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HYBRID LIGHTING SYSTEMS: COSTS AND BENEFITS

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Abstract
This paper analyses costs and benefits of using hybrid lighting systems (HLS) as an alternative to conventional electric lighting system in locations throughout Europe. Whole life-cycle costing evaluation method is used to estimate the payback period of currently available hybrid systems. The influence of variations in system and energy prices on payback period and viability of hybrid systems is investigated.

Keywords: Hybrid lighting systems, cost, benefit, payback period.

1. INTRODUCTION

Daylight is the preferred source in buildings due to its beneficial effect on human well-being and performance. Its potential to conserve energy and hence protect the environment has stimulated interest as an electric lighting substitute. The recent development of 'daylight guidance technology' allows redirection of daylight into areas of buildings that cannot be lit using conventional glazing. The two main guidance types are the commercially successful tubular daylight guidance systems (TDGS) and the newer hybrid daylight/electric systems (HLS). This study of costs and benefits of hybrid systems makes the case for utilizing this form of daylight provider as an alternative to TGDS in combination with a conventional electric lighting system (ELS).

2. EVALUATION METHOD

The methodology used to evaluate system costs and benefits is Whole Life Cycle Costing (WLCC). This provides more realistic comparison data than the simple payback method which is commonly used for lighting system evaluation.

2.1. Whole life cycle costing (WLCC)

WLCC takes into account the costs of running and operating buildings (or components) over their lifespan as opposed to a specified period of time. The concept of 'time value' reflects the fact that present capital is more valuable than a similar amount of money received in the future. Its computation is based on present value, compounding and discounting techniques [3], which can be computed according to the formulae:

$$PV = FV\,(1 + r)^{-t} \tag{1}$$
$$FV = K\,(1 + i)^{t} \tag{2}$$

Where: PV = present value, FV = future value of capital, K= annual cost, r = discount rate, i = inflation rate, t = period of analysis.

2.2. Net Present Value (NPV)

NPV is a variation of WLCC where the PV of cash flow is subtracted from the PV of cash outflows. NPV is thus a metric for measuring the net value of an investment in building assets in today's money. Accordingly, when the difference between alternative lighting systems reaches zero, this is a turn point where a system pays back the investment and gains benefits. NPV is calculated using the formula:

$$NPV = \Sigma\,(PV_b - PV_c) \tag{3}$$

Where: PV_b = discounted present value of benefits, PV_c = discounted present value of costs.

From Eq. 3 the NPV can be calculated as follows:

$$NPV = I_{0\_EL} + \Sigma\, PV_{E\_EL} + \Sigma\, PV_{M\_EL} - [(I_{0\_EL} + \Sigma\, PV_{E\_EL} + \Sigma\, PV_{M\_EL}) + (I_{0\_DL} + \Sigma\, PV_{M\_DL}) + \Sigma\, PV_J - \Sigma\, \Delta PV_S - R_0]$$
$$= \Sigma\, \Delta PV_S + R_0 - [I_{0\_DL} + \Sigma\, PV_{M\_DL} + \Sigma\, PV_J] \tag{4}$$

Where: I_{0_EL} *the electric lighting system initial investment [£]*
I_{0_DL} *the daylighting system initial investment [£]*
PV_{E_EL} *the PV of electric system annual energy cost [£]*
PV_{M_EL} *the PV of electric system annual maintenance cost [£]*
PV_{M_DL} *the PV of daylighting system annual maintenance cost [£]*
PV_J *the PV of future investment for replacement [£]*
ΔPV_S *the PV of total annual cost saving according to reference case [£]*
R_0 *residual value of the lighting system [£]*

In this work a system is considered to have both a daylight and electric component and thus for hybrid systems the cost of a separate electric system is zero. Daylight costs comprise capital costs and maintenance. Therefore a NPV of zero means that the sum of the savings and residual value pays the daylight initial, replacement and maintenance costs.

From Eqs. (1) & (2) PV can be expressed as follows:

$$PV = K\,(1 + i)^t / (1 + r)^t \qquad (5)$$

From Eqs. (4) & (5) NPV can be expressed as follows:

$$NPV = \frac{\quad}{\quad} + R_0 - [I_{0\_DL} + \frac{\quad}{\quad} + \frac{\quad}{\quad}] \qquad (6)$$

Where: ΔK_S *Total annual cost saving according to reference case [£]*
K_{M_DL} *Daylighting system annual maintenance cost [£]*
I_j *The investment for replacement j at time x, y or z [£]*
t *Considered time period for evaluation [year]*
i_M *Maintenance inflation*

3. EVALUATION PROCESS

Previous work studied the light delivery potential of using HLS at various locations throughout Europe [9]. This work studies the cost of their use in representative locations.

3.1. Locations and lighting systems

Four locations from the HLS feasibility study were used for this study - London (51˚N, 0°), Moscow (56˚N, 38°E), Valencia (39˚N, 0°) and Athens (38˚N, 24°E) – representing maritime and continental; and northern European and Mediterranean locations. The guidance systems are the commercially available hybrid systems: Hybrid Solar Lighting (HSL), Parans and Solar Canopy Illuminance (SCIS) systems and, for comparison, passive TDGS.

3.2. Building type

The systems were assumed to light office spaces. Offices are major employment locations and constitute a large sector of the total building stock. For almost all office buildings working hours coincide with daylight hours. Electric lighting is the major energy consumer in offices and thus a case exists for the provision of daylight as a substitute. This work is based on the lighting of a windowless modular space of 6m x 12m x 3m high, with the short edge facing south, using each system in turn. Reflectance of ceiling, walls and floors are 70%, 50% and 20% respectively. Average illuminance level on work plane, 0.8m from the floor, is assumed 300 lx over annual working hours of 3650 hours.

3.3. Calculation and results

The current study focuses only on the monetary costs and benefits – no attempt is made in incorporate benefits of user well being due to daylight. A life-cycle study of 20 years is used as being a typical life of lighting equipment. The results of this study are expressed in terms of payback period (PB). For each system in every location the PB curves use electricity prices ranging from 10p/kWh to 50p/kWh. The electricity price median over EU-27 countries in 2009 is 14.01p/kWh, which has risen some 46% in 5 years [7]. The PB shows the annual variation for both system, and electricity, price variation.

4. LIGHTING COSTS

4.1. Cost data

Initial capital cost is one-off costs of equipment at the beginning of a project. For purposes of this work the standard elements used in the calculations include equipment price and

Table 1. Lighting systems' capital and annual running costs summery.

System	N°	Low volume production capital cost (£) Initial	Installation	Total	Cost/m²	High volume production capital cost (£) Initial	Installation	Total	Cost/m²	Annual running cost (£)
Elec.*	-	-	-	-	-	-	-	3672	51.0	126
TDGS	10	-	-	-	-	4118	2359	6477	90.0	89
HSL	2	20000	3750	23750	329.9	3750	1250	5000	69.4	424
Parans	8	84964	1061	86025	1194.8	19984	1061	21045	292.3	289
SCIS	2	7470	2184	9654	134.1	1250	2184	3434	47.7	314

* Fit out cost only is included to be comparable with the other systems.

installation fees (excluding delivery charges, taxes, design fees, building adaptation cost, and overheads). The data are either obtained from manufacturers' price lists if available or calculated from engineering price databases such as SPON [5].

Running costs are incurred throughout the life of the project include maintenance, repair and replacement costs (hereafter, altogether simply called maintenance) and electric power cost. Lamps are assumed to be replaced at the end of their nominal life. Passive and active daylighting elements are assumed to require regular cleaning, and active systems assumed to require also regular visits for repair and inspection by skilled labour. Labour rates and estimated cleaning time was obtained from maintenance price books [2]. Electricity rates have been obtained from the European Commission statistics [7].

4.2. Electric system cost

For each office module nine luminaires are required to achieve the specification, each containing two 40W/TT5 lamps (rated at 3150 lumens) with electronic dimming ballasts. The maximum annual electricity consumption is 2628 kWh. Capital costs, obtained from SPON include shell and core costs ranging from 15 £/m² to 20 £/m²; fit out costs from 40 £/m² to 60 £/m², and includes dimming controls and tax [5].

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4.3. TDG system cost

Using the CIE calculation method, 10 N° Ø450mm TDGSs were necessary to give 300 lux assuming an external illuminance of 35klx (hourly mean of global horizontal illuminance over Europe) [4, 15]. TDGS manufacturer's prices were used for components [10].

4.4. Hybrid lighting systems costs

The efficiency of each HLS was as stated by the system developer or manufacturer. In summary, these were one HSL system for 90-100m²; one Parans system for 20-30m² and one SCIS for 3m x 10m [8, 12, 13]. Assuming an external normal beam illuminance equal to 30 klx; two HSL systems, two SCIS, or eight Parans systems are required to meet the recommended illuminance level. As the HLS market is still a growing two capital costs are used, the first the current cost for low volume production, and the second that predicted for high volume. In the absence of either the 'experience curve' approach is used in which costs fall by a constant and predictable percentage each time cumulative volume doubles. Studies suggest reduction of 10% to 30%, which used to estimate Parans high volume and SCIS low volume [6]. The low volume cost for HSL was its 2007 launch cost, and a predicted high volume cost was provided by the developer [8]. Since the Parans system is available on the market, the current list price was used. Installation costs were obtained using manufacturers' instructions and standard labour costs [5]. The SCIS is still in the demonstration stage and actual costs are not available. The developers suggest a cost of £625[1] for the whole system based on 10000 units produced per year [14]. An estimate of low volume production cost; using the 'experience curve' suggests a unit cost of £3735. An estimate by the authors based on system components prices, and standard labour costs gives £3800.

5. LIGHTING BENEFITS

5.1. Saving in capital cost of the ELS

The important feature in HLSs is that since they include their own lamps they can replace conventional electric lighting systems, giving a saving in the capital cost. Assuming that the light output from the HLS can provide the required illuminance level during night operating hours, the fit out costs that estimated in Section 4.2 will be completely saved. However shell and core costs will still be required to cover the cost of items not included in the HLSs packages such as wiring and switches.

[1] Currency exchange rate of £1 = US $1.6 is used wherever needed through the whole paper.

5.2. Saving in running cost of the ELS

Most TDGS may be linked to an ELS such that available daylight is used to supplement or replace ELS output, offsetting energy consumption and reducing maintenance costs. Also lamp replacement intervals will increase because of reduced burning hours. Energy load saving is estimated using software developed by the authors [9]. For the purpose of this work, the percentage maintenance cost saving is assumed to be equal to the percentage of full daylight utilization during the assumed annual working hours. The benefits apply to all maintenance costs, notably, lamp replacement and cleaning, and longer lamp replacement intervals. During periods of hybrid lighting usage lamps will be dimmed with a positive effect on lamp life. For this calculation it is assumed that cleaning costs are also a function of daylight utilization hours obtained from the mentioned software.

5.3. Residual value

No residual value guarantee scheme is offered by the developers of HLS to purchase the assets on a future date at a pre agreed value. The residual values of HLSs are likely to be solely the recycling value which is negligible in comparison with capital cost.

6. USING WLLC METHOD TO ESTIMATE PAYBACK PERIODS

NPV was calculated for each of the 20-year period of study in order to determine the payback point. The calculation was repeated for each system and each location using the full range of electricity prices.

6.1. Inflation and discount ratios

Typical inflation in countries with stable economies is under 5%. In the UK over the last decade, the consumer price index (CPI) of annual inflation ranged between 0.8% and 3.8%, with mean of 2.3% [11]. Over the same period of time electricity inflation has been between -2.1% and 23.4%, with mean of 6.5%[2]. Labour costs inflation was between -6.7% and 13.8%, with mean of 2.8%[3]. The average annual UK official bank interest rate is between 0.5% and 6%, with mean of 4.3% [1]. In this work the mean values used and thus 2.3%, 6.5%, 3.5% and 4.3% represent the general inflation, electricity inflation, labour cost inflation and the discount rate respectively.

6.2. Estimated payback periods

The following charts illustrate the PB, calculated using Eq. (6) using costs values summarized in Table 1, likely savings as described in Section 5, and the inflation and discount ratios outlined above. The system current cost is expressed as 100% representing low volume production level of HLS. The TDGS information is based on current manufacturers cost. The predicted high volume costs, as a percentage of the current cost, are 21%, 24.5% and 35.6% for HSL, Parans and SCIS respectively. PB less than five years is considered a 'reasonable' PB.

6.3. Results

Estimated PBs are influenced by two main factors: electricity price and system cost. The dotted line identifies the local electricity price for 2009 for each location. In general it is can be observed that the HLS systems have long PB even using favourable assumptions. Investment in TDGS, with its current price, results in a PB of 5-6 years assuming electricity prices of 50p. Whilst these might be reached in the long term price a short term expectation of 20p results in PB of 12-16.5 years (see Figure 1).

The HSL system with its current cost has an unacceptable PB but using the high volume cost (21% of current) leads to PB of less than 5 years at electricity price level around 25p in the Southern and Eastern locations (see Figure 2).
Parans system even with high volume production cost, (24.5% of current) has a long PB. A cost no more than 10% of that current is necessary to pay the investment back in five years in the Southern locations assuming electricity at 50p. Otherwise, it needs to be installed in locations with mean external illuminance greater than 60 klx (see Figure. 3).

The low volume estimated cost for SCIS gives a pay back in reasonable period in Southern locations using 50p electricity. A 30% reduction in capital cost gives a five year payback by 30p level in the South and by 40p level in the North. However for the high volume cost, 35.6% of the current, the cost of 47.7£/m^2 is cheaper than the ELS at 51£/m^2 (see Figure 4).

7. DISCUSSION

It is apparent that the simplest systems, which rely on low concentrations of sunlight, have the

[2] Electricity inflation percentages have been calculated using the electricity prices over the last decade [7].
[3] Labour costs inflation percentages have been derived from the UK hourly labour costs [7].

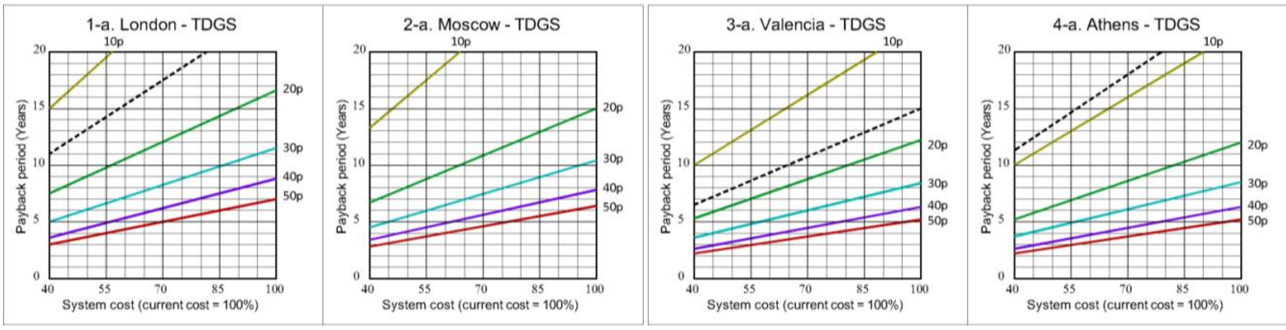

Figure 1. TDGS payback periods.

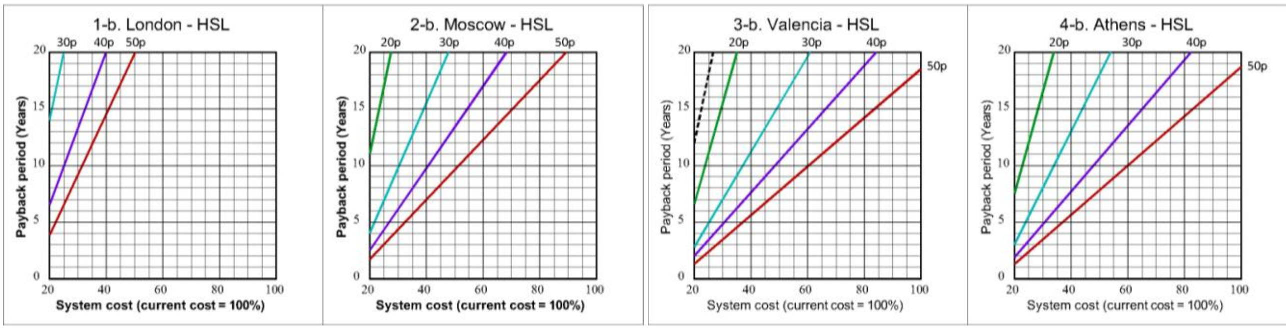

Figure 2. HSL system payback periods.

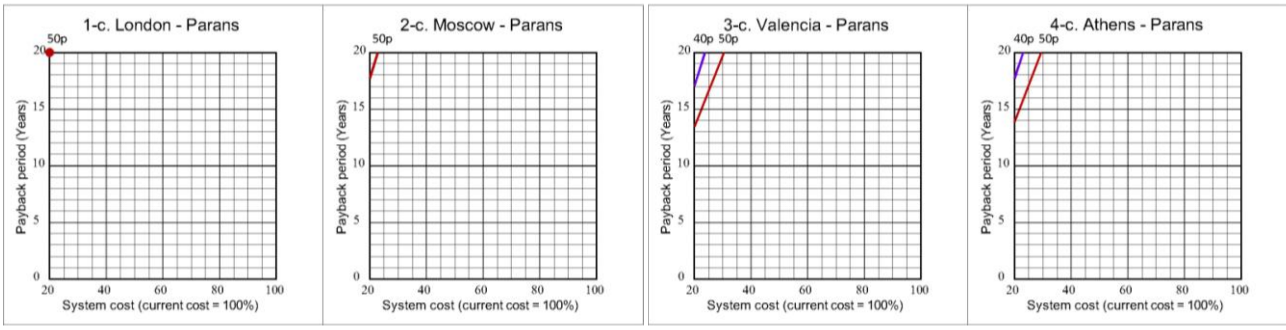

Figure 3. Parans system payback periods.

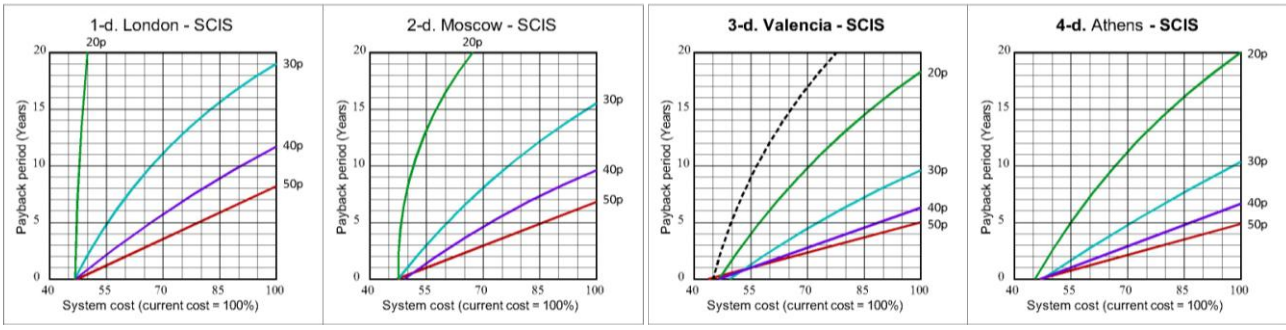

Figure 4. SCIS payback periods.

shortest PB because less investment is required. This relationship is believed to be true either at the current or predicted level of production. The one possible exception is the high volume SCIS, which is claimed to be cheaper than the simpler system TDGS. The TDGS is a mature commercially available technology but is still unable to return the investments in a five year period in Europe with the current prices of electricity. To approach the reasonable PB, TDGS needs average electricity prices to be at least doubled and the system price to be reduced by no less than 30%. That the technically simple TDGS technology struggles to achieve to economic payback suggests the same is true for HLS.

Currently HLS have long PB. Three influences have to work together to shrink the PB; electricity price, system capital cost, and available external local mean illuminance. The trend for electricity price is universally upwards – over five years from 2005 the UK rise is 70%, and about 46% all over the EU-27 countries [7]. That suggests that in ten years the electricity price in the EU-27 is likely to exceed the average of 30p/kWh, making the technologies more economic. The current hybrid capital costs are a significant barrier to their use, but further development and increasing production may lead to reductions. A capital cost equal to one fifth the current price in combination with 30p electricity price level would allow HSL to approach the reasonable PB zone in most European locations. However a price of one tenth that current combined with 50p electricity price level is required to bring Parans system to that point. However only a 30% cut the SCIS current price is required to allow it to approach a five year PB with electricity prices of 30p in the Southern locations or 40p in the Northern locations.

High external illuminance levels help to reduce the required number of TDG, HSL or Parans systems, and hence, significantly reduce the capital cost. Whilst SCIS numbers can't be reduced due it is nature, its performance will be enhanced, so the hours of daylight utilisation will be increased. In southern European below 40˚N latitude; the hourly mean of normal beam illuminance exceeds 50klx, which leads to at least 40% decrease in the number of TDGS, HSL or Parans systems required thus cutting capital cost by 40%. Under these circumstances HSL will have a satisfactory PB with a 30% cut in capital cost and 30p electricity level, and that for the Parans system requiring an 80% capital cost reduction and electricity price at the 50p level.

For consistency, peripheral and intangible benefits are not taken into account in this work as they are building specific. Some may be assigned a monetary value, for example cooling loads savings and carbon emission costs, and these could be included in future cost/benefit exercises. User productivity enhancement due to the beneficial effects of daylight is not presently quantifiable. Given that staff costs are the largest component of running an office, the creation of good visual conditions using daylight guidance represents a powerful argument for their use in offices. Further investigations of these aspects on the PB periods of HLS are necessary before investors will be persuaded to back the technology for mainstream lighting applications.

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