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Proposal to forest Alpine tunnels surroundings to enhance energy savings from the lighting installations. Towards a standard procedure

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ABSTRACT

The lighting installation in tunnels is a major problem in terms of drivers safety, energy consumption and use of raw materials. According to the recommendations of the International Commission on Illumination (CIE), the demand of tunnels in terms of luminance mainly depends on three factors: maximum speed allowed inside the tunnel, tunnel orientation and the characteristics of the portal gate surroundings. Focusing on this last factor, this study analyses how changes in the vegetation of the portal gate surroundings in an Alpine environment can contribute to save energy from the lighting installation. Its main target is to achieve a low L20 luminance through the lowest reflectance of portal surroundings, which is connected to a minor luminance requirement inside the tunnel. Departing from several autochthonous species growing in that climatic zone, photometrical considerations are introduced in order to find the most accurate one to maximize savings without impairing the safety. It has been concluded that common ivy is the most suitable specie to forest the entrance of the tunnels in Alpine zone, allowing decreases in the installed power between 22 and 53 kW in the tunnels considered in this research. The accuracy of common ivy is specially relevant because other research based on completely different environments and climates also concluded that this specie is the best in terms of energy and installed power savings. These data show that a standard procedure based on climbing species like common ivy can allow the achievement of more sustainable road tunnels.

1. Introduction

According to the data published by the "Azienda Nazionale Autonoma delle Strade"(ANAS) in 2012, 87% of energy expenditure on conservation and maintenance of roads in Italy was spent on tunnels. These costs are mainly divided into ventilation and illumination, being the latter responsible for more than 80% of the total costs (Valente, 2012).

Although there is a limited probability of suffering accidents in tunnels this does not decrease the severity of these types of accidents when they occur. During the period between 1999 and 2006 the Alps zone witnessed some of the biggest car tragedies in the History of Europe. The accidents in the tunnels of Mont Blanc (39 deaths), Tauern (12 deaths and 40 injuries) and Saint Gothard (11 deaths) prove such severity and the social alarm caused.

Hence, Directive 2004/54/EC (European Parliament, 2004) on minimum safety requirements for tunnels in the Trans-European Road Network especially insists on the importance of tunnel lighting: "The visual perception of the road must be guaranteed by correct illumination and signage of all elements (vehicles, signals, exits…), it has a very important influence on the stopping sight distance and other parameters linked to road safety, because of which, accurate knowledge and control can enable the engineer to save lives".

However, to achieve this requirement is a complex task which depends on very different factors: driver characteristics (visual capacity, age and personal habits), physical and weather conditions of the road, maximum speed allowed in the tunnel, length of the gallery, orientation and traffic conditions (density, volume and speed) and tunnel surroundings among other (CIE Publ. 88, 2004).

Concerning lighting, the slow visual adaptation of humans when going from bright environments to darker ones (about 8 min) (Schmidt, 1978; Peña-García et al., 2012), requests strong illuminance levels in the threshold zone of road tunnels, which extends along the first meters at the safety distance. This highlights one extremely important fact: energy consumption in road tunnels is much higher during daytime, when drivers eyes are exposed to luminance levels of hundred of cd m^{-2} and need visual adaptation. On the other hand, during night time drivers eyes are just exposed to the 1–2 cd m^{-2} provided by the headlamps (CIE Publ. 88, 2004), and no specially high luminance is required in the tunnel to ensure a correct adaptation.

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Furthermore, associated to the tunnels can appear three effects which will condition the behaviour and the state of mind of the driver: the black hole effect, the wall effect and the flickering effect (CIE Publ. 88, 2004; Mehri et al., 2017).

In summary, lighting levels in road tunnels must be remarkably high during daytime in order to ensure the visual adaptation. This is achieved by installing hundred of luminaries in every tunnel providing high luminous fluxes during daytime. The consequence is a high consumption in energy and raw materials, a high environmental impact due to the emissions of greenhouse gases and waste generated by manufacture and electricity production and, as consequence, a very high economical impact.

There are two ways to decrease such impact of lighting: taking one part of the necessary luminous flux from the sun of the light, complementing the global needs of the tunnel and decrease such needs by means of certain strategies. Fortunately, both ways to consider the problem of energy consumption in tunnels are compatible.

To use the light coming from the sun, some strategies have been aimed to introduce the solar luminous flux inside the tunnel (Gil-Martín et al., 2014; Qin et al., 2015; Peña-García et al., 2016). Other researchers have developed models to partially shift the threshold zone out of the tunnel by means of tension structures (Gil-Martín et al., 2011; Peña-García et al., 2011, 2012; García Escribano, 2011), pergolas (Peña-García & Gil-Martín, 2013; Gil-Martín et al., 2015) or other kind of shifting structures (Abdul Salam and Mezher, 2014; Wang et al., 2015; Drakou et al., 2015, 2016, 2017). These strategies show good results and their implementation in real tunnels is already a reality in some countries, alone or together with regulating systems to dim flux of LED projectors (Wang & Zhou, 2009; Salata et al., 2016, Qin et al., 2017a, 2017b).

The second way to optimize the impact of tunnel lighting (compatible with those highlighted above) is to decrease its flux requirements with special pavements and forestation of surroundings. Concerning the first, different kinds of asphalt have been proposed to reflect the same flux with lower installed power (Salata et al., 2015; Moretti et al., 2016). The second strategy (forestation) is the target of this research and will be treated in more detail.

The luminance in the access zone, called L20 luminance (CIE Publ. 88: 2004), is the luminance on the eye of one driver approaching the tunnel from the safety distance (SD). The luminance in the following zones inside the tunnel is determined by the value of L20.

L20 depends on the maximum vehicle speed allowed in the tunnel, the orientation and location of the tunnel and the reflectance of the tunnel surroundings. This last item is especially important: depending on the landscape elements, more or less sunlight will be reflected, increasing the L20 and, hence, requiring a more severe visual adaptation. Obviously, a more severe visual adaptation will require higher luminance levels in the threshold zone, which means higher electrical consumption.

For this reason, it is important to build the tunnel surroundings with elements of minimum reflectance without impairing the mechanical properties on the mountainside, the landscape integration and other important parameters of the tunnel that, one way or another, contribute to safety and sustainability (López et al., 2017).

In previous works (López et al, 2014; Peña-García et al., 2015), the forestation of the surroundings of portal tunnels with different climbing species has been successfully considered. The choice of vegetal species instead of other strategies (painting the portal surroundings in black or similar) has the advantage of a good retention of the soils, landscape integration and the obvious contribution to a healthier environment. However, these studies highlighted that there is no universal solution in the choice of the species since different locations of the tunnels will have different climates, soils and hydrological conditions. Peña-García et al (2015), worked in Mediterranean environments and proved the accurateness of common ivy (hedera helix) to forest the surroundings of tunnels in that location. However, tunnels in other climates could need other species.

Departing from these previous results, the objectives of this work are the following:

– Determine the luminance requirements of some tunnels in an Alpine environment.
– Identify several autochthonous plants that might cover the mountainside in the surroundings of the gate.
– Determine the one with lowest reflectance.
– Estimate the savings if the surroundings of the considered tunnels were forested with the selected specie.

In the following sections, these objectives will be reached with the target of establishing a standard procedure to minimize energy consumption and environmental impact of lighting installations based on the forestation of gates surroundings.

2. Materials and method

Several road tunnels in the region of Valle d'Aosta and Piemonte, in Northwestern Italy have been selected to study the impact of foresting their surroundings with different species. These tunnels are Mont Blanc, Grand Saint Bernard, Frèjus and Col de Tenda. Their locations are shown in Fig. 1:

They are all strategic international connections between European countries (Italy with France or Switzerland).

Their most important features are the following:

(1) Mountain peaks in this area easily exceed 4000 m in height. For this reason, tunnel lengths are over 1000 m in all cases.
(2) The majority of the tunnels in this study have a North-South orientation, with the exception of Mont Blanc which is Northeast-Southwest.
(3) The traffic speed on these sections of the road is around 70 km/hour except for Col de Tenda (50 km/hour).
(4) The average age of these tunnels is approximately 40 years with the exception of Col de Tenda (opened in 1882). As a consequence, the traffic is bidirectional in all of them. This was the most common solution at the time all them were built.

To choose and propose vegetal species for reforestation of portal surroundings, the most important factors taken into consideration were climatology, terrain conditions and their actual existence and survival there. As a result, six species were initially recommended for their considerations: clematis alpina, hedera helix, lonicera caprifolium, calluna vulgaris, rhododendron ferrugineum and juniperus sabina.

However, some features led to finally reject some of them because their flowering process with leaf loss on the road under the portal, can create a sliding layer extremely dangerous for the drivers.

In addition, it was considered that the climbing species could be planted on the soil in both sides of the portal or in certain parts of the mountain and be easily guided with wires or other media. Hence it is possible to create a thick and homogeneous vegetal surface completely covering the mountainside and with lower reflectance than the bushes and trees usually found in the portal surroundings.

Both constrictions, evergreen and climbing species, resulted in the final choice of three species: hedera helix, juniperus sabina and rhododendron ferrugineum (Fig. 2).

Once chosen, their individual contributions to L20 in terms of luminance was measured in a plants nursery under identical insolation conditions and a totally clear sky according to the procedure described in CIE Publ. 88: 2004 (distance, height etc). Luminances were measured in the most unfavourable time, that is, when solar illumination is higher, around noon (12:00). The pots were placed on a concrete pavement in front of a white wall background on the Sierra Nevada road (Granada, Spain). Several plants were put together to simulate a high