INTELLIGENT SOLUTIONS FOR ENERGY EFFICIENT TUNNEL LIGHTING

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Abstract

The tunnel lighting environment has evolved significantly in recent years. Not only has LED technology entered the tunnel lighting world but the control of the different systems available in the tunnel has become an important element.

Today, despite these recent developments, the vast majority of tunnels are still lit entirely by high-pressure sodium lamps or high-pressure sodium with fluorescent lamps (HID solutions).

There are only a few cases of maintenance management or lamp lifetime optimisation. These HID solutions are not optimised and they consume a lot of energy; a total power consumption of more than 100kW for a 300m long tunnel.

We will illustrate how tunnel lighting can be more efficient, using control systems, better lamp lifetime management and LED lighting.

Maintenance management and control

It is possible to improve tunnel lighting design - whether HID or LED - to increase efficiency. There are five major areas where savings can be made:

- develop a precise management of the lighting stages;
- raise the number of lighting stages;
- adjust the levels according to traffic speed;
- integrate control systems;
- the use of LEDs.

The tools to improve the efficiency of a tunnel lighting design must be defined before elaborating the first tunnel lighting design.

In complex tunnel environments, we have to consider the lighting control system as part of the complete tunnel control network, including ventilation, evacuation, traffic signalisation and security measures.

Lighting manufacturers use industrial Ethernet based protocols to control the lighting network. These are easy to integrate into the tunnel management system.

Lighting stages management

In most tunnels, four different lighting stages are used in the entrance zone. Sometimes, mainly in northwest Europe, the highest lighting level only represents five per cent of the total operating time over a year.

In Table 1, we propose three alternatives for managing the different lighting stages. In this table, the luminaires are grouped within the same circuit (C1, C2…). The lighting stage "Simple" is the usual lighting stage management.

In this type of management, the same luminaire is switched on in each lighting stage. Therefore the light source of the luminaires in circuit 1 (C1) will reach the end of its life before other light sources.

Another lighting stage management (Dimming) can be implemented with a simple control system using not only ON/OFF but also 50 per cent dimming to optimise the replacement of the light sources and installation costs.

The third alternative is the optimum solution because the management system can choose several groups of luminaires to light the same lighting stage.

This way, for HID solutions, we extend the period between the lamp replacement from three years to eight or even 10 years.

Consequently, maintenance costs are significantly reduced. The maintenance lifetime of an HID solution can thus reach the maintenance lifetime of the LED solution. These three alternatives for managing the different lighting stages are not the only ones, other solutions do exist.

Table 1. Different lighting stages management. *cl/250w bi-power ballast

	Mngmt ->	Simple				Dimming					Choice of several groups					
	Power	12.50%	25%	50%	100%	12.50%	25%	50%	100%	12.50%	12.50%	25%	50%	50%	50%	100%
1	HPS 400W	C1	C1	C1	C1	C1/250W*	C1	C1	C1	C1		C1	C1	C1	C1	C1
2	HPS 400W				C2				C2				C2			C2
3	HPS 400W			C3	C3			C3	C3					C3		C3
4	HPS 400W				C2				C4						C4	C4
5	HPS 400W		C4	C4	C4	C1/250W*	C1	C1	C1		C5	C5	C5	C5	C5	C5
6	HPS 400W				C2				C2				C2			C2
7	HPS 400W			C3	C3			C3	C3					C3		C3
8	HPS 400W				C2				C4						C4	C4
9	HPS 400W	C1	C1	C1	C1	C1/250W*	C1	C1	C1	C1		C1	C1	C1	C1	C1
10	HPS 400W				C2				C2				C2			C2
11	HPS 400W			C3	C3			C3	C3					C3		C3
12	HPS 400W				C2				C4						C4	C4
13	HPS 400W		C4	C4	C4	C1/250W*	C1	C1	C1		C5	C5	C5	C5	C5	C5
14	HPS 400W				C2				C2				C2			C2
15	HPS 400W			C3	C3			C3	C3					C3		C3
16	HPS 400W				C2			-	C4						C4	C4
17	HPS 400W	C1	C1	C1	C1	C1/250W*	C1	C1	C1	C1		C1	C1	C1	C1	C1
18	HPS 400W				C2				C2				C2			C2
19	HPS 400W			C3	C3			C3	C3					C3		C3
20	HPS 400W				C2				C4						C4	C4
21	HPS 400W		C4	C4	C4	C1/250W*	C1	C1	C1		C5	C5	C5	C5	C5	C5

Closer to the CIE 88 curve

A tunnel is always over-lit in the entrance zone. With a better use of the CIE 88: 2004 curve, taking into consideration the lighting levels outside, the losses due to this excess lighting can be reduced.

These savings can reach up to 20 per cent by increasing, for example, the number of lighting stages from four to eight. In a tunnel with four lighting stages, if the luminance in the access zone increases to 60 per cent of the L20 [Figure 1a], the management system will switch on the 100 per cent lighting stage.

In this case, the power is 40 per cent higher than needed. If we add, for example, a 75 per cent lighting stage [Figure 1b], the losses will be reduced (15 per cent instead of 40 per cent).

With a 100 per cent LED installation in the entrance zone, the lighting could be permanently closer to the CIE curve 88.

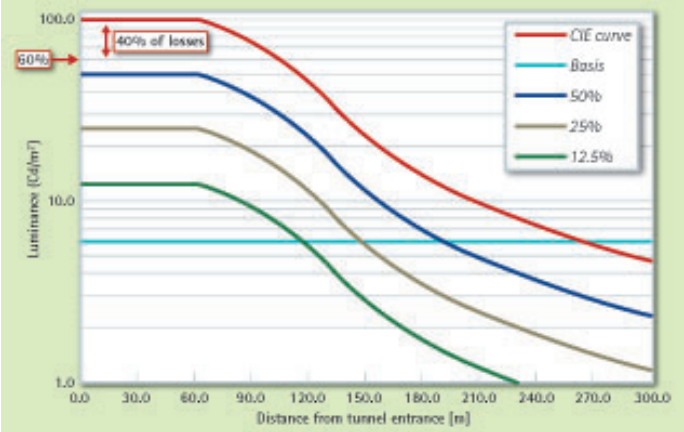

Figure 1a

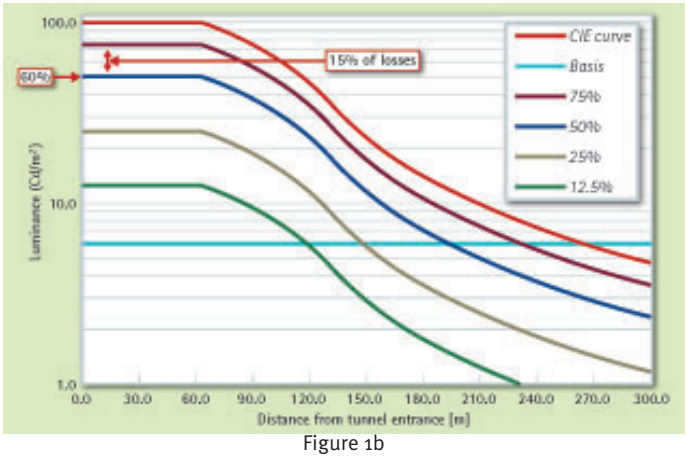

Figure 1b

Adjusting the levels to traffic speed

Traffic speed is a critical element to determine the luminance level needed at the tunnel entrance. The speed criterion should be taken into account in the tunnel lighting design to generate the first energy savings.

In the case of an urban tunnel, by measuring the speed of traffic at rush hour, we can further adapt the levels at the entrance of the tunnel. Energy savings of 5 to 10 per cent can be achieved this way.

Control systems

The commissioning and maintenance in tunnels is a very important issue and should be as simple and as fast as possible. The maintenance costs have an important impact on the total cost of the system.

Having a flexible control system makes it possible to easily integrate extra features like adapting the lighting according to traffic density, pollution environment adjustment, dynamic lighting evacuation systems and more.

Monitoring and reporting the energy consumption and failures of luminaires, meters etc, provides managers with additional network information and visibility.

Another important element in determining an efficient tunnel lighting design is the operating time of each lighting stage. In road lighting, it is easy to calculate for example, the annual consumption because only the night time variation is needed.

in a tunnel, the operating time of each lighting stage depends on the weather conditions. The average operating time can only be measured over a one year period.

LED tunnel lighting

LEDs entered the tunnel lighting field a few years ago. In tunnel lighting solutions, we distinguish the entrance zone and the interior zone.

While in the past tunnels were lit with HID luminaires for the entrance and HID or fluorescent fixtures for the interior zone, now we have moved towards HID or LED solutions for the entrance and almost completely to LED technology for the interior zone.

The requirements for the entrance are very different from those for the interior zone. The entrance requires 150 - 350cd/m², depending on the country, type of tunnel, orientation, speed, etc.

With a HID solution, sources of up to 400W were needed for the entrance zone. Nowadays, the luminous flux of LEDs can compete with these high power HID sources. However, the ease of adaptation of the LED photometry to the tunnel's geometry ensures that LED installations reach the same results with lower power consumption.

The lighting in this zone is coupled to a L20 luminance meter. This luminance meter is situated outside the tunnel and has a variable output depending on the luminance outside.

For the interior zone, we only need two lighting stages: day and night. In this zone it is easy to move completely towards an LED solution because the requirements are much lower than the entrance zone, only 1 - 10cd/m².

The long lifetime of an LED installation is another advantage. Without any management, we can consider 12 years with no replacement.

Comparative study

For the purpose of this analysis, we have compared 3 types of installation:

- 100% HID
- hybrid (a combination of LED and HID sources)
- 100% LED.

For each installation, two types of tunnel were analysed:

- luminance threshold (Lth) of 150cd/m² for a length of 220m
- luminance threshold (Lth) of 350cd/m² for a length of 350m.

The chosen tunnel is just long enough to ensure that we reach the end of the entrance zone. We take this hypothesis because the interior zone is repeated along the tunnel.

Four daytime lighting stages were taken into consideration: 100 per cent, 50 per cent, 25 per cent, 12.5 per cent; and one night-time level: 33 per cent of the basic daytime level.

For the 100 per cent HID installation, the luminaires are equipped with high-pressure sodium (HPS) and bi-power ballasts. The interior zone is lit by HPS or fluorescent lamps.

For the hybrid installation, the interior zone and the first two lighting stages are lit by LEDs. The remaining lighting stages are with luminaires fitted with HPS lamps.

The LED luminaires can be dimmed to switch between interior and lighting stages. And for the 100 per cent LED installation, all fixtures are equipped with LEDs and can be dimmed.

Yearly power consumption and maintenance

The annual consumption is calculated by counting the power of each system during their operating time throughout the year.

The hybrid solution uses between 15 and 20 per cent less energy than the HID solution. The LED solution uses between 25 and 30 per cent less energy compared to the HID solution.

We can decompose the annual consumption between the entrance and the interior zone. For the entrance zone, a 100 per cent LED solution can generate savings of up to 25 per cent in comparison with an HID solution.

For the interior zone, more generous savings of to 60 per cent can be achieved.

The HID solution requires maintenance every three years to replace some of the lamps (interior zone and first stage lamps).

For the hybrid and the 100% LED solution, a lamp replacement is only required after 12 years (HPS sources have a shorter lifetime than LEDs).

In an example for the hybrid solution, in a set-up in Liège, Belgium, the operating time of the lighting stages are measured as:

- 100% ≈ 100h/y
- 50% ≈ 350h/
- 25% ≈ 1200h/y
- 12.5% ≈ 3500h/y

LED luminaires are used for the interior zone and for the lighting stages of 12.5 per cent and 25 per cent while the HID luminaire will only be switched on for 450 hours/year. If you expect 16,000 hours for HPS lifetime, you can reach 35 years between each light source replacements.

Fixture quantity

The 100 per cent HID solution (with only HPS) remains the most interesting in terms of minimum quantity of fixtures to install. The hybrid solution requires 10 per cent more fixtures and has been considered as a compromise between investment cost and savings. The LED solution requires up to 15 per cent more fixtures but offers a real alternative to HID solution.

Conclusions

Even more than in road lighting, lighting management is necessary in tunnel lighting. However, this may only apply to new installations and must be implemented at the start of the project.

Simple lighting management makes it possible to obtain interesting savings, even with HID. However, to carry out these studies, the tunnel lighting designer needs data. We strongly encourage tunnels managers to collect data.

To obtain efficient solutions, LED luminaires combined with dimming options are necessary. The improvements in LEDs and drivers means that they now offer a high lumen package to cover all the tunnel applications needs. Moreover, the white light provided by an LED solution (due to a much higher CRI than HPS lamps) offers better visibility when driving and improves the overall feeling of safety in tunnel conditions.

Table2. Results of the comparison between the different solutions

	100% HID installation	Hybrid installation	100% LED installation
Energy savings per year compared to HID installation	n/a	- 15 to - 20%	- 20 to - 25%
Maintenace: lamp replacement	Every 3 years	Every 12 years	Every 12 years
Quantity of fixures installed compared to HID installation (100% HPS)	n/a	5 -10% more luminaires	10 -15% more luminaires
Advantages		White light in interior zone	100% white light

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