MANAGING BUILDING SERVICES COSTS AND SUSTAINABLE ENVIRONMENT

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ABSTRACT

In Hong Kong, the degree of energy consumption is escalating for various types of buildings. There has been a global trend in energy saving to aim for achieving a more sustainable environment, with the adoption of different energy reduction opportunities. Various methodologies have been introduced by both private sector and local government to better minimize energy usage. In this research, we'll focus on exploring the performance of an essential building services design/device, electronic ballast in mitigating energy consumption through practical experimentation, accounting techniques such as internal rate of return, total life cycle costs, net present value, and case studies to justify further the practicality of involving these energy reduction measures.

Keywords: Electronic ballast, power quality, energy consumption/reduction, internal rate of return, total life cycle costs.

1. INTRODUCTION

Hong Kong is a leading commercial and financial centre and the energy consumption is increasing substantially over the years. The electricity consumption in the commercial sector, as the fastest growing sector, is increasing at about 7% p.a. Lighting energy consumption of a commercial building reaches 25 to 30% of the total energy consumption. Since fluorescent lighting is the most preferred lighting system, different energy saving approaches aimed at fluorescent lighting are available in the market, and electronic ballast retrofit is one of the widely adopted practice. This action research aims to demonstrate how to conduct an electronic ballast retrofit to achieve energy saving through a case study on a ten stories office building of about 180,000 s.f.. The relevant background, technical details, performance/cost comparisons of different ballasts and their measurement data; as well as the building's power quality problem will be explored.

Electromagnetic ballast - a transformer-like device, can produce significant degree of waveform distortion which eventually incurs serious harmonic distortion to the power circuit and degrades the power factor of the system. This would increase the loading and cause potential interruption to the computer and communication system. Current electronic ballasts possess built-in harmonic filters that can effectively 2 reduce the harmful harmonic distortion, whereby improve the power quality also. This study starts with assessing the performance of some selected electronic ballasts, its' effects on overall building power quality, then the potential cost savings. The scope/sequence of research composes mainly the followings:

- Relevant products would be initially selected according to requirements, their respective specification, standards etc. with respect to also branding, job references for a six-week performance test against the tradition electromagnetic ballast.
- The power quality parameters are collected through field measurement with a power monitoring system installed to the building electrical system.

- Major electrical performance parameters are captured for comparison to identify technically the best-performed electronic ballast.
- With the chosen electronic ballast, different light fitting configurations will be setup for testing the light level and energy cost to identify the alternative energy cost saving options.
- Existing lighting energy cost and the potential energy cost saving will be estimated.
- Various electronic ballast retrofit and relighting proposals will be established. Their respective Internal Rate of Return (IRR), Life cycle Cost (LCC), Net Present Value (NPV) and operating periods will be analysed to identify the most cost-effective one.

2. TECHNICAL REVIEW

Power quality is an issue that receives increasing attention in recent years. Electronic devices e.g. computers, process controls and communication equipments are sensitive to power system disturbances. The increasing dependence on data processing equipment nowadays makes the power quality issue more important. According to survey in USA, in 1980 only 3 percent of data processing equipment downtime was attributed to poor power quality. By 1990, this percentage climbed to 27 percent and 47 percent in 2000. Almost half of the downtime would be attributed to the power quality issue. The severance of impact to operation is also increasing due to the higher dependence on these computing equipments (Qayoumi, 1996). A research regarding electronic ballast was conducted by Stanford University on parameters such as input power, power factor, relative light output, voltage regulation, flicker, harmonic content, and conducted EMI (Thumann, 1989).

It was found that electronic ballasts performed 14% to 20% better than 3 electromagnetic ballasts. Flicker reduced by half with electronic ballasts. Harmonic content varied from ballasts to ballasts. The high frequency operation of electronic ballasts might interfere with sensitive electronic equipment. The electronic ballasts installed in fluorescent lighting system could save energy but often blamed for increasing harmonic distortion levels. It is important to check the Total Harmonic Distortion (THD) level when specifying electronic ballasts. After reviewing the technical literatures, a bench test would be carried out to compare the performance capabilities of the various electronic transformers against electromagnet ballast. The disadvantage of relative measurement is that they cannot be readily compared with measurements from other sources. Generally, the effects of harmonic distortion are localized. If the magnitude is large, the problem will spread to the electrical system such as:

- Deterioration of electronic equipment performance
- Failure of fluorescent lighting ballasts
- Temperature rise in transformer and neutral conductor
- Low power factor
- Nuisance tripping of circuit breakers

  Not all harmonic distortion problems are originated from electromagnetic ballast of the fluorescent lighting system, but it would deteriorate a building's power quality.

3. SELECTION OF ELECTRONIC BALLASTS FOR TESTING

Among the various electronic ballast products in the market, Brands P, O, C, H (their names are disguised for protection) are chosen for testing, based on:

- Their reputation in the market
- Their extensive job reference
- They are all on the list of "Electronic Ballasts Meeting Electrcial & Mechanical Services Department's (EMSD's) Minimum Technical Requirements".

4. TESTING OF ELECTRONIC BALLAST VS ELECTROMAGNETIC BALLAST

The test is divided into 2 parts to examine the electrical performance of electronic ballasts and the change of lumen output when comparing with electromagnetic ballasts. The overall performance of the electronic ballast is assessed, based on the ability in:

- Reducing the power consumption.
- Improving power quality of the building in terms of power factor, total harmonic distortion, reactive power etc.
- Maintaining the existing lighting level.

4.1 Electronic Ballast Performance Test

The objective is to find out the best electronic ballast, among the samples that has superior electrical performance.

4.1.1 Methodology

Thirty luminaries each comprising of 3 x 36W lamps are divided into five groups which four of them were replaced with the four selected electronic blasts to be tested and the last group was connected to electromagnetic ballasts as control. Each group is divided into two half, that is three luminaries, with one of them running at 12 hours a day while the other half running 24 hours a day respectively to simulate the office and public area operating condition. A power harmonics analyzer was used to record all electrical parameters including active power, apparent power, power factor, voltage, current and total harmonic distortion, etc. in the test. The characteristic curve of the various key circuit parameters for both the electronic ballast and magnetic ballast are shown in Appendix 1. The test lasted for 12 weeks and performance data is continuously monitored and analysis. The testing results are summarized and tabulated in Table 4.1, the best performance figures are circled for easy reference.

Table 4.1: Electric and Electromagnetic Ballasts Performance Summary

Type of Ballast		Magnetic	Electronic (T8)			
Brand		G	P	O	H	C
Current	I	4.849	2.638	2.767	2.653	**2.610**
Power Factor	PF	68.006	97.686	98.618	**99.734**	99.663
Total Current Harmonic	$I_{Total\ HD}$	15.072	10.704	4.830	7.307	**4.156**
Apparent Power	kVA	1.059	0.571	0.604	0.583	**0.572**
Reactive Power	kVAR	0.777	-0.122	-0.100	**-0.038**	-0.047
Active Power	kW	0.720	0.558	0.595	0.582	**0.570**

Table 4.2: Electronic Ballast vs Electromagnetic Ballast

Ballast Type		Magnetic	Electronic	% Difference
Band Name		G	H	
Current	I	4.894	2.633	46.20%
Power Factor (%)	PF	67.699 (lagging)	99.732 (leading)	47.32%
Total Current Harmonic Distortion (%)	I_{THD}	15.076	7.267	51.80%
Apparent Power	kVA	1.072	0.580	45.90%
Reactive Power	kVAR	0.789	-0.039	95.06%
Active Power	kW	0.725	0.579	20.14%

4.1.2 Findings

- The electronic ballast has better performance than magnetic ballast. The characteristic curve of the various key circuit parameters for both the electronic ballast and magnetic ballast are shown in Appendix 1. The key circuit parameters such as current harmonic, power factor and active power has been greatly improved by 51.80%, 47.32% and 20.14% respectively as shown in Table 4.2.
- The electronic ballasts H and C have sound performance result and have better electrical characteristics than that of P and O. In addition to the inherent power factor improvement on the lighting system from 67.7% (lagging) to 99.7% (leading), the special electronic ballasts' leading power factor characteristic will have further favorable effect on improving the whole building supply power factor which is normally of lagging in nature.
- The undesirable power factor was mainly due to the under-designed capacitors inside the light fitting (only one 5 uF capacitor was used for the whole fitting).
- The annual lighting energy consumption is about 2,066,000kWh (i.e. HK$1,520,000), about 25.6% of the building's total energy consumption. According to the electronic ballasts' operations parameters captured in the past 12 weeks, the actual lighting energy cost is reduced by at least HK$111,000 (20.14%) annually if electronic ballasts are installed to replace the existing magnetic ballasts.
- However, C electronic ballast is of the series configuration type which will all be blacked out in case one of the lamps is burnt; and cannot be automatically restarted after re-lamping without power off reset. Such feature makes it a major drawback as compared with H, which has no such problem.

4.2 Illuminance Test for Electromagnetic Vs Electronic Ballasts *Objective*

- To ensure the lux level shall not be degraded after the replacement of the electronic ballasts.
- To seek for further energy cost saving availability of the retrofit with the reflective parabolic louver twin light fitting to replace the existing triple lamp diffuser light fitting.

4.2.1 Methodology

- A triple lamp test rack was set up for mounting the luminaries under test.
- The electronic ballasts are connected to the light fitting and with digital luxmeter placed at a fixed test point directly underneath the luminaries to measure illuminance in lux for comparison purpose.

The different brands of electronic ballasts were connected to same light fitting to take the measurements.

4.2.2 Findings

Based on the Lux Level testing result in Diagram 4.1, both H and C have better lumen factor, greater than 0.99 which denotes no obvious degrading in the lux level after the retrofit.

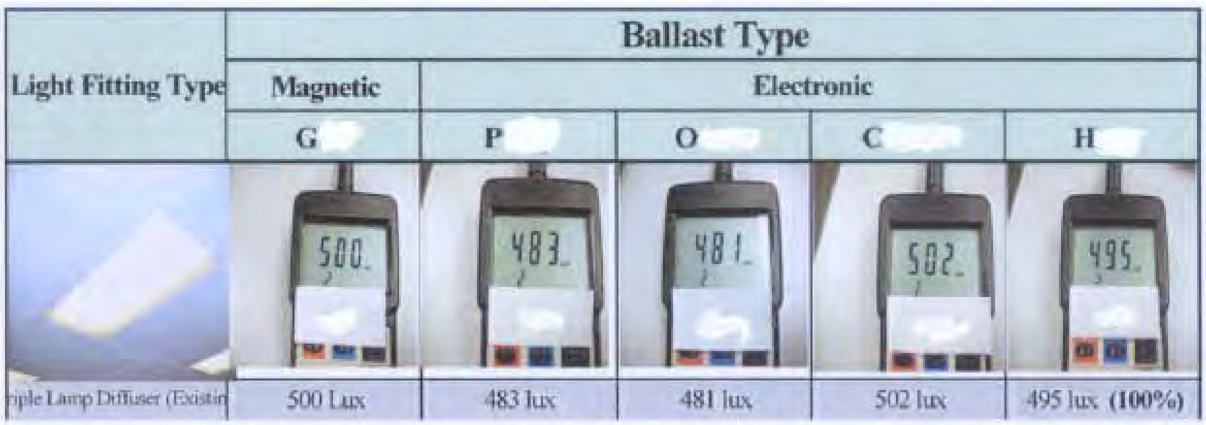

Diagram 4.1: Illuminance Level Testing Result

4.3 Summary

The following observations would be drawn for the electronic ballast performance test:

- All brands of electronic ballast perform better than magnetic ballast. The characteristic curve of the various key circuit parameters for both the electronic ballast and magnetic ballast are obtained (App. 1). The key circuit parameters such as current harmonic, power factor and active power has been greatly improved by 51.80%, 47.32% and 20.14% respectively as shown in Table 4.2.
- H is found to have better overall performance in terms of hardware configuration, lumen output and electrical characteristics as compared with P, O and C.

5. LIGHTING SYSTEM MODIFICATION OPTIONS & EVALUATION

5.1 Modification Options

To retrofit with electronic ballast is one of the energy saving options. Three other options would also help:

- Option 1 - Retrofit the existing diffuser light fitting with magnetic ballast by T8 electronic ballast, which is the simplest modification.
- Option 2 - Relighting by replacing the existing diffuser light fittings by higher lumen output reflective parabolic louver fitting with T8 electronic ballast.
- Option 3 - Relighting by replacing the existing diffuser light fittings by higher lumen output reflective parabolic louver fitting with T5 electronic ballast, which is the latest energy saving design.

For Option 1, the technical benefits of electronic ballast over electromagnetic ballast have been well discussed in above paragraphs. For Option 2 and 3, relighting with higher lumen output reflective parabolic reflector light fitting impose a possibility to use less fluorescent tube for each light fitting, which provide a more direct cost saving benefit. However, reducing lamps with reflectors would decrease light levels, and they must be measured to maintain within current lighting standards and not adversely affect worker productivity.

The illuminance test process was repeated for the illuminance using reflective parabolic louver with twin lamp and triple lamp respectively and findings are given in Diagram 5.2. From the test results, there would be a dilemma for parabolic reflector while there is an obvious variance in illuminance either below or over the specified value. The twin lamp parabolic louver, which provides about 86.46% lumen output of existing triple lamp diffuser, does not provide the equivalent lux level. Therefore, further energy cost saving study on the relighting by using the higher reflective twin light fitting is deemed not practical. To fulfill the function requirements, the merits must be corresponding to a reasonable modification cost. An in-depth cost analysis of the three options would be carried out to justify.

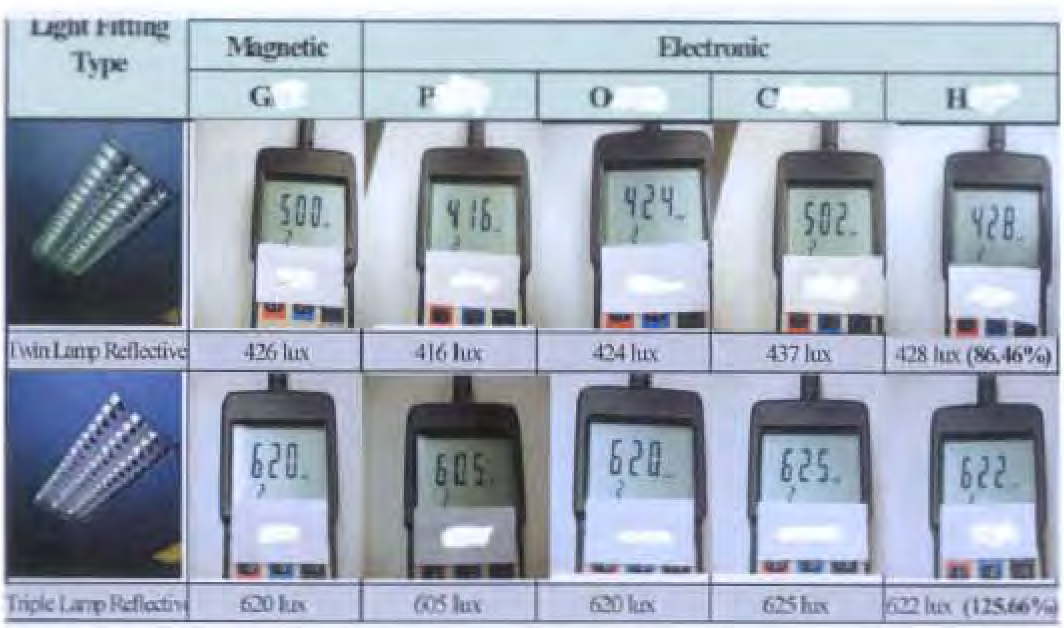

Diagram 5.2: Illuminance Test with Parabolic Reflector

5.2 Internal Rate of Return & Life Cycle Cost Evaluation

The Internal Rate of Return (IRR), Life Cycle Cost (LCC) and Net Present Value (NPV) methodologies are adopted, with the following options:

- IRR with a return period of 5 years
- IRR with a return period of 8 years
- Life Cycle Costs are calculated based on four different rates of return – 5%, 8%, 12% and 15% and each rate of return will further calculate under 5 years, 8 years and 15 years of operating period.

To cater for the different characteristics of these three options, low initial input with lower return cash flow for ballast retrofit or high initial input with higher return cash flow for relighting with T5 light fitting, IRR of 8 years would also be tabulated. The primary consideration will be based on 5 years return period unless there is a very significant saving revealed at the LCC analysis. For similar reason, the three options as short term, mid term and long term investment at different rate of return would be tabulated also, with following assumptions:

- The T8 fluorescent lamp life cycle is 8,000 hours while T5 is about 20,000 hours according to manufacturers' specifications.
- □Both T5 & T8 electronic ballast life cycle is 50000 hours (about 8 years operation).
- Existing plastic diffuser will be replaced every 5 years due to aging.
- The price of a 28W T5 energy efficient fluorescent tube is about HK$25 while the equivalent 36W T8 fluorescent tube is about HK$5.7 for Option 3 evaluation.

5.3 Option 1 Cost Evaluation (Electronic ballast vs Electromagnetic ballast)

Table 5.2: IRR Evaluation Summary – By Years

			G		P		O		C		H	
Initial Investment			0		1,056,428		1,055,720		1,446,913		780,000	
IRR for 5 years			0.00%		14.55%		18.80%		4.43%		29.63%	
IRR for 8 years			0.00%		24.35%		28.06%		15.61%		37.60%	
Saving received against using electromagnetic ballast												
NPV	Rate of Return	Period	(HK$)	(%)	(HK$)	(%)	(HK$)	(%)	(HK$)	(%)	(HK$)	(%)
	5%	5 Year	0	0.00	293,526	4.28	432,447	6.31	(22,871)	-0.33	596,840	8.70
		8 Year	0	0.00	958,836	9.36	1,165,875	11.38	678,953	6.63	1,275,401	12.45
		15 year	0	0.00	1,657,764	10.05	1,990,288	12.07	1,193,192	7.23	2,176,840	13.20
	8%	5 Year	0	0.00	188,520	2.98	316,691	5.01	(133,639)	-2.11	489,743	7.74
		8 Year	0	0.00	735,404	8.07	919,567	10.09	443,260	4.87	1,047,520	11.50
		15 year	0	0.00	1,207,178	8.87	1,481,492	10.89	767,828	5.64	1,675,045	12.31
	12%	5 Year	0	0.00	67,560	1.18	183,347	3.21	(261,238)	-4.57	366,374	6.41
		8 Year	0	0.00	492,508	6.25	651,803	8.27	187,033	2.37	799,786	10.15
		15 year	0	0.00	775,082	7.15	993,475	9.17	360,336	3.33	1,193,489	11.02
	15%	5 Year	0	0.00	(11,208)	-0.21	96,513	1.82	(344,329)	-6.48	286,037	5.38
		8 Year	0	0.00	342,742	4.81	486,703	6.84	29,047	0.41	647,037	9.09
		15 year	0	0.00	536,516	5.77	724,096	7.78	135,095	1.45	927,834	9.97

Table 6.1: IRR Evaluation Summary by Rate of Return

			G		P		O		C		H	
Initial Investment			0		1,056,428		1,055,720		1,446,913		780,000	
IRR for 5 years			0.00%		14.55%		18.80%		4.43%		29.63%	
IRR for 8 years			0.00%		24.35%		28.06%		15.61%		37.60%	
Saving received against using electromagnetic ballast												
NPV	Period	Rate of Return	(HK$)	(%)	(HK$)	(%)	(HK$)	(%)	(HK$)	(%)	(HK$)	(%)
	5 Years	5%	0	0.00	293,526	4.28	432,447	6.31	(22,871)	-0.33	596,840	8.70
		8%	0	0.00	188,520	2.98	316,691	5.01	(133,639)	-2.11	489,743	7.74
		12%	0	0.00	67,560	1.18	183,347	3.21	(261,238)	-4.57	366,374	6.41
		15%	0	0.00	(11,208)	-0.21	96,513	1.82	(344,329)	-6.48	286,037	5.38
	8 Years	5%	0	0.00	958,836	9.36	1,165,875	11.38	678,953	6.63	1,275,401	12.45
		8%	0	0.00	735,404	8.07	919,567	10.09	443,260	4.87	1,047,520	11.50
		12%	0	0.00	492,508	6.25	651,803	8.27	187,033	2.37	799,786	10.15
		15%	0	0.00	342.742	4.81	486,703	6.84	29,047	0.41	647,037	9.09
	15 Years	5%	0	0.00	1,657.764	10.05	1,990,288	12.07	1,193,192	7.23	2,176,840	13.20
		8%	0	0.00	1,207,178	8.87	1,481,492	10.89	767,828	5.64	1,675,045	12.31
		12%	0	0.00	775,082	7.15	993,475	9.17	360,336	3.33	1,193,409	11.02
		15%	0	0.00	536,516	5.77	724,096	7.78	135,095	1.45	927,834	9.97

5.3.1 Findings

- The saving from using P electronic ballast ranges from $343,000 to $1,658,000 for the rate of return 5-15% within a period of 5-15 years except that loss is reported with 5% at 5 years.
- The IRR of P electronic ballast is the best among others at 14.55% and 24.35% for a period of 5 years and 8 years respectively.
- The saving from using O electronic ballast ranges from $97,000 to $1,990,000 for the rate of return 5-15% within a period of 5-15 years.
- The IRR of O electronic ballast is the best among others at 18.8% and 28.06% for a period of 5 years and 8 years respectively.
- The saving from using C electronic ballast ranges from $29,000 to $1,193,000 for the rate of return 5-15% within a period of 8-15 years. Because of the high initial cost, the saving from energy cost comparing with electromagnetic ballast could not offset the opportunity cost, and losses are reported for a 5 years investment period.
- The IRR of C electronic ballast is the best among others at 4.43% and 15.61% for a period of 5 years and 8 years respectively. The low IRR value mainly relates to its high initial cost.
- The saving from using H electronic ballast ranges from $286,000 to $2,177,000 for the rate of return 5-15% within a period of 8-15 years.
- The IRR of H electronic ballast is the best among others at 29.63% and 37.6% for a period of 5 years and 8 years respectively.

5.4 Option 3 Evaluation

Table 5.3: Test Result of T5 vs T8 & Electromagnetic Ballast

Ballast Type		Magnetic	Electronic T8	Electronic T5
Band Name		G	H	H
Current	I	4.849	2.653	**2.356**
Power Factor	PF	68.006	**99.734**	98.485
Total Current Harmonic Distortion	$I_{Total HD}$	15.072	**7.307**	9.245
Apparent Power	kVA	1.059	0.583	**0.495**
Reactive Power	kVAR	0.777	-0.038	**-0.036**
Active Power	kW	0.720	0.569	**0.489**

Cost Saving Summary of Alternative Options vs Electromagnetic Ballast

Table 5.4: Cost Analysis Summary of Retrofit Options by Years

			Option 1		Option 2		Option 3	
Initial Investment			780,000		1,434,535		1,714,435	
IRR for 5 years			29.63%		3.53%		14.78%	
IRR for 8 years			37.60%		14.84%		23.10%	
Saving received against using electromagnetic ballast								
	Period	Rate of Return	(HK$)	(%)	(HK$)	(%)	(HK$)	(%)
NPV	5 Years	5%	596,840	8.70	(176,246)	-2.57	267,832	3.91
		8%	489,743	7.74	(291,301)	-4.61	96,463	1.52
		12%	366,374	6.41	(423,836)	-7.42	(100,943)	-1.77
		15%	286,037	5.38	(510,140)	-9.60	(229,491)	-4.32
	8 Years	5%	1,275,401	12.45	665,640	7.31	1,215,738	11.78
		8%	1,047,520	11.50	430,795	4.73	872,544	9.58
		12%	799,786	10.15	175,649	1.93	498,969	6.33
		15%	647,037	9.09	18,442	0.20	268,286	3.77
	15 Years	5%	2,176,840	13.20	1,602,159	9.71	3,158,357	19.15
		8%	1,675,045	12.31	1,084,053	7.97	2,278,888	16.74
		12%	1,193,489	11.02	586,601	5.41	1,430,552	13.20
		15%	927,834	9.97	312,135	3.35	961,326	10.33

Cost Saving Summary of Alternative Options vs Electromagnetic Ballast

Table 5.5: Cost Analysis Summary of Retrofit Options by Rate of Return

			Option 1		Option 2		Option 3	
Initial Investment			780,000		1,434,535		1,714,435	
IRR for 5 years			29.63%		3.53%		14.78%	
IRR for 8 years			37.60%		14.84%		23.10%	
Saving received against using electromagnetic ballast								
NPV	Rate of Return	Period	(HK$)	(%)	(HK$)	(%)	(HK$)	(%)
	5%	5 Year	596,840	8.70	(176,246)	-2.57	267,832	3.91
		8 Year	1,275,401	12.45	665,640	7.31	1,215,738	11.78
		15 year	2,176,840	13.20	1,602,159	9.71	3,158,357	19.15
	8%	5 Year	489,743	7.74	(291,301)	-4.61	96,463	1.52
		8 Year	1,047,520	11.50	430,795	4.73	872,544	9.58
		15 year	1,675,045	12.31	1,084,053	7.97	2,278,888	16.74
	12%	5 Year	366,374	6.41	(423,836)	-7.42	(100,943)	-1.77
		8 Year	799,786	10.15	175,649	1.93	498,969	6.33
		15 year	1,193,489	11.02	586,601	5.41	1,430,552	13.20
	15%	5 Year	286,037	5.38	(510,140)	-9.60	(229,491)	-4.32
		8 Year	647,037	9.09	18,442	0.20	268,286	3.77
		15 year	927,834	9.97	312,135	3.35	961,326	10.33

5.5 Modification Options Evaluation Summary

Based on above, the following findings are observed:

- Although T5 relighting option can save 11% more electricity cost annually and improve the existing lux level when compared with Option 1, but its total initial investment and subsequent 10 years maintenance will cost about 5.3 million, which is nearly 3 times for the electronic ballasts retrofit proposal (Option 1). Such upgrading proposal would not generate any subsequent cost saving at all, and not worth considering.
- The simplest improvement is to retrofit the existing magnetic ballast by electronic ballast, with saving HK$318,000 (about 21%) of the annual lighting energy charge.
- Option 1 is the cheapest retrofit proposal which costs about HK$780,000 while Option 2 is 84% higher than it. Option 1 offers faster payback period of 2.45 years and attractive IRR of 29.63%.

Based on the test results of P, O, C, H electronic ballasts, H has superior electrical characteristic and overall performance among others. The initial cost of H is also the lowest. Retrofit of the existing diffuser light fitting with magnetic ballast by electronic ballast (Option 1) is the most practical and cost-effective. The initial investment cost will be HK$780,000 and the estimated annual energy cost saving is about HK$318,000, which is approx. 21% of the lighting energy charge.

6. PILOT RETROFIT PROJECT

A pilot retrofit project based on Option 1 is adopted, to retrofit two floors of light fittings with electronic ballast. The light fittings at each floor would be divided into two half that operated under similar conditions; and power analyser are connected to the circuit to capture power data for analysis. The site measurement before ballast retrofit indicates that the two floors have a total weekly energy consumption of 4110 kWh at an average power factor of 84.5 (lagging). The undesirable power factor was mainly due to the under-designed capacitors inside the light fitting (only one 5 uF capacitor used for the whole fitting).

7. CONCLUSIONS

Based on above, the followings are observed:

- As the average weekly lighting energy consumption for two half-floors measured on site before retrofit was 4110 kWh, the projected whole building annual power consumption would be 2,137,200 kWh (close to previous estimate 2,066,012 kWh with 3% variance). The average weekly lighting energy consumption for two half-floors measured on site after retrofit is 3190 kWh, the projected whole building annual power consumption would be 1,658,800 kWh (close to previous estimate 1,633,338 kWh with 1.5% variance). The energy saving is about **22.37%,** which is even better than previous estimate 20.94%.
- The power factor of the lighting circuits is greatly improved from 84.5 lagging to 98.48 leading, resulting in lower circuit current, lesser reactive power, smaller distribution loss and demand charge.
- Total Harmonic Distortion (THD) of current appears to have 50% improvement, resulting in fewer problems to the power quality of the building.

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