiations interact with the fluorescent powder coated inside the lamp and convert to visible light.

2. Advantages of Induction lamps

The loss of cathode emission materials, due to evaporation and sputtering caused by ion bombardment, limits the life of fluorescent lamps to between 5,000 to 15,000 hours, while the life of some induction lamps on the market today reaches 100,000 hours. This makes it beneficial to use such lamps in applications where lamp maintenance is expensive (e.g. decorative lighting on top of the suspension rope of Tsing Ma Bridge using Philips QL 85W induction lamp (Fig. 4 & 5)).

Fig. 4: Induction lamps used on ropes and bridge sides in Tsing Ma Bridge

The elimination of electrodes and their power losses opens up unlimited possibilities in the variety of possible lamp shapes and increases their efficiency respectively. The present of hot electrodes limits the fill gas pressure and its composition to avoid chemical and physical reactions that destroy the electrodes. There is no such restriction in induction lamps, where gas pressure is optimised for maximum efficiency.

As far as lamp rating of fluorescent lamp is concerned, cathode emission takes place from a tiny spot heated by the discharge current, which cannot be over 1.5A – this limits the maximum power rating and light output of these lamps (e.g. the highest rating of high output T5 lamp is 80W). For induction lamps, there is no such restriction and rating of lamp could be up to 150W (e.g. 150W Osram Endura long life lamp as shown in Fig. 6). Theoretically, induction lamps have instant and harmless starting and are more convenient for dimming, as maintenance of high cathode temperature during dimming is no longer required.

Fig. 5: Philips QL 85W Induction Lamp

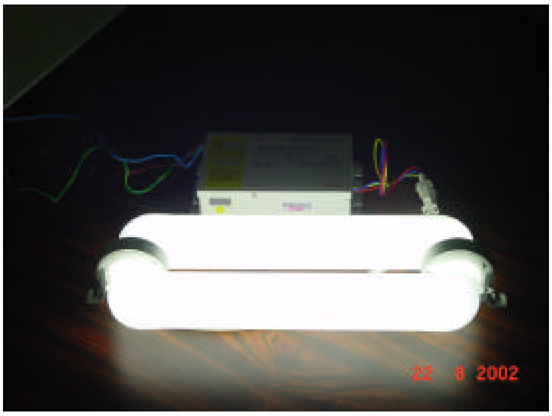

Fig. 6: Osram 150W Endura Induction Lamp

3. Types of Induction Light Sources

There are several commercial available induction lamps in the lighting market nowadays. The development of induction lamps involve decades of effort in researches on relevant gas discharge physics, solid-state physics, material science and electronic ballasts. The outcome is to bring the induction lighting concepts to engineering and eventually to commercial products in the 1990s.

3.1 Separate-ballasted Cavity Induction Lamps

The cavity design has the advantage of reassembling the shape of an incandescent lamp. The cavity at the centre of the lamp is used to accommodate the induction core and coils (Fig. 2 & Fig.7).

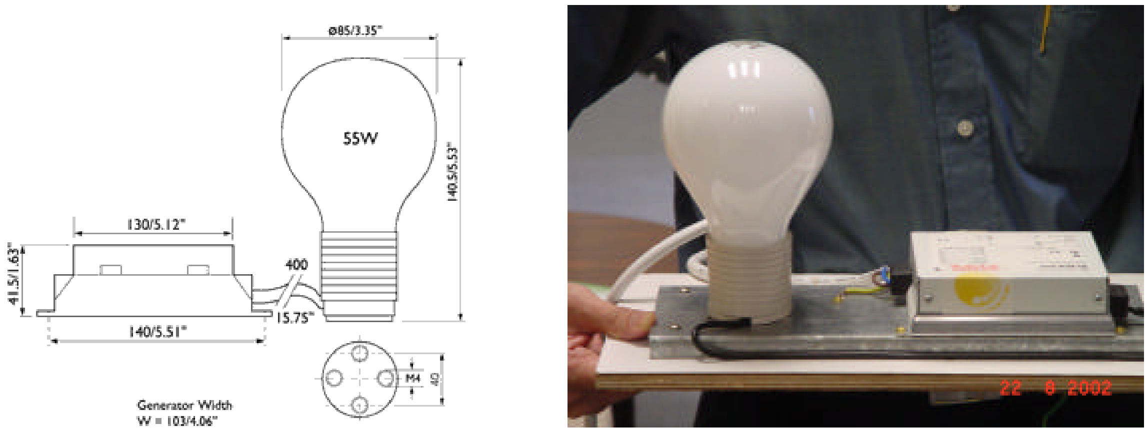

Fig. 7: Separate-ballasted cavity induction lamp

This electrodeless fluorescent induction lamp operates at 2.65 MHz with system power 55W and an efficacy of about 70 lm/W. The 2.65 MHz is specifically allocated in according to IEC regulations, for industrial application as radio frequency lighting devices. Lamps having the higher rating of 85W and 165W are also available for application where high intensity lighting is required. The lamp is filled with argon at 0.25 Torr. Mercury pressure is controlled by two amalgams: one is for lamp starting and the other maintain optimal mercury pressure over a wide range of ambient temperature. The induction coil of the lamp is wound on a ferrite core and is housed within the lamp cavity. The ferrite core has an internal copper conductor rod connected to the lamp base for cooling of the induction cool and cavity. These lamps are driven by remote ballasts connected to the lamps by coaxial cables.

3.2 Self-ballasted Cavity Induction Lamps

Another version of cavity induction lamp is designed to integrate the RF generating ballast into the lamp (Fig. 8). This kind of induction lamp looks similar to a compact fluorescent lamp and could be used to directly replace an incandescent reflector lamp with much higher efficacy and longer service life. The lamps operate at the same frequency of 2.65 MHz but have lower lamp power of 23W at 48 lm/W efficacy, and the lamp life is rated up to 15,000 hours. EMI is the major restriction of using these lamps in sensitive areas and significant efforts have been made for suppressing magnetic and electric components to comply with existing EMC regulations. The cost of the lamp is over HK$400 at the moment and is relatively much higher than those of tungsten and compact fluorescent lamps.

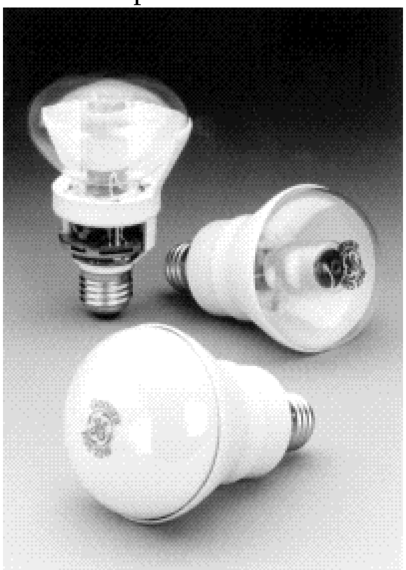

Fig. 8: Self-ballasted Cavity Induction Lamp

3.3 External-coil Induction Lamps

The external-coil induction lighting system is shown in Fig. 3 and Fig. 9. The likeness to a standard transformer of this lamp is more apparent than for any other induction lamps. The lamp is made from a 54 mm diameter tube encircled by two closed ferrite cores. The lamp rating available are 75W, 100W and 150W at an efficacy of 80 lm/W. The designed operating frequency is 250 kHz only, which is not governed by the radio frequencies allocated for industrial applications such as 2.65, 13.56, 27.12 and 40.68 MHz. The decrease in working frequency has reduced EMI problems, ballast complexity, and cost as compared to other induction lamps working at 2.65 MHz.

Due to the closed magnetic path of the ferrite cores, the power-transfer efficiency and efficacy of this lamp are extremely high; they are 98% and 80 lm/W respectively. The rated life of this induction lighting system is 60,000 hours, which is determined by the life of electronic ballast but not the lamp. The high system efficiency is achieved by the distributed power deposition along the lamp in contrast with the cavity induction lamp where power transfer is localised around the coupling induction coil, causing local thermal stress and overheating that limits maximum lamp power.

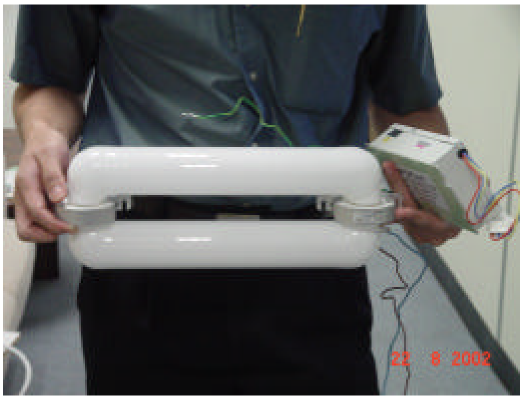

Fig. 9: External-coil induction lamp

4. Case Study of Induction Lamp used for Squash Court Lighting

The Energy Efficiency Office (EEO) of Electrical and Mechanical Services Department (EMSD) has recently completed a pilot project using the latest induction lighting technology in Squash Court No. 2 at Kowloon Bay Indoor Games Hall. The work covered the supply and installation of four new high-bay luminaries (Fig. 10 & 12), completed with 2 nos. 150W external-coil induction lamps and electronic ballasts, to replace the existing six 250W metal halide high-bay luminaries (Fig. 11) in the squash court.

Fig. 10: New high-bay luminaire with 2x150W external-coil induction lamps

Fig. 11: Existing HID lighting system

Fig. 12: New induction lighting system

Installation works of the new induction lighting system completed in March 2003. Measurements have been done on site for assessing its energy and visual performance. Fig. 11 and 12 highlight the differences in visual environment between the two lighting systems. Improvement is very obvious in terms of illuminance and colour rendering of the squash court.

4.1 Energy Performance

Energy performance of the two lighting systems was measured on site in March 2003. The measured results were summarised in Table 1. It was found that the total power reduction for the new induction lighting system was about 400W (i.e. -24%) and improvement in current THD was also very apparent (reduced from 36.7% to 5.7%). As the squash court is fully air-conditioned, reduction in heat gain from lighting would also decrease cooling load of the AC plant. The estimate reduction in cooling load would be about 30% of the reduced lighting load (i.e. 120W).

Table 1: Energy Performance of the Existing HID and New Induction Lighting Systems

	Existing HID Lighting System	New Induction Lighting System	% difference
Lighting Power (W)	1650 W	1256 W	- 24%
Average Illuminance	471 lux	712 lux	+51%
Power Factor.	0.91	0.98	+ 7.7%
Current THD	36.7%	5.7%	- 84%

Table 2/Fig. 13 and Table 3/Fig. 14 below show test results of individual 250W metal halide lamp and 150W induction lamp respectively. Other than improvement in energy saving, it is obvious by comparing the two current waveforms that induction lamp achieved less distortion and had less adverse effect in the power quality problems nowadays.

Table 2: Test results of the existing 250W metal halide lamp operating on conventional magnetic ballast

			Voltage	Current
Frequency	50 Hz	RMS	220.4V	2.29A
Power:		Peak	306.5V	1.37A
W	275W	DC Offset	0.0	-0.03
VA	302VA	Crest Factor	1.39	1.67
var	125var	THD rms	2.30%	34.45%
Peak W	460W	THD fund	2.30%	36.70%
Phase	14° lag	H rms	5.1V	0.46A
Total PF	0.91	KFactor		8.96
DPF	0.97			

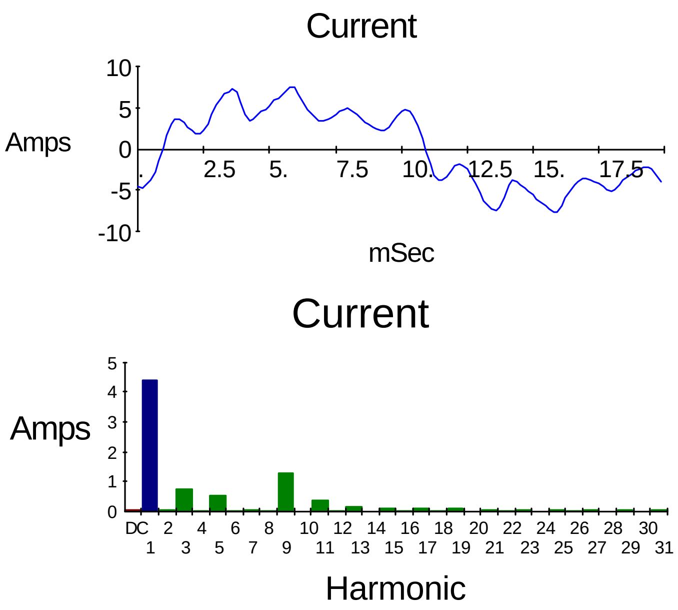

Figure 13 - Current waveform and harmonic content of 250W metal halide lamp

Table 3: Test result of a single 150W induction lamp driven by electronic ballast

			Voltage	Current
Frequency	50.05 Hz	RMS	223.6	0.718 A
Power		Peak	311.1	1.051 A
W	157 W	DC Offset	0.0	-0.001 A
VA	161 VA	Crest Factor	1.39	1.46
var	33 var	THD rms	2.79 %	5.68 %
Peak W	316 W	THD fund	2.79 %	5.69 %
Phase	12° lead	H rms	6.2 V	0.41 A
Total PF	0.98	KFactor		1.12
DPF	0.98			

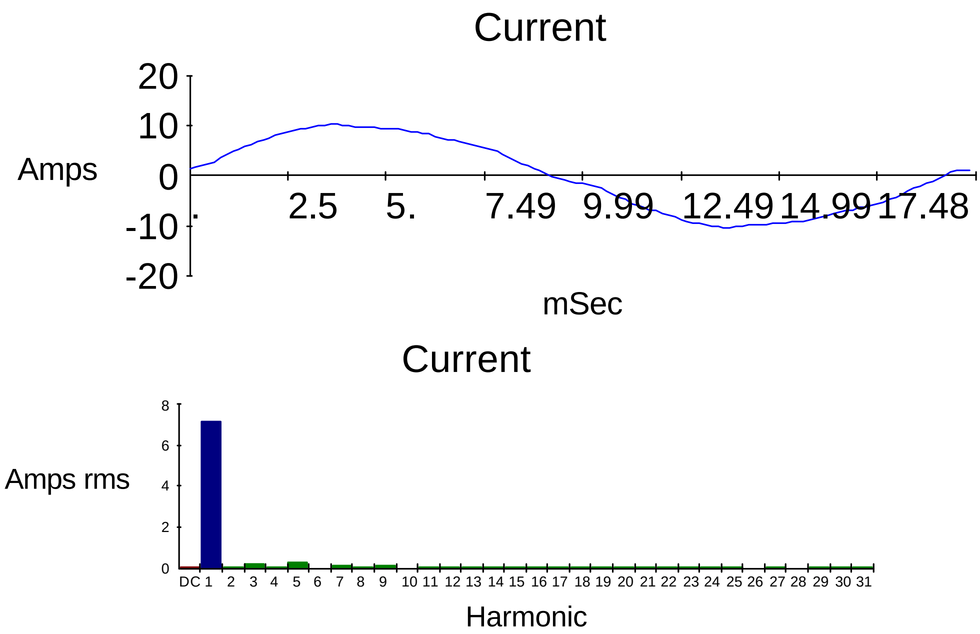

Figure 14 - Current waveform and harmonic content of 150W induction lamp

4.2 Illuminance Measurement

Illuminance in lux (i.e. lumen/m^2) of a point at a horizontal plane illuminated by a lighting system is one of the most important parameter defining the quantity of light received at the point. The horizontal illuminance at floor level was measured in March 2003 with both HID and induction lighting systems. The average illuminance measured for the existing lighting system was 471 lux with a maximum of 542 lux occurred at the centre of the squash court. For the new induction lighting system, the average measured illuminance was 712 lux and the maximum illuminance occurred at centre of the hall was 786 lux. There was an average increase of 51% in illumination when the games hall was lit by the new induction lighting system. This simple comparison has not taken into account the effect of what is known as the "maintenance factor" in lighting calculation.

Figure 15 - Direct illuminance comparison between court 2 (induction) and court 3 (HID)

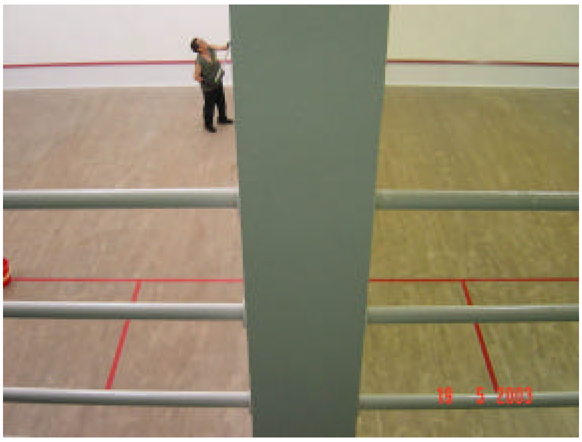
Figure 16 - Direct colour rendering comparison between court 2 (induction) and court 3 (HID)

4.3 Colour Temperature and Colour Rendition

Other than the measurable parameters mentioned above for assessing the quality of the visual environments of the two lighting schemes, colour temperature and colour rendition properties could also play their parts in the appraisal. The induction lamps used have a colour temperature of 4000° K (i.e. cool white) and could maintain the colour appearance throughout their lives. Metal halide lamps have an initial colour temperature of 6000° K (daylight) and their colour appearance could deviate during their operation lives resulting in a non-consistent colour appearance among lamps.

Measured to a scale of 0 to 100, the colour rendering index (CRI) describes the capability of a light source to accurately render a sample of eight standard colours relative to a standard source. The induction fluorescent lamp used in this project has CRI above 80 and that for metal halide lamps is 65. Figure 16 highlights the difference in colour rendering properties of the two squash courts lit by induction lamps (left) and metal halide lamps (right) respectively. A CRI of at least 60 is recommended by CIBSE Lighting Guide 4 for multi-purpose sport halls to reveal the correct colour pitch markings.

5. Conclusions

5.1 The pilot project using the latest induction lighting technology in Squash Court No. 2 at Kowloon Bay Indoor Games Hall was proved to be more energy efficient, higher illumination and better colour rendering. The electrodless induction lamps have extreme long life and the lifetime of the system is determined primarily by the lifetime of the ballast (i.e. 60,000 hours). Measurements on site indicated that the power consumption of the squash court reduced from 1.65 kW to 1.25 kW and the average illumination increased from 470 lux to 710 lux. Other advantages of the new induction lighting system include instant flicker-free starting and restrike, higher colour rendering index (>80), lower luminous depreciation and less maintenance requirements due to much longer lamps and equipment life. The estimated payback period is 5 to 8 years.

5.2 As far as electromagnetic interference (EMI) is concerned, electronic ballasts for induction lamps with increasing frequency (e.g. 2.2 to 3.0 MHz allocated for RF lighting devices) create more serious EMI problems and regulations are more stringent. Possible EMI problems must be taken into account when induction lamps are installed in sensitive areas equipped with delicate computing, control, medical or communication equipment. Ballast efficiency and cost would also increase with the rise of designed operating frequency. The development trend of induction lamps is now toward lower frequency design. The operating frequency of the induction lamps used in the pilot project is 250 kHz. The EMI requirements at this frequency are more tolerant and could easily be complied in the design of electronic ballasts.

5.3 The application of induction lamp is very similar to T5 lamps. However, T5 lamps are more appropriate for uses in areas where high efficiency and sophisticate lighting control (e.g. Dimming or Digital Addressable Lighting Interface system) are required to suit lighting levels of various functional requirements. T5 lamps are linear light sources and could be easily arranged in continuous rows to provide more glare free and uniform illumination level especially in large games hall.

5.4 Induction lamps are most suitable for use in areas or locations where maintenance and access are very difficult, EMI requirements are not critical and dimming control is not required (e.g. decorative lighting on top of the suspension rope of Tsing Ma Bridge, atrium lighting, high level hanger, warehouse, railway station, bus terminal, and street lighting).