Public Lighting: Switch off or smarter lighting?

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Abstract

Since the late seventies, the debate of switching off street and highway lighting has been raised nearly every 10 years. Every time the lights have been switched off, the main goal is to achieve energy savings. Each time, papers are published to demonstrate the benefits of street lighting for safety. And shortly afterwards, the street lights are switched on again.

Public authorities are not on an equal footing where lighting is concerned. For example, street and highway lighting together represent less than one per cent of the annual Belgian electrical consumption. However, for a village, street lighting can represent up to 60% of its electrical consumption [MC (2009)]. At this level, the challenge of maintaining lighting throughout the night can be better understood.

This paper includes a review from major Belgian and international studies on street and highway lighting and its effects on road safety. The reader will realise why this question regarding street lighting comes and goes in the news. We will focus mostly on street lighting and not ambient lighting, which has other objectives than street lighting.

The author will illustrate with an example, that it is possible to maintain this service and safety level for users whilst saving energy. New terms are defined, such as the service level, which measures the service rendered to the user and the losses caused due to street lights being switched on whilst no one is present. For this, six scenarios comprising different management options, sources, etc. have been studied and compared.

Smart management of public lighting, thanks to new possibilities offered by technology, makes it possible to satisfy the needs of the public authorities in terms of energy savings whilst serving the needs of the users in terms of safety and service.

Public lighting and road safety: review of major studies

The debate of lighting streets and highways has existed since it was decided to light them at night. The first recognised study was written in France, in 1935 [Geets R. (1980)]. It established even at that time that “the lighting of major road networks is a requirement”. The first street lighting installation in Belgium was on the Brussels-Antwerp road and dates back to 1938. The question of street lighting, in general, has become a topic of recurrent debates in Belgium and overseas for many decades.

Since 1968, a census to determine whether to light roads based on traffic volume criteria has been conducted in Belgium. The goal is to find the right method to decide whether to light or not. The emphasis is on safety. A measurement campaign was set up to classify roads depending on their traffic density. In 1978, the first results, for the lit sections, were published [Geets R. (1980)] following the decision to light our roads and highways. Globally, a 30% drop in accidents was confirmed. This drop is more significant for injuries and deaths.

The same Geets report mentions that highway lighting represents less than 0.1% of the state’s budget, including investments and maintenance. The consumption represents only 0.07% of the total energy consumption of Belgium.

However in 1981, the Belgian government decided to not only switch off highway lighting for part of the night, but to also halve the luminance levels by disconnecting halve of the luminaires during the start-up period.

A statistical study of the results of this decision on the rate of accidents was published in 1987 [De Clercq, G. (1987)]. This paper first included the analysis of papers outside Belgium:

- <u>Study 1950 UK (Transport and road research Laboratory)</u>
  - The number of accidents leading to death and serious injuries could have been reduced by approximately 30% through street lighting.
- <u>Paper CIE N° 93 (1992) (in progress at the time of the paper) [CIE (1992)]</u>

  244 roads in towns and municipalities:
  - Reduction in the number of deaths from 45% to 68% and in the number of serious injuries from 24% to 20%.
  - Total number of accidents had been reduced between 14% and 53%.

Followed the above mentioned study:

- <u>Statistical study between 1981-1982 following the first luminaire switch off on highways.</u>

The results of this study are displayed in table 1. At that time, a first decision was made to switch off lighting on some roads and highways. A second decision was made to disconnect every second light despite its negative influence on the photometric performance of the system (uniformity).

Switched of public lighting	**Increase**
Accidents	6.3%
Deaths	38.5%
Serious injuries	108%
Public lighting reduction	**Increase**
Accidents	23.9%
Deaths	10%
Serious injuries	98.6%

Table 1: Percentage of additional accidents for the 2 implemented scenarios

This study confirmed the conclusions from the previous studies that street lighting has a positive influence on the number of accidents, serious injuries and deaths. Following the conclusion of this study, the luminance level was returned to the initially recommended levels and the luminaires were switched off depending on the traffic and no longer at set hours.

Ten years later, new studies were done. The AFE (French Lighting Agency) requested the CNRS (National Centre for Scientific Research) to undertake a study between 1998 and 2002 [AFE (2009)]. This time, the study did not take into account any statistics on the ground but only drivers’ reactions in their vehicles. The driving environment and conditions (lighting, weather, road condition, fatigue…) were controlled and measurable.

This experiment, done on a simulator, removed factors skewing the statistics whilst ensuring the safety of the person running the test in case of accident. Through these studies, they were able to verify whether street lighting contributed to improved safety, or not. For example, during the study, a potential accident situation was created to test the driver’s reactions.

	Good anticipation	**Accident**
Not lit	4 drivers	4 drivers
Lit	10 drivers	2 drivers

Table 2: Results on the driver’s anticipation

Other points [AFE (2009)]:

- The simulator measurement showed that drowsiness during the first hour of driving is less with public lighting.
- Professor Rea showed a correlation between the driver's perceived risk and the number of accidents [CNBE (2004)].
  We speak of a risk compensation: the less risk we perceive, the safer we feel. Without lighting, we have a lower perception of risk.
  For example, if the perceived risk is higher than the actual risk, traffic flow decreases and traffic jams build up. If the perceived risk is lower than the actual risk, the accident rate increases.
  It is therefore important to provide the driver with the most accurate information possible, to empower him to improve his judgment so as to reduce the gap between the perception of risk and the actual risk.
- Energy savings must not be the main factor when deciding whether to decrease or switch off lighting. The priority is safety but if we can maintain safety levels, we must not hesitate to decrease lighting.
- 70% of the information perceived by a driver's brain comes from sight and is therefore directly related to his capacity to analyse.
- Quality lighting, even if comfortable, enables us above all to anticipate events and makes it possible for our brains to react. Therefore, the COMFORT = LUXURY equation is completely incorrect in the field of street lighting.

One of the most important papers from the last few years is a PhD thesis written in Norway by P.O. Wanvik. Street lighting at night reduces accidents with injuries by 30%. Major effects are:

(1) 60% reduction of fatal injuries
(2) 45% reduction of accidents involving pedestrians resulting in injuries
(3) 50% reduction of accidents with injuries on highways.

Comparing a specific road section before and after the implementation of street lighting [Wanvik, P.O (2007)], the observed effect was a 28% reduction of accidents with injuries when the street lighting was on. The observed effect became more important as the speed increased. This improvement was less on roads with an AADT (annual average daily traffic volume) › 8.000 vehicles than on roads with an AADR ‹ 8.000 vehicles.

The main effect of street lighting was a 50% reduction of accidents with injuries when compared to non-lit roads, as indicated in a paper relating to accidents on 'normal' roads in the Netherlands [Wanvik, P.O (2009a)]. There was a 54% reduction on regional roads only. The result of accidents with pedestrians, bicycles and mopeds was greater than that on accidents with vehicles and motorbikes. The differences were actually significant. There was no significant difference between the various types of accidents (back or rear impacts, etc.) or between drivers from age groups 60-74 and 30-39. The effect on fatal accidents was slightly higher than on accidents with injuries.
In the Netherlands, there was a 49% reduction in accidents with injuries on highways with street lighting versus non-lit roads [Wanvik, P.O (2009b)]. However, the effect was less important on highways in England and Sweden (± 30%).

Conflict zones: ring roads, junctions, highway exits, intersections, etc. are the best locations to study the influence of lighting on road safety. A recent study [Bullough, J. D (2013)] analysed accidents by day and by night on lit and unlit intersections in a different way. Different types of intersections were mentioned:

- Urban, suburban
- Rural
- With and without signage
- With and without lighting.

Different cases show a 13% reduction on night-time accidents when the intersection was equipped with public lighting and signage. The author complemented his study with a comparison on the improvement of visibility between the different cases. Other cars' lights and shiny objects are easily visible at night, but night driving requires more than these two data points. A driver must often estimate the relative speed, the direction of movement, the elements that make up his environment. Everything that can improve the driver's capacity to judge, visual guidance and the reflectivity of objects is important for safety. Public lighting plays a non-negligible role.

In addition to this paper, the author did a financial analysis of the costs and benefits of implementing public lighting. On the one hand, he included all intersection lighting costs (installation, maintenance/year and consumption/year), independently of road traffic volume. On the other hand, he considered the average cost of an accident for society only in terms of medical and material expenses for the casualties. These amounts were compared with day/night reports from his statistic study. In rural areas without signage, annual costs were recovered in less than 6 months.

This study sample shows that street and highway lighting is required to improve users' safety. However, the decision to light or not, remains in the hands of public authorities. It would be detrimental if road safety decreases due to an economic criterion; conversely constant lighting everywhere is not a solution either.

Many tools exist today (norms, sources, technologies…) to enable lighting authorities to light with the right level, the right place and why not, at the right time! All this, whilst complying with the economic and safety specifications from public authorities and users. It is today's challenge for tomorrow's street and highway lighting. It is for this purpose that we offer an example showcasing current alternatives.

Maintain lighting and generate savings: an example

Since the first roads were lit, lighting and methods of lighting have evolved significantly. This is not the case for the type of sources that equip our road and highway network, which has remained unchanged over 30 years: the low pressure sodium light source. Admittedly, its lighting efficiency (lumen/watt) remains unmatched. But today, it is not only the efficiency of the source that needs be considered.

In the meantime, other types of sources have evolved in various aspects: light efficiency, colour temperature, colour rendition, lifetime and finally, the dimming ability versus lifetime. The widespread use of electronics in auxiliaries makes it possible to offer new features (constant lumen output, adjustable lumen output…). The same equipment improves the operation of sources with better regulation of supply voltage, power factor…. Finally, control options (unidirectional and bidirectional) can manage not only the light flow, but also the light in its totality (running time, source mortality, failures…). Recent progress brings an optimised maintenance for public lighting.

However, there is one domain where we can still improve: managing the lighting levels based on the needs at the time it is required.

Take for example, a road where the public lighting needs to be replaced. The public authorities are asking for several technical solutions for the project. These solutions must satisfy several needs:

- Retrofit HPS (high-pressure sodium) or LED
- Estimation of annual energy consumption

In this context, we add two complementary criteria to estimate the efficiency of the luminaire or the installation:

- Service level: percentage of users (vehicles, pedestrians, cyclists, …) who benefit from the light at night
- Loss level: ratio between the accumulative time of absence of users when the light is switched on and the night duration.

A traffic evolution model during the night is required to estimate service and loss levels. These values do not depend on the lighting level at the time when an user is under the switched on light. In the context of this paper, we considered the entire installation and not a unique luminaire.

For this simulation, we take into account several hypotheses:

- Conformity with NBN 13201
- Average night of 12h
- Night traffic mostly concentrated over 4h
- 6 lighting level modulation scenarios

	Night profile	Configuration
1		100% throughout the night
2		50 % from 10pm to 6am
3		0% from 10pm to 6am
4		Detection from 10pm to 6am
5		Detection throughout the night
6		Detection throughout the night + 50% from 10pm to 6am

Figure 1: Definition of scenarios for the comparison of solutions

The first 3 scenarios are set without specific equipment; it is a simple gradation or a switch off. The 3 other scenarios need a detector to manage the switching on and off of the lights based on the presence or absence of an user. As the switching on and off phases are quick and unpredictable when a sensor is used, only the LED solution will be calculated for the last 3 scenarios.

Some principles were taken in the hypotheses for this comparison (for example average night duration), however they remain the same for all scenarios and types of sources.

Comparison

The existing lighting for the area is provided by 7 luminaires fitted with 100W high-pressure sodium lamps and 22 fixtures equipped with 125W high-pressure mercury vapour lamps. The recommended HPS solution is composed of 31 luminaires with 100W lamps while the LED solution incorporates 38 fixtures of 54W.

Based on the imposed hypotheses, we can establish the annual consumption of the existing solution. We can also establish the two replacement solutions as well as solutions for each scenario.

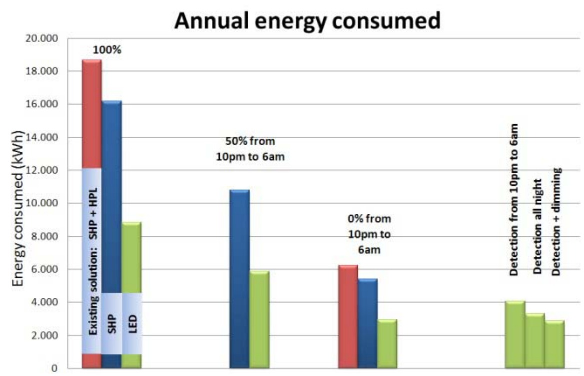

Figure 2: Comparison of annual energy use per scenario

On the basis of this comparison, we are tempted to switch off the existing scheme between 10pm and 6am to generate more than 66% savings with a minimal investment. This does not take into account the maintenance of this aging equipment, a maintenance that will not decrease over time. In addition, only considering annual energy usage as a criterion does not take into account the needs of the user.

Public lighting is a service to the population. The users ask to see and to be seen during their trips, their activities at night, and for their safety… This service must be available 100% of the time. However, we estimate that these luminaires do not need to be lit when there is no one present. It is at this moment that the service and loss levels come into play. We must maximise the former whilst minimising the latter. Figure 3 shows the ratio of these two criteria in the different scenarios.

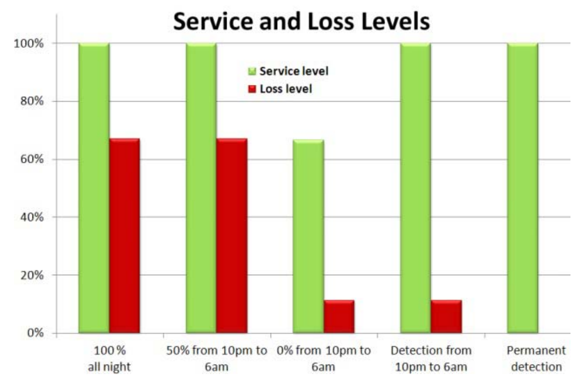

Figure 3: Service and loss levels for the different scenarios

If the night is split into switch on and switch off phases $P_1,\ldots, P_i$ according to the chosen scenario. Then, we define a presence model using the occupation rate $\tau_{occ,i}$ under the light for each of the phases P_i. We define the service level by:

$$\tau_{Serv} = \sum_i k_i \tau_{occ,i}$$

where

k_i=0 or 1 based on the light switch on or off scenario

We define, based on the occupancy rate under the light, a time $t_{abs,i}$ for each of the phases Pi, time period during which there is no user under the light. We define the loss level by:

$$\tau_{loss} = \frac{\sum_i k_i t_{abs,i}}{t_{night}}$$

where

k_i=0 or 1 based on the switching on or off scenario of the light

t_{night} = average duration of the night

We estimate that the service level is maintained at 100% from the moment we switch on the light no matter which level of light is maintained. The loss level follows the same principle, no matter what the level of light is; there is a loss from the moment the public lighting is switched on without the presence of an user. However, these ratios are different when applying different light management schemes.

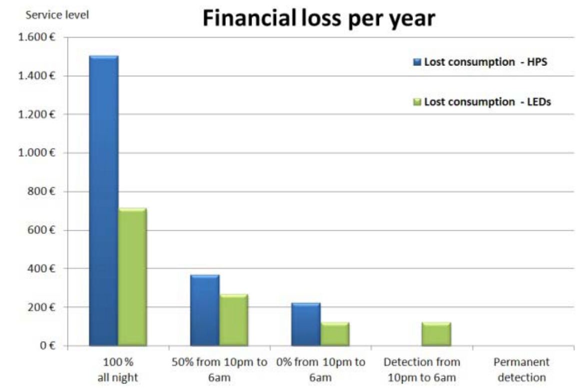

Figure 4: Financial losses for the two solutions based on the scenario

The estimation of financial losses [Figure 4], highlights losses generated by keeping lights on when there is no one around. LEDs can help achieve zero financial loss, something that traditional sources cannot achieve as they do not allow for constant detection. Again, the choice of management type is critical in this comparison. For example, financial losses are the same if the lights are switched off from 10pm until 6am or for lighting equipped with detection over this period. However, the service level rendered to the population is not the same.

Discussion

The positive influence of public lighting on road safety must still be proven despite the number of studies suggesting this influence. So much so that safety is always at the mercy of recurrent needs for savings. At each switch off cycle, short-term experience shows that the lights must be switched on again. Without having any considerations on other measures of managing lighting.

Street and highway lighting is required for:

- Driver's to anticipate what is on the road (deceleration, obstacle, accident, road condition,…)
- The police to identify road accidents and highway evacuation
- Defective vehicles on the emergency lane:
    - Visibility
    - Lighting assistance for repairs (changing a tyre).
    - Towing vehicles …

Today, it is possible to adapt public lighting to the needs of each user. A light management system suitable for the needs of users can also achieve the financial savings required by public authorities. In fact, the middle ground must be a compromise between the two parties. Simply switching off existing equipment is not the solution in the long term. A global solution must be found for tomorrow's smart street lighting.

The most economic solution from our example is not the solution that works everywhere and all the time. For example, a solution with permanent detection is not adapted in a residential street. Indeed, switching on and off public lighting as cars, pedestrians and bicycles travel… might become an issue for the residents in terms of intrusive light. A global solution for public lighting cannot be improvised.

Public lighting is not only a light source, a reflector and a luminaire anymore. It is a global solution that needs be implemented: source, photometry, luminaire, installation, maintenance, management and interconnections. A broader reflection on the needs of the different parties must be initiated. Latest technological progress offers the ability, in this period of crisis, to put in place structural savings in the public lighting sector.

This paper mainly deals with street and highway lighting, however the same philosophy can be applied to external lighting, in general. At the time of finalizing this paper, the AFE sent a statement [AFE (2013)]. From 1st, July offices, shops and buildings are "invited to switch off unnecessary lighting at night from 1am until 7am". This goes to show that the 'switch off' rather than 'manage' philosophy remains strong.

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