Report of the Pilot High Output 'T5' Fluorescent Lighting Project at East Kai Tak Indoor Games Hall

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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 recently complete a pilot lighting project at East Kai Tak (EKT) Indoor Games Hall. The new lighting system made use of the latest T5 lighting technology for illuminating the high ceiling game hall. As compared with the existing high-bay lighting using High Intensity Discharge (HID) lamps, the new high output T5 lighting system was found to be more energy efficient and offered many other benefits which provide users of the game hall a more comfortable visual environment for their sporting activities. There were totally 48 high-bay HID luminaries existing in the game hall. Half of the lamps were 400W metal halide and the rests were 250W high pressure sodium (SON) lamps. The new T5 lighting system included 56 special impact resistant luminaries accommodating 3x49W high output T5 lamps and electronic ballasts (168 T5 lamps in total). Power consumption was 17.2kW for the existing lighting system. Measurement on site for the new T5 lighting system was 8.7kW, which represents a power reduction of almost 50% in lighting. The average illuminance measured at floor level was found to be 760 lux and 480 lux for the new T5 lighting system and the existing high-bay lighting system respectively. Other than the 58% increase in illumination level, improvement in the lighting quality in terms of glare, colour appearance and colour rendition were also recorded. Surveys were also carried out to collect users' opinion on the new lighting system. Majority of the users' feedback was in favour of the new T5 lighting system. General comments included brighter than before, more comfortable, less glare, softer visual environment and better colour appearance. The total cost of this pilot project was $182,400 and the estimated payback period is less than 3.7 years.

1. Introduction

The existing lighting installation in East Kai Tak (EKT) Indoor Games Hall consists of 24 numbers 400W metal halide lamps and 24 numbers 250W high pressure sodium (SON) lamps mounted inside the industrial type high-bay luminaries with parabolic reflectors. Fig. 1 shows the existing lighting layout plan and Fig. 2 shows a photograph of the existing lighting environment with HID lamps. The metal halide and SON luminaries were designed to mount in pair (Fig. 3) adjacent to each other for colour blending. All existing HID lamps were switched on for the whole opening hours of the game hall because these HID lamps need at least 5 minutes warming up period to start up and instant re-strike after switching off or a power interruption is also not possible. The colour appearance of metal halide lamp is typical cool white in colour (6000°K) and that for SON is yellow (2000°K). Neither metal halide lamps (too cool) nor SON lamps (too warm) are suitable to be used alone for indoor game halls lighting and they are therefore employed in pair for colour mixing and to create an appropriate visual environment for sporting purposes. Metal halide lamps are also characterised by their good colour rendering property (essential for live TV broadcasting) but less efficacy (76 lm/W). SON lamps have relatively poorer colour rendition (rich in yellow/orange

spectrum) and possible shift of colour appearance in operation but much higher efficacy (100 lm/W).

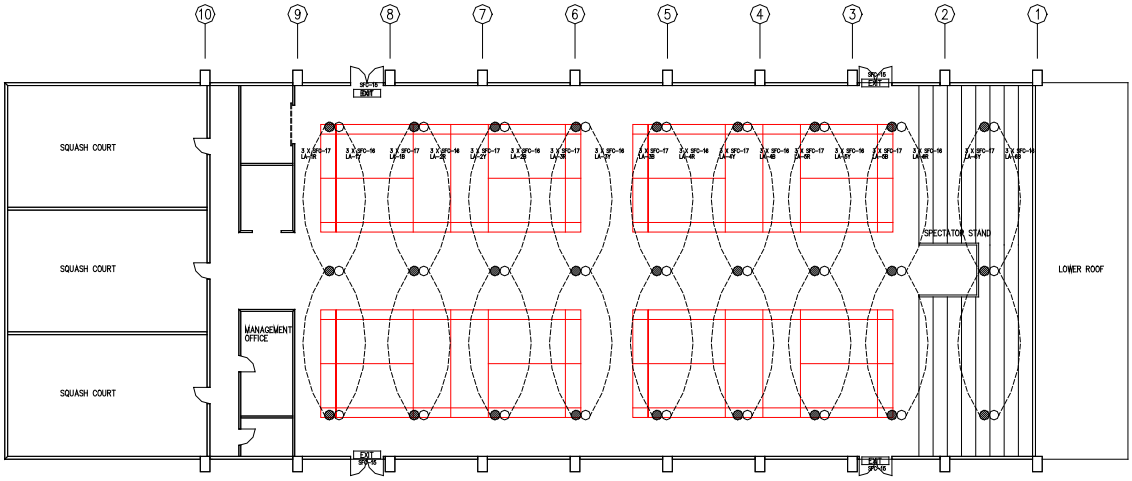

Fig. 1: Existing HID lighting layout at EKT Indoor Game Hall

Fig. 2: Existing lighting environment with HID lamps

Fig. 3: Existing HID lamps and high-bay luminaries at EKT Indoor game Hall

Tubular fluorescent lamps are essentially the opposite of “point-source” HID lamps and are regarded as “linear-source”. They emit relatively diffuse light from long glass tubes.

This characteristic of diffusivity has enabled fluorescent luminaries to dominate the market for lighting commercial, institutional and industrial spaces with ceilings less than 5 meters high. In recent years, however, the emergence of more intense and efficient T5 fluorescent lamps and of specially designed reflective luminaries has enabled fluorescent systems to break through the ceiling height barrier and compete directly with HID lamps in high ceiling indoor application.

In this pilot project, we attempted to introduce the high output version of T5 lamps for indoor game hall lighting. The new T5 lighting system was installed alongside with the existing HID lighting system. Both lighting systems had undergone intensive studies for comparison in terms of improvement in both energy performance and visual environment.

2. New High Output T5 Lighting System

The new pilot T5 fluorescent lighting system we used in EKT Indoor Game Hall consisted of 4 rows of 14 specially designed impact resistance luminaries complete with 3x49W high output T5 lamps and electronic ballasts (Fig. 4 and Fig. 5). The design illuminance was 500 lux at floor level as recommended by CIBSE Lighting Class II for indoor sports and mid-level competition such as regional or local club competition, which generally involved medium size spectators capacity with medium viewing distances. High-level training can also be included in this class.

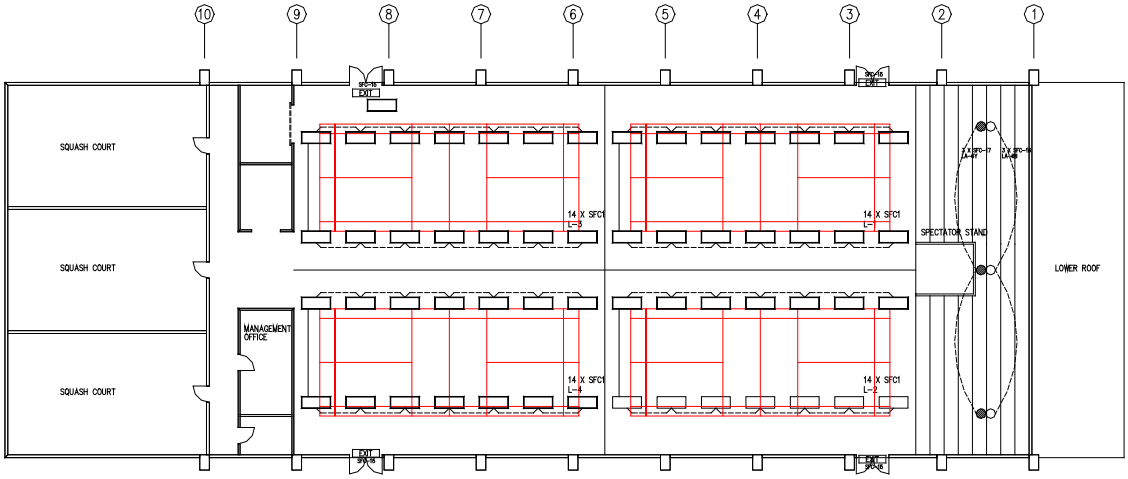

Fig. 4: Lighting layout of the new high output T5 lighting at EKT at EKT Indoor game Hall

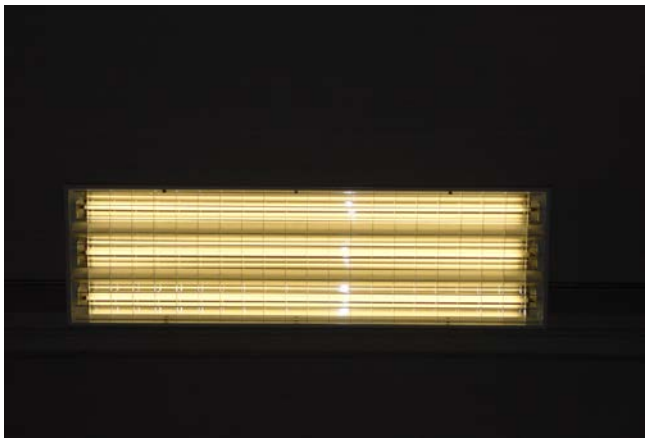

Fig. 5: New impact resistance luminaires complete with 3x49W T5 lamps and electronic ballasts

Unlike HID lamps, T5 fluorescent lamps could be switched on and off instantly without a long warming up period. Operation of the new T5 lighting system could then be arranged to suit the schedule of game hall booking and the switching circuits have also been arranged in 4 separate zones to tie in with the layout of the 4 badminton courts.

Fig. 6: Visual environment of the new T5 lighting at EKT Indoor Game Hall

3. Energy Performance

The electrical parameters of similar HID lamps and the new T5 luminaire were measured individually in EEO offices. Table 1 and Fig. 7 show the measured electrical parameters of a 400W metal halide lamps similar to those used at EKT Indoor Game Hall. The total circuit power of the lamp was 460W and the corresponding power factor and current total harmonic distortion (THD) were 0.91 and 36.7% respectively. THD is an important electrical parameter in a power distribution system, which affects the supply power quality and indicates the seriousness of power losses in a power distribution system. Table 2 and Fig. 8 show the measured electrical parameters of the new 3x49W high output T5 luminaires used in the game hall. Results revealed that the total circuit power of the luminaire was only 156W when operated with electronic ballasts. The circuit power factor was almost unity and the current THD was only 4.7%.

Table 1: Measured electrical parameters of 400W metal halide lamp

			Voltage	Current
Frequency	50 Hz	RMS	220.4V	2.29A
Power:		Peak	306.5	3.82A
W	460W	DC Offset	0.0	-0.03
VA	505VA	Crest Factor	1.39	1.67
var	122var	THD Rms	2.30%	34.45%
Peak W	98	THD Fund	2.30%	36.70%
Phase	14°lag	HRMS	5.1V	0.84A
Total PF	0.91	KFactor		8.96
DPF	0.97			

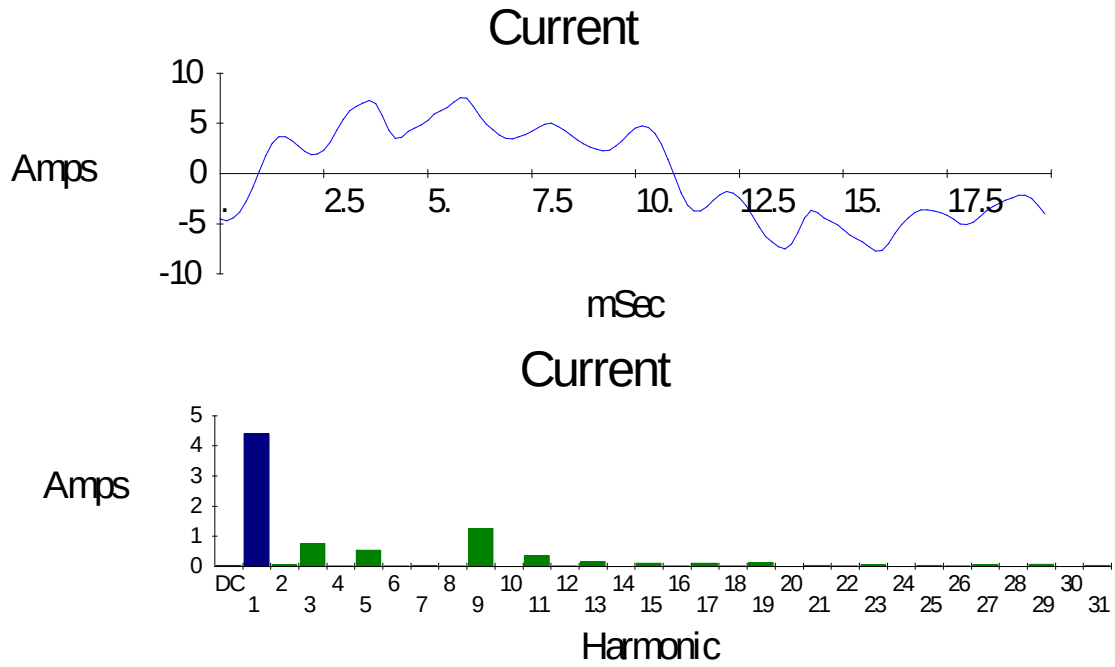

Fig.7: Current waveform and harmonic content of 400W metal halide lamp

Table 2: Measured electrical parameters of the new 3x49W T5 luminaire

			Voltage	Current
Frequency	50Hz	RMS	220.4V	0.72A
Power:		Peak	308.5V	1.04A
W	156W	DC Offset	0.0V	-0.03A
VA	158VA	Crest Factor	1.39	1.44
var	22var	THD Rms	2.30%	4.60%
Peak W	98W	THD Fund	2.30%	4.70%
Phase	8˚lead	HRMS	5.1V	0.03A
Total PF	0.99	KFactor		1.19
DPF	0.99			

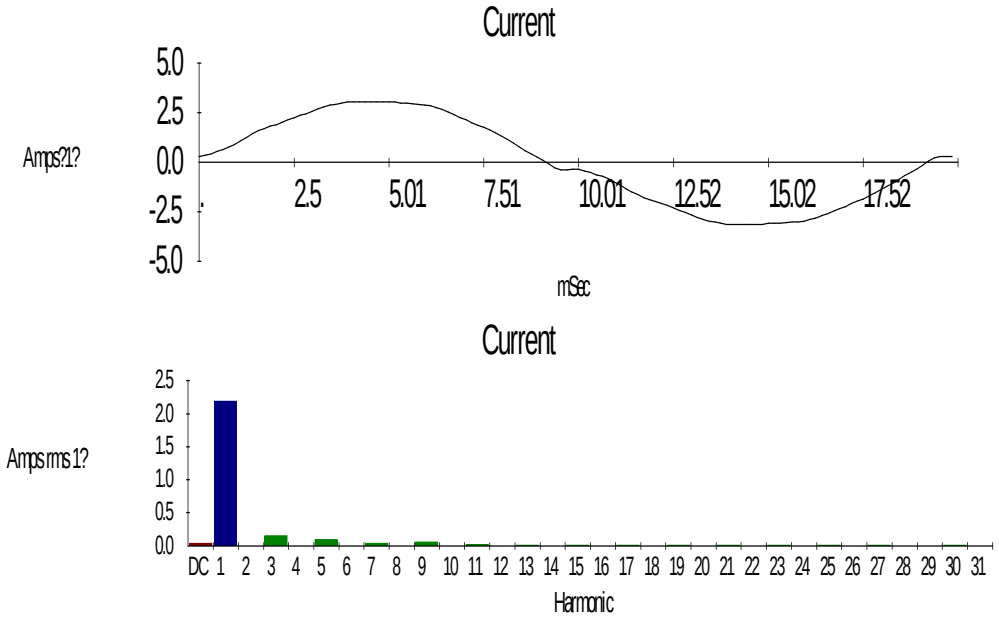

Fig.8: Current waveform and harmonic content of the new T5 luminaire

Energy performance of the two lighting systems was measured on site on 23 July 2001. The measured results were summarised in Table 3. It was found that the total power reduction for the new T5 lighting system was 8.5kW (49%) and improvement in current THD was also very apparent (reduced from 23.6% to 4.7%). As the game hall is fully air conditioning, 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. 2.5kW).

Table 3: Energy Performance of the Existing HID and New T5 Lighting Systems

	Existing HID Lighting System	New T5 Lighting System	% difference
Active Power (kW)	17.2 kW	8.7 kW	- 49%
Power Factor.	0.97	0.99	+ 2%
Current THD	23.6%	4.7%	- 80%
Lighting Power Density	26.3 W/m^2	13.3 W/m^2	- 49%

4. Visual Performance

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 on 22 May 2001 with both HID and T5 lighting systems. Results of the measurements are shown in Table 4 and Table 5. The average illuminance measured for the existing lighting system was 479 lux with a maximum of 642 lux occurred at the centre of the game hall. For the new T5 lighting system, the average measured illuminance was 760 lux and the maximum illuminance at centre of the hall was 998 lux. There was an average increase of 58% in illumination when the game hall was lit by the new T5 lighting system. The uniformity found for both old and new lighting systems were 0.48 and 0.51 respectively. The minor improvement was due to the closer spacing of T5 luminaires at ceiling level.

Table 4: Measured illuminance in lux for the existing HID lighting system

	Y(m)																	
X(m)	0.75	2.75	4.75	6.75	8.75	10.8	12.8	14.8	16.8	18.8	20.8	22.8	24.8	26.8	28.8	30.8	32.8	Average
0.75	343	387	370	364	374	426	469	492	508	513	457	342	356	375	343	278	235	390
2.25	374	431	452	452	481	505	497	523	541	558	565	540	496	428	370	299	243	456
3.75	403	456	480	473	522	535	545	553	565	588	592	569	520	447	379	309	253	482
5.25	423	485	506	504	544	566	574	579	594	609	615	594	545	446	366	304	251	500
6.75	455	500	522	532	562	579	588	597	611	619	618	605	550	440	364	301	272	513
8.25	424	517	452	531	571	591	598	603	611	631	628	616	564	448	363	298	233	511
9.75	447	520	446	547	570	600	604	606	613	642	637	621	564	450	364	300	230	515
11.3	474	523	519	553	565	590	600	603	613	629	628	613	554	446	365	301	231	518
12.8	455	499	522	528	568	590	596	593	602	619	617	606	548	446	366	308	270	514
14.3	411	467	493	547	551	565	578	581	578	600	601	580	530	447	367	312	269	499
15.8	367	434	443	530	516	539	544	554	536	558	559	542	493	442	372	306	239	469
17.3	352	412	431	499	477	523	526	539	527	543	530	532	495	425	351	280	230	451
18.8	366	397	434	453	484	490	513	433	510	469	404	308	442	425	336	292	229	411
Average	407	464	467	501	522	546	556	558	570	583	573	544	512	436	362	299	245	**479**

Table 5 Measured illuminance in lux for the new T5 lighting system

X(m) \ Y(m)	0.75	2.75	4.75	6.75	8.75	10.8	12.8	14.8	16.8	18.8	20.8	22.8	24.8	26.8	28.8	30.8	32.8	Average
0.75	402	509	566	582	606	625	641	639	648	640	628	610	597	574	544	519	519	579
2.25	489	598	680	715	747	742	749	747	753	748	760	747	720	674	649	615	626	692
3.75	552	685	756	796	827	837	850	850	856	847	847	826	800	759	723	694	687	776
5.25	594	727	817	865	897	913	921	925	926	923	918	903	876	837	792	745	714	841
6.75	609	744	836	891	932	944	956	960	960	958	952	936	905	861	814	769	760	870
8.25	624	746	846	907	956	971	979	985	985	982	973	956	927	884	828	776	608	878
9.75	628	746	862	918	956	978	983	998	998	996	985	970	939	895	836	783	609	887
11.3	620	749	826	891	928	958	963	971	968	972	964	952	915	876	818	776	653	871
12.8	610	742	815	863	902	925	926	938	937	944	931	925	892	853	803	760	768	855
14.3	586	705	766	826	851	877	871	890	883	896	882	879	840	806	751	720	704	808
15.8	525	636	702	750	763	793	785	807	792	807	787	782	744	722	670	652	558	722
17.3	449	545	589	641	642	677	660	686	668	683	653	659	635	619	575	559	384	607
18.8	384	450	502	478	432	546	579	584	605	582	527	453	476	521	495	485	417	501
Average	544	660	736	779	803	830	836	845	845	844	831	815	790	760	715	681	615	**760**

Glare is a major concern in an indoor game hall for both players and spectators alike. The concentrated point source of HID lighting can cause problematic glare. The condition occurs whenever someone looks directly or very close to an HID lamp in the line of sight. When the eye "sees" the extremely bright light source, the pupil becomes very small. Then, when the eye looks elsewhere, it cannot be able to focus properly for a few seconds. The situation is similar to your eye response when a camera flash blinds your subjects during a photo shoot. The linear and diffused light source of T5 lamp does not create the same problem. Although they are quite bright, T5 lamps are not "blinding" like the HID lamps.

Glare caused by a light source is directly proportional to its brightness. Luminance in candela per square meter (cd/m^2) is a physical measure of a surface brightness caused by light emission or reflection. Table 6 below shows the measured luminance for both HID and T5 luminaries at various observation angles. Because of the parabolic effect, maximum luminance (1.160×10^5 cd/m^2) occurred at about 60^o for 250W SON luminaries, which is almost 11 times brighter than the new T5 luminaire at the same observation angle. As far as disability glare is concerned for players viewing upward in the game hall, HID luminaries would create more serious problem than T5 luminaires.

Table 6 Measured luminance of high-bay and T5 luminaires at EKT Indoor Game Hall

Observation angle with light sources	Measured luminance in candela per square meter (cd/m^2) for:		
	400W metal halide high-bay luminaire	250W SON high-bay luminaire	3x49W high output T5 luminaire
90^o (vertically)	0.772×10^5	0.694×10^5	1.120×10^4
75^o	0.748×10^5	0.951×10^5	1.042×10^4
60^o	0.925×10^5	1.160×10^5	0.613×10^4
45^o	0.518×10^5	0.636×10^5	0.570×10^4
30^o	0.220×10^5	0.301×10^5	0.264×10^4
15^o	0.628×10^4	-------	0.210×10^4

Table 7 shows the measured luminance of game hall ceiling for both HID and T5 lighting systems at various viewing angles. The ceiling brightness with T5 lighting was found to be more than 100 times higher than that with HID lighting. This means contrast between the T5 luminaires and their background ceiling is much lower than the HID lighting system and would cause less discomfort glare for players and spectators. Fig. 9 shows a photo taken to highlight the glare problem and effect of surface reflectance created by the bright HID lamps at ground level.

Table 7 Measured ceiling luminance for HID and T5 lighting systems at EKT Indoor Game Hall

Observation angle with light sources	Measured ceiling luminance in candela per square meter (cd/m^2) for:	
	Existing HID high-bay lighting system	New high output T5 lighting system
90º (vertically)	0.327×10^2	0.402×10^4
75º	0.363×10^2	0.390×10^4
60º	0.426×10^2	0.442×10^4
45º	0.427×10^2	0.388×10^4
30º	0.450×10^2	0.415×10^4
15º	0.419×10^2	0.485×10^4

Fig.9: Reflective glare of HID lamps from floor surface

Other then the measurable parameters 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 light colour of a lamp is expressed as colour temperature in Kelvin (K). The T5 lamps used have a colour temperature of 4000ºK (i.e. cool white) and could maintain the colour appearance throughout their lives. Metal halide and SON lamps have an initial colour temperature of 6000ºK (daylight) and 2000ºK (yellow) respectively 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. Light sources that exhibit higher CRIs render colour better than sources with low CRIs. The T5 fluorescent lamp used in this project has CRI above 80 and those for metal halide and SON lamps are 65 and 27 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.

The average rated life for HID lamp is about 20,000 hours and for T5 lamps is 16,000 hours. They lose some of their light output as they age. Expressed quantitatively, it is common for the output of HID sources to degrade by nearly 40 percent over their lifetime, whereas T5 lamps exhibit lumen depreciation as low as 5 percents. The T5 lighting scheme would therefore maintain a much more consistent lighting level throughout their lifetime than their HID counterparts. If the economic lamp life (i.e. 30% depreciation) were taken into account for bulk lamp replacement schedule, the advantage of longer lamp life for HID lamps would then be diminished.

5. Surveys on Users' Feedback

In order to collect data on the users' opinion of the new high output T5 lighting system in EKT Indoor Game Hall, two separate surveys were conducts on 22 May 2001 and 23 July 2001. Questionnaire forms were prepared for the surveys. The same group of the game hall users, who experienced badminton playing under both lighting systems, were asked to complete the questionnaires regarding their views of the two lighting systems. There were totally 32 returns collected. Results of the users' feedback were summarised in Fig. 10 and majority of the users involved in the surveys agreed that that the new T5 lighting system was superior than the old HID lighting system in the aspects of brightness, comfort, glare, colour appearance and colour rendition.

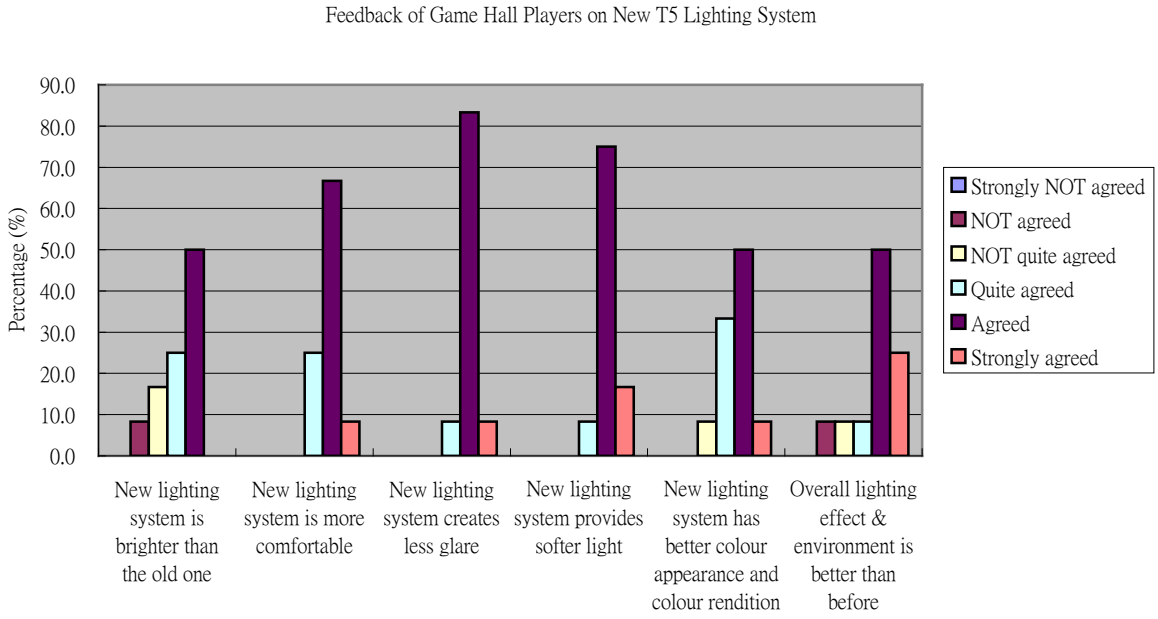

Fig.10: Feedback of players on the new T5 lighting system at EKT Indoor Game Hall

6. Conclusion

The new high output T5 lighting system installed at EKT Indoor Game Hall has now been operating continuously for more than 3 months since installation completed on 21 May 2001. According to feedback from management staff of the game hall, the new T5 lighting system has given them more flexibility in lighting control of the game hall in according to the hall booking schedule. Lighting for the four badminton courts could now be switched on and off independently. The recorded total energy consumption

(lighting and AC) in June and July 2001 for EKT Indoor Game Hall was 123,670kWh. Energy consumption for the same period last year was 131,330kWh. There was an apparent energy saving of 7,660kWh (about $7350 in money term) in these two busy summer months. The anticipated annual saving would be at least $45,000. Based on the information reported above, the following comparison table for the two lighting systems are highlighted for easy reference:

	Reference Items	Existing HID Lighting System	New High output T5 Lighting System
1	Luminaire Arrangement	24x400W Metal Halide and 24x250W SON High Bay Luminaires	54 nos. 3x49W High Output T5 Impact Resistant Luminaires
2	Total Circuit Power	17.2 kW	8.7 kW
3	Total Power Factor	0.97	0.99
4	Current Total Harmonic Distortion (THD)	23.6%	4.7%
5	Lighting Power Density	26.3 W/m^2	13.3 W/m^2
6	Measured Average Illuminance	479 lux	760 lux
7	Switching Arrangement	One Zone	Four Zones (to suit 4 Badminton Courts)
8	Capital Cost	HK$350,000 (Estimated)	HK$182,400 (Actual)
9	Annual Running Cost based on 16 hours daily operation	HK$100,000	HK$51,000
10	Rated Life	20,000 hours	16,000 hours
11	Cost of Lamp	HK$300	HK$50
12	Light Depreciation during Lift-time	40%	10%
13	Starting and Re-striking Time	> 5 minutes	Instant
14	Colour Temperature	6000°K for Metal Halide and 2000°K for SON	4000°K
15	Colouring Rendering Index	65 for Metal Halide and 27 for SON	>80
16	Glare	Higher because of Intensive Point Source	Less due to Linear Diffused Light Source
17	Dimming Options	Not Possible	Achieved by using Dimmable Electronic Ballasts
18	Voltage Fluctuation	Drop in Light Output	Constant Light Output
19	Emergency Lighting	Separate	Achieved by using Emergency Power Pack

Assuming the game hall lighting is fully on and operating 16 hours a day (7:00 a.m. to 11:00 p.m.) for the whole year, the simple payback period for the new high output T5 lighting system would be about 3.7 years. The payback period would be much shorter if partial lighting or the dimming option could be adopted to meet the actual demand of the game hall.

With the kind permission of Leisure and Cultural Services Department (LCSD), EMSD is planning another T5 lighting project at Kowloon Bay Indoor Game Hall. The new pilot project will make use of the innovative T5 lighting technology and digital dimmable control to suit the various functions and illumination requirements of the multiple-purpose sport hall.