

T5 FLUORESCENT LAMP SYSTEMS AND BUILDING SUSTAINABILITY

T.M. CHUNG

Department of Building Services Engineering, The Hong Kong Polytechnic University

Hung Hom, Kowloon, Hong Kong

e-mail : tm.chung@polyu.edu.hk

Abstract

T5 linear fluorescent lamps are a new member of the fluorescent lamp family. The main advantages of the new lamp are that they are smaller in size, have higher luminous efficacy, better lamp lumen maintenance and more environmental friendly. The smaller T5 lamp saves not only energy but also saves raw materials, e.g. glass, phosphors and packaging material, for the production and transportation of the lamp. Using T5 lamps also helps to reduce the amount of mercury that would pollute the environment at the end of lamp life and/or the cost for waste treatment or recycling. However, T5 lamps require a higher ambient temperature than T8/T12 lamps for optimum light output. This may cause great problems in using open-bottom luminaires in air-conditioned rooms because cool air can enter the lamp compartment resulting in significant reduction in light output. The temperature issue has left many lighting designers wondering whether they should consider T5 systems instead of T8 systems, in air-conditioned new constructions and retrofitting old T8/T12 magnetic systems. This paper clarifies these important issues and discusses the contribution of T5 fluorescent lamp systems to the sustainability of buildings. The discussion will address the 3 issues: energy, economics and environment. Demonstrations will be given using design case studies with economic analysis to compare the performance of T5 lamps systems with T8 lamp systems. The demonstrations show that with careful design, in particular when the temperature issue is carefully considered, T5 lamp systems contribute significantly to the sustainability of the environment.

Keywords : Fluorescent lamps, Luminous efficacy, Optimal operation temperature, Cost analysis, Environmental impact.

1. Introduction

Fluorescent lamps are among the man-made white light sources with the highest luminous efficacy (lumens per watt, lm/W). Because of their high efficacy, good colour rendering, wide choice of colour temperatures and other advantages, fluorescent lamps are nowadays the most widely-used man-made light sources. It has been estimated that more than 50% of all electric lighting applications use fluorescent lamps (Kane and Sell, 2001). Among all forms of fluorescent lamps, tubular fluorescent lamps are the most popular ones. It has become a custom to label tubular fluorescent lamps by a capital letter T (denoting that the shape is tubular) followed by a number that indicates the diameter of the tube in eighths of an inch. When the tubular fluorescent lamp was first put into the market about 70 years ago, it was T12, having a diameter of 38 mm (1.5 inches). Some 25 years ago the T8 lamp with a diameter of 26 mm (1 inch) started to appear in the market. The most recent addition, entering the market about 8 years ago, is the T5 lamp which has a diameter of 16 mm (0.625 inch). Lamp manufacturers market T5 lamps by promoting their advantages as significantly smaller than previous versions, higher luminous efficacy, better lamp lumen maintenance and more environmental friendly. The marketing campaign of T5 lamps have left many lighting designers wondering whether they should consider T5 systems instead of T8 systems, in new constructions and retrofitting old T8 or T12 magnetic systems. Designers and engineers may be confused by the small difference in the efficacy between T5 and T8 systems. They may also be confused by the 10°C higher optimal temperature for T5 systems to operate most efficiently. This paper gives clarification to these important points as well as discusses the new T5 lighting system under three headings: energy, economics and environment.

2. Characteristics of T5 Lamps

2.1 Dimensions

T5 fluorescent lamps were designed with no consideration of compatibility with their predecessors. T5 lamp bases have different pin separations and different lengths from T8 or T12 lamps. Therefore, T5 lamps require different lamp holders and fittings and T5 lamps do not fit into T8/T12 luminaires. The lengths of T5 lamps have been optimized to fit into standard ceiling grid systems so that it is now possible to install recessed T5 luminaires end-to-end in a standard ceiling system. End-to-end installation in a standard ceiling grid is not possible for T8/T12 luminaires because the lamp itself is already of the length of the standard grid size so that the fitting must be longer than the standard grid separation.

2.2 Electrical and luminous characteristics

T5 lamps are available in two versions: a high efficiency (HE) version and a high output (HO) version. High efficiency T5 (T5 HE) lamps are available in 14, 21, 28 and 35 watts, corresponding to nominal lengths of 550 mm, 850 mm, 1150 mm and 1450 mm, respectively. T5 high-output (T5 HO) lamps are available in 24, 39, 54 and 80 watts, corresponding to the same series of lengths as the T5 HE lamps; several manufacturers also produce a 49 W version of the nominal 1450 mm HO lamp. T5 lamps are designed to operate only on electronic ballast. In almost all cases, T5 lamps do not work with T8/T12 ballasts and vice versa. Most manufacturers claim that their high-quality T5 ballasts have total harmonic distortion (THD) of less than 15% and power factor of higher than 0.95. Most T5 ballasts provide constant lamp current so that the lamp gives constant light output within a range of input voltage, say 180-250 V, and independent of the mains supply fluctuations. Dimming ballasts for T5 lamps are also available in the market.

T5 HO lamps are less efficacious than T5 HE lamps. T5 HE lamps have slightly lower maximum luminous flux output per unit length, but consume less power per unit length, than the new generation T8 triphosphor lamps. Therefore, T5 HE lamps have higher luminous efficacy than T8 triphosphor lamps. However, T5 HO lamps have higher maximum luminous flux output per unit length than T8 triphosphor lamps. Here, maximum luminous output refers to the luminous output at the most efficient ambient temperature, which is 35°C for T5 and 25°C for T8 lamps. The energy efficiency comparison between T5 and T8 lamps is complicated by the temperature effects and a detailed discussion on this issue is given in Section 3. Tables 1(a)-(b) list the electrical and luminous characteristics of T5 HE and T5 HO lamps, respectively.

2.3 Effects of lamp ambient temperature

Fluorescent lamp light output depends strongly on the ambient temperature around the lamp. This is due to that light output depends on the mercury vapour pressure which varies strongly with temperature. Some more explanation on this aspect is given by Chung and Yip (2002). T5 fluorescent lamps are designed such that they give maximum light output at a lamp ambient temperature of 35°C (NLPIP, 2002). This is 10°C higher than that for T8/T12 lamps which operate most efficiently at 25°C. Figure 1 shows the relative light output of T5 and T8 lamps as a function of lamp ambient temperature. The significant difference between the two curves shows that comparisons of the energy efficiency based on the quoted maximum luminous efficacy values may not indicate which lamp is more efficient for a given application. The light output and electrical performance at 25°C and 35°C are listed in Tables 1(a)-(b) for all common T5 lamps. The impact of ambient temperature on energy and economics will be discussed in Sections 3 and 4.

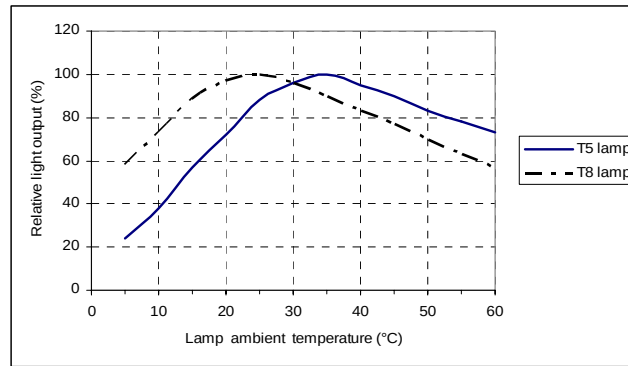


Fig.1 Variation of light output with ambient temperature for T5 and T8 lamps

Table 1(a). Typical electrical and luminous characteristics of T5HE lamps (data from manufacturers' catalogs)

Nominal length (mm)		550	850	1150	1450
Nominal lamp power (W)		14	21	28	35
Lamp power (W)	25°C	14.0	20.6	27.9	35.5
	35°C	13.7	20.7	27.8	34.7
Lamp voltage (V)	25°C	86	126	166	205
	35°C	82	123	167	209
Lamp current (A)	25°C	0.165	0.165	0.170	0.175
	35°C	0.170	0.170	0.170	0.170
Initial luminous flux output (lm)	25°C	1250	1900	2600	3300
	35°C	1350	2100	2900	3650
Luminous efficacy (lm/W)	25°C	89	92	93	93
	35°C	98	101	104	105
Lumen maintenance at 10,000 hours (%)		92	92	92	92
Rated life (165 min on, 15 min off cycles) (hours)		20,000	20,000	20,000	20,000

Table 1(b). Typical electrical and luminous characteristics of T5HO lamps (data from manufacturers' catalogs)

Nominal length (mm)		550	850	1150	1450	1450
Nominal lamp power (W)		24	39	54	80	49
Lamp power (W)	25°C	22.5	38.0	54.1	79.8	49.2
	35°C	22.5	38.0	53.8	80.0	49.3
Lamp voltage (V)	25°C	77	118	120	152	195
	35°C	75	112	117	145	191
Lamp current (A)	25°C	0.295	0.325	0.455	0.530	0.255
	35°C	0.300	0.340	0.460	0.555	0.260
Initial luminous flux output (lm)	25°C	1750	3200	4450	6450	4450
	35°C	2000	3500	5000	7000	4900
Luminous efficacy (lm/W)	25°C	78	84	82	81	90
	35°C	89	92	93	88	99
Lumen maintenance at 10,000 hours (%)		92	92	92	92	92
Rated life (165 min on, 15 min off cycles) (hours)		20,000	20,000	20,000	20,000	20,000

3. Energy Issues

One advantage of T5 lamps over T8 lamps is the higher lamp efficacy. However, comparisons of the performance between T5 and T8 systems based on the maximum light output values lead to a distorted picture. In fact, T5 lamps are not always the most energy efficient light source for an application. Detailed study has to be carried out case by case before deciding which lamp system, T5 or T8, has higher efficacy for the particular application. T5 lamps are designed for electronic ballasts, therefore, the published values of maximum light output and lamp efficacy refer to the values measured using electronic ballast with the lamp at the optimum ambient temperature of 35°C. T8 lamps are originally designed for magnetic ballasts and the published values of light output and lamp efficacy usually refer to the standard photometric condition with the lamp operated by standard magnetic ballast and the measurements carried out at an ambient temperature of 25°C. Table 2 gives a comparison of light output and efficacies at different temperatures among three lamp-ballast systems: 28W T5 lamp (all T5 lamps use triphosphors and must be operated with electronic ballast), 36W T8 triphosphor lamp with magnetic ballast, and 36W T8 triphosphor lamp with electronic ballast.

Table 2. Light output and typical lamp and circuit efficacies at various ambient temperatures in still air

	Lamp and ballast type (nominal 4-foot or 1200 mm)	15°C	20°C	25°C	30°C	35°C
Light output (lm)	T5 28W Electronic	1650	2150	2600	2800	2900
	T8 36W Magnetic	2950	3200	3350	3200	3000
	T8 36W* Electronic	2850	3050	3200	3050	2900
Lamp efficacy (lm/W)	T5 28W Electronic	66	80	93	100	104
	T8 36W Magnetic	84	89	93	89	86
	T8 36W* Electronic	92	95	100	95	94
Circuit efficacy (lm/W)	T5 28W Electronic	57	69	81	88	91
	T8 36W Magnetic	64	68	71	68	65
	T8 36W* Electronic	81	85	89	85	83
*Note: typical T8 36W lamp/electronic ballast system operates with lamp power of 32 W.						

Table 2 shows that at ambient temperature of 25°C, a T5 28W lamp has approximately equal efficacy with a magnetic-ballast-operated T8 36W lamp. When the power consumption of the ballast is taken into account, at 25°C, the circuit efficacy of the T5 lamp system (about 81 lm/W) is higher than that of T8 triphosphor lamp circuit with magnetic ballast (about 71 lm/W) due to the much higher power consumption of the magnetic ballast. However, at 25°C, both the lamp and circuit efficacies of a T5 28W lamp system (93 and 81 lm/W respectively) are lower than the corresponding value for a T8 36W triphosphor electronic system (100 and 89 lm/W). The table also shows that at ambient temperatures of 15° and 20°C, T8 electronic systems have much higher lamp and circuit efficacies than T5 systems. This means that for open-bottom luminaires installed in air-conditioned spaces, where the air temperature inside lamp compartments is near to or lower than 25°C, T8 triphosphor lamp systems with electronic ballasts can be more energy efficient than T5 systems. When cool air from air diffusers can enter directly into the luminaire, the lamp ambient temperature can be quite low and the lamp wall cooling effect is further enhanced by the air flow current around the lamp tube. The above discussion shows that comparisons of lamp and system efficacies based on published maximum values, which occur at different temperatures for T5 and T8 lamps, may be misleading and could lead to wrong decisions in respect of lamp selection.

In addition to higher lamp efficacy, the energy efficiency of T5 lighting systems can be further improved by better optics of the luminaire. The light output ratio (LOR), which measures the luminaire efficiency, of a T5 luminaire is higher than that of a T8 luminaire due to reduced self-shielding of the light by the lamps. Furthermore, miniaturization of T5 lamp gives two additional improvements of luminaire efficiency. Firstly, the thinner T5 lamp is nearer to a line source so that better optical system can be designed for directing more light to where it is needed. Secondly, high reflectance reflector material becomes economic because less material is needed in a T5 luminaire due to the reduced size. The luminaire efficiency depends on the material used and the luminaire design, here a comparison is made for luminaires with high reflectance material. Table 3 gives a comparison of efficacies between T5 and T8 1200 mm (4-foot) single lamp luminaires produced with the same material but with reduced size for the T5 luminaire. The values are estimated based on typical values for power consumption, light output ratio and maximum light output values without considering temperature and other factors.

Table 3. Comparison of maximum efficacies with lamps operating under the respective optimum conditions

Lamp at optimum operating temperature (i.e. T8 at 25°C and T5 at 35°C)	T8 36W lamp with magnetic ballast	T8 36W lamp with electronic ballast	T5 28W lamp with electronic ballast
Initial lamp lumen output	3350 lm	3200 lm	2900 lm
Lamp power	36 W	32 W	28 W
Circuit power	47 W	36 W	32 W
Circuit efficacy based on initial lamp light output	71 lm/W	89 lm/W	91 lm/W
Light output ratio of luminaire	0.7	0.7	0.8
Initial light output from luminaire	2340 lm	2240 lm	2320 lm
Luminaire efficacy	50 lm/W	62 lm/W	72 lm/W

From Table 3, although the T5 lamp produces a smaller lamp lumen output than the T8 lamp, the light output of the T5 luminaire is roughly equal to or even slightly higher than that of the T8 luminaire due to the higher luminaire efficiency as a result of the smaller size and better optical design. Provided that T5 lighting systems are used at or near to the optimum conditions, they can give significant energy savings. However, the effect of temperature has been ignored in the design and application of many T5 lamp systems. In order to demonstrate the effect of temperature on T5 and T8 lamp systems, a comparison is given below for three T5 and T8 lamp systems.

Fig.3 shows the variation of the luminaire light output with lamp ambient temperature of three single-lamp luminaires: T5 28W (electronic), T8 36W triphosphor magnetic ballast, T8 36W triphosphor electronic ballast. Fig.4 shows a graph of the luminaire efficacy (light output from luminaire divided by electric power input) plotted against ambient temperature of these three systems. The graph shows that the T5 luminaire has higher efficacy than T8 magnetic ballast luminaire for lamp ambient temperatures higher than around 15°C. The T5 luminaire has higher efficacy than T8 electronic ballast system for lamp ambient temperature higher than about 23°C. This means that T5 lamp systems using open-bottom louvred luminaires may not be more energy efficient than T8 electronic ballast systems in modern air-conditioned offices where room air temperature is often kept at below 25°C and cool air supply from air diffusers in the ceiling may enter the luminaire lamp compartment resulting in temperature around the lamps of below 20°C. When the luminaire light output and efficacy are plotted for the three different lamp systems with the same light output ratio, graphs like Fig.5 and 6 can be obtained. These graphs show that the T5 system is less efficient than the T8 triphosphor electronic system for lamp ambient temperatures lower than about 28°C if the T5 luminaire provides no extra gain in luminaire efficiency, i.e. not higher in LOR. Even for lamp ambient temperatures higher than 28°C, the T5 system has only a small gain in luminaire efficacy (<15% at 40°C) over the T8 system.

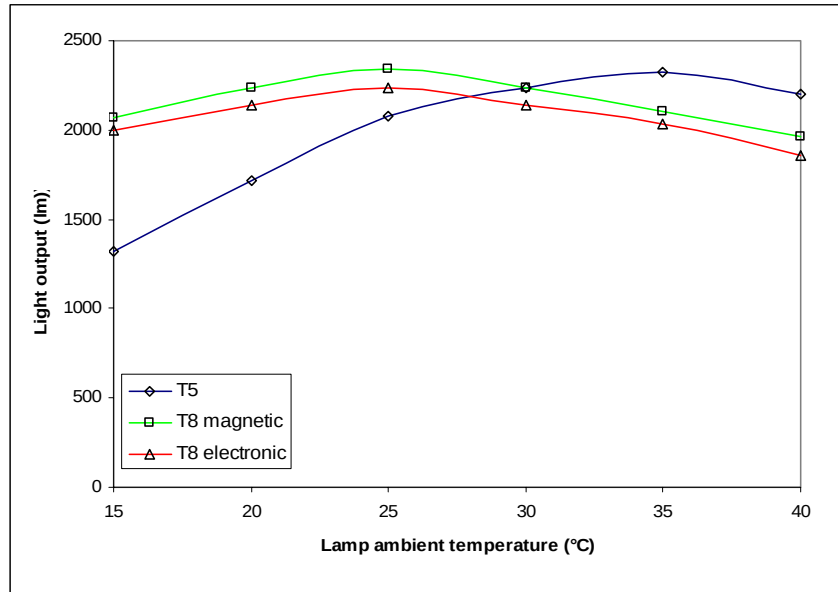


Fig.3 Luminaire light output of 1200mm single-lamp T5, and T8 magnetic and electronic systems at different ambient temperatures.

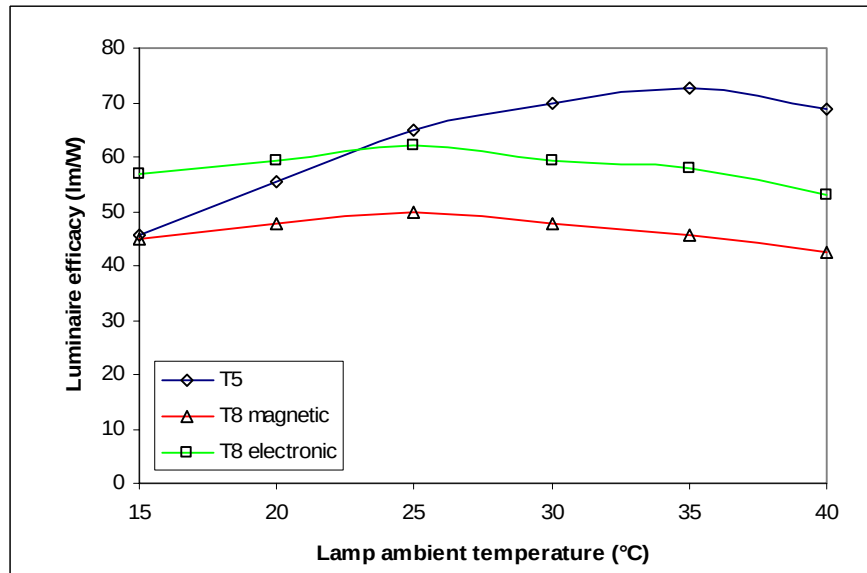


Fig.4 Luminaire efficacy of 1200mm single-lamp T5, and T8 magnetic and electronic systems at different ambient temperatures.

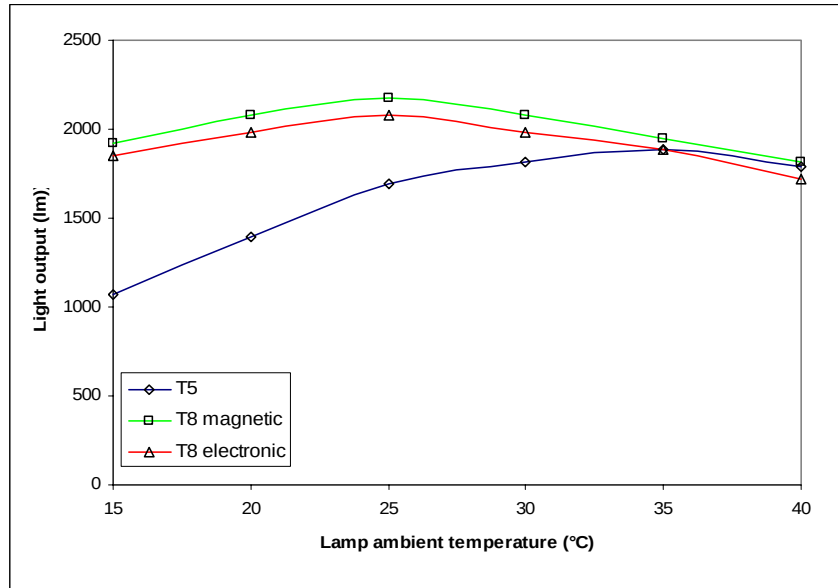


Fig.5 Luminaire light output of 1200mm single-lamp T5, and T8 magnetic and electronic systems at different ambient temperatures when the three systems have the same light output ratio.

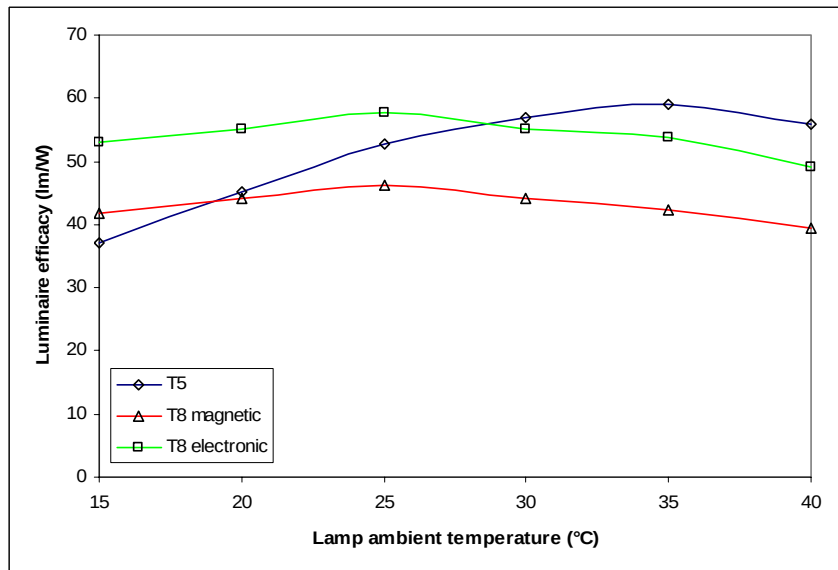


Fig.6 Luminaire efficacy of 1200mm single-lamp T5, and T8 magnetic and electronic systems at different ambient temperatures when the three systems have the same light output ratio.

4. Economic analysis

Lighting costs depend on many factors, which vary with time and location. As a result, accurate economic analysis valid for all places is not possible. Luminaire cost for a given type of lamp can vary widely. Installation costs vary from place to place and from time to time. Electricity costs vary with location and time as well. For demonstration of economic comparison between T5 and T8 systems, lighting costs have been calculated for comparison between: (i) T8 and T5 direct lighting systems; and (ii) T8 and T5 HO indirect uplighting systems. A medium size open-plan office of dimensions 15 m by 15 m was used in the cost analysis calculations. Both the T8 direct and uplighting systems use 36W triphosphor lamps, the direct system uses 2-lamp luminaires with a single electronic ballast while the uplighting system uses 3-lamp luminaires with also a single electronic ballast. The T5 direct lighting system uses luminaires with 2 T5 HE 28W lamps and a single electronic ballast. The T5 indirect uplighting system uses luminaires with 2 T5 HO 54W lamps and a single electronic ballast. The

following assumptions have been made in the economic analysis: (i) the office is illuminated to about 500 lux over the whole working plane; (ii) the lamps operate 3000 hours annually, (iii) the lighting installation has a life of 10 years. The last assumption takes into consideration of the dynamic business environment that offices are renovated in periods shorter than the actual hardware life time of lighting systems, a life of 10 years is a conservative estimate. Table 4 lists the economic analysis comparison results.

Table 4. Cost comparison between T5 & T8 lighting systems for a medium size open-plan office

Lamp system	Direct lighting		Indirect uplighting	
	2-lamp T8 36W electronic	2-lamp T5 HE 28W	3-lamp T8 36W electronic	1-lamp T5 HO 54W
Layout	6 x 6	6 x 6	5 x 6	5 x 5
No. of luminaires	36	36	30	25
No. of lamps	72	72	90	50
Power per luminaire	72 W	64 W	108 W	120 W
Total lighting power	2592 W	2304 W	3240 W	3000 W
Lighting power density	11.5 W/m ²	10.2 W/m ²	14.4 W/m ²	13.3 W/m ²
% increase of initial cost of T5 system over T8 system	-	+11%	-	+1%
% increase of operation cost of T5 over T8 system	-	-8%	-	-6%
% increase of total cost of T5 system over T8 system	-	+4%	-	-2%

Based on current prices, T5 direct lighting system is about 11% higher on initial cost than T8 direct lighting system. T5 direct lighting system is 8% lower on energy and maintenance costs than T8 system. However, the total lighting cost of T5 system is still 4% higher than T8 system if a 10-year life time is considered. For indirect uplighting system, the initial costs of the T8 and T5 systems differ only very slightly since much less T5 luminaires are required. The operation cost of the T5 uplighter system is about 6% lower than that of the T8 system so that the T5 system is 2% lower in the total lighting cost in 10 years. In this medium size office, using T5 HO uplighting can achieve an almost equal initial cost and a significant reduction in operating cost compared with T8 uplighting system. If the project is larger, using T5 luminaires can provide higher economic benefit by reducing initial cost as well as the operation cost (NLPPI, 2002).

5. Indoor visual environment

A disadvantage of T5 lamps is the higher glare they may produce, especially for the direct lighting system. Glare is related to the luminance of the lamp surface. Due to similar light output from a reduced surface area, T5 lamps have much higher surface luminance than T8 lamps. Measurements showed that T5 HE lamps are brighter than T8 triphosphor lamps of similar length by about 15% (for the longer lamp) to 70% (for the shorter lamp). T5 HO lamps have luminance 2.1 to 2.5 times the luminance of T8 triphosphor lamps of similar length. Table 5 lists the luminance, in kcd/m², of T5 HE, T5 HO and T8 triphosphor fluorescent lamps. T5 HO lamps are much brighter than T5 HE lamps due to the increase in light output for the same lamp length.

The higher luminance of T5 lamps leads to larger glare and discomfort for room occupants and may also cause higher reflected glare on computer screens or other visual display units. Proper glare control can be achieved by parabolic louvers, metal mesh filters or acrylic diffusers. Cleef and Bex (1998) have described the use of an omnidirectional luminance control (OLC) system which uses lamella louver to shield the lamp so that it is not visible at critical angles of view while still allowing the maximum amount of light to pass through the louver. If an indirect uplighting system is designed for attaining higher lighting quality, using T5 HO lamps is more sustainable than using T8 lamps as discussed above.

Table 5. Lamp surface luminance for T5 HE, T5 HO and T8 triphosphor lamps

Lamp nominal length	Lamp surface luminance in kcd/m ²		
	T5 HE	T5 HO	T8 triphosphor
550/600 mm	17	25	10
850/900 mm	17	28	11
1150/1200 mm	17	29	12
1450/1500 mm	17	32	15

6. Impact to the global environment

The slightly higher energy efficiency of the T5 lamps makes them more environmental friendly by saving fossil fuels, although by only a small amount as compared with the new generation T8 lamps. Nevertheless, T5 lamps do create less impact to the global environment in other aspects as a result of the use of less material in the production, transportation and sales of the lamps.

All fluorescent lamps contain mercury, which is a toxic material. Earlier fluorescent lamps contain large dose of mercury, up to several hundred milligram, due to the technical difficulty in the past in introducing small dose into the lamp tube. Larger dose was required due also to the absorption of mercury by the phosphor and glass wall. T5 lamps have an improved phosphor coating that prevents mercury from being absorbed into the phosphor and glass wall. Improved mercury dosing technology allows a very small amount of mercury (about 3 mg) to be put into the lamp. Reduction of mercury content in the T5 lamps is a positive contribution to a better environment as less toxic material will go into the landfill even if the lamps are not recycled at the end of their life.

The smaller dimension of the T5 lamps is a real advantage over T8 lamps in the contribution to a better global environment. T5 lamps use fewer materials in the production and packaging. The amount of glass and phosphors used in a T5 lamp is less than 60% of that used in a T8 lamp of the same nominal length, i.e. about 40% saving of raw materials. This not only saves raw materials but also saves the energy used in the production of T5 lamps. The volume of a T5 lamp is less than 40% of the volume of the T8 lamp of similar length. Therefore, the packaging material used for transporting the T5 lamps and luminaires from the manufacturing plant to the user is greatly reduced by over 60% when compared with the T8 system. The packaging material used for one T8 lamp can be used for approximately two and a half T5 lamps. Packaging material is commonly carton paper produced from wood. The large saving in packaging material contributes greatly to the conservation of natural resources and hence to environmental sustainability. The reduced size and weight also allow the use of less energy in the transportation of T5 lamp systems.

The coating applied to the phosphor layer in T5 lamps improves the lumen maintenance of the lamp. The light loss due to lamp depreciation is only about 7% after 10,000 hours of operation of T5 lamps as compared to 15% for uncoated triphosphor lamps. If this is considered in lighting design, then a larger maintenance factor can be used. This results in that a smaller number of luminaires is required to give a certain maintained illuminance. If designed properly, this achieves significant energy saving and hence contributes to a sustainable global environment. The better lumen maintenance also allows a longer economical life of the T5 lamp, which is as long as 20,000 hours, about 25% longer than a normal triphosphor T8 lamp. However, the improved phosphor coating is not unique in T5 lamps; new

generation T8 triphosphor lamps also have this coating which gives similar lumen maintenance and economical life as the T5 lamps.

7. Conclusion

The characteristics of T5 lamp systems have been reviewed and compared with those of T8 systems. The T5 lamp has higher efficacy than the T8 lamp and T5 luminaires have higher luminaire efficacy than the T8 luminaires. However, temperature effects on light output and the fact that T5 and T8 lamps operate optimally at different temperatures make the performance comparison difficult. T5 lamp systems with exposed lamps may not be more energy efficient than T8 lamp systems in air-conditioned rooms. Careful design of the lamp system should consider its interaction with the air-conditioning system so that the most efficient system can be selected. T5 lamp systems do contribute to a better global environment due to the savings in raw material in the production and transportation of the lamps and luminaires and the savings in energy for production and operation of the lamp. T5 lamps produce less pollution to the environment due to the use of smaller amount of mercury. The application of a phosphor coating also contributes to the sustainability due to lengthening of the economic life of the lamp. Economic analysis show that although currently T5 lamps are more expensive than T8 lamps, using T5 high output lamps can provide an economic benefit by reducing the number of luminaires used so that both initial and operation costs are reduced.

Acknowledgements

This work is supported by a Research Grant (G-T454) of the Hong Kong Polytechnic University.

References

- Chung T.M. and Yip C.H. (2002). Use of infrared thermograph imaging technology in the assessment of fluorescent lamp operating performance. *Proceedings of Joint Symposium 2002: Achieving Sustainable Performance in Built Environment – HKIE, ASHRAE, CIBSE, PolyU – 19 November 2002, Hong Kong*. pp. 2.1-2.10.
- Kane R. and Sell H. (2001). *Revolution in lamps: A chronicle of 50 years of progress*, 2nd edition, The Fairmont Press, Lilburn.
- NLPIP (2002). *Lighting Answers: T5 Fluorescent Systems*. Volume 6 Issue 1, July 2002. National Lighting Product Information Program. Lighting Research Center, Rensselaer Polytechnic Institute.
- Van Cleef, P. and Bex, J.M.G. (1998). 'TL'5: The Opportunity for Fluorescent Lighting In Offices, Shops, and Public Buildings, *Lighting Research & Technology*, 30(1), 19-23.