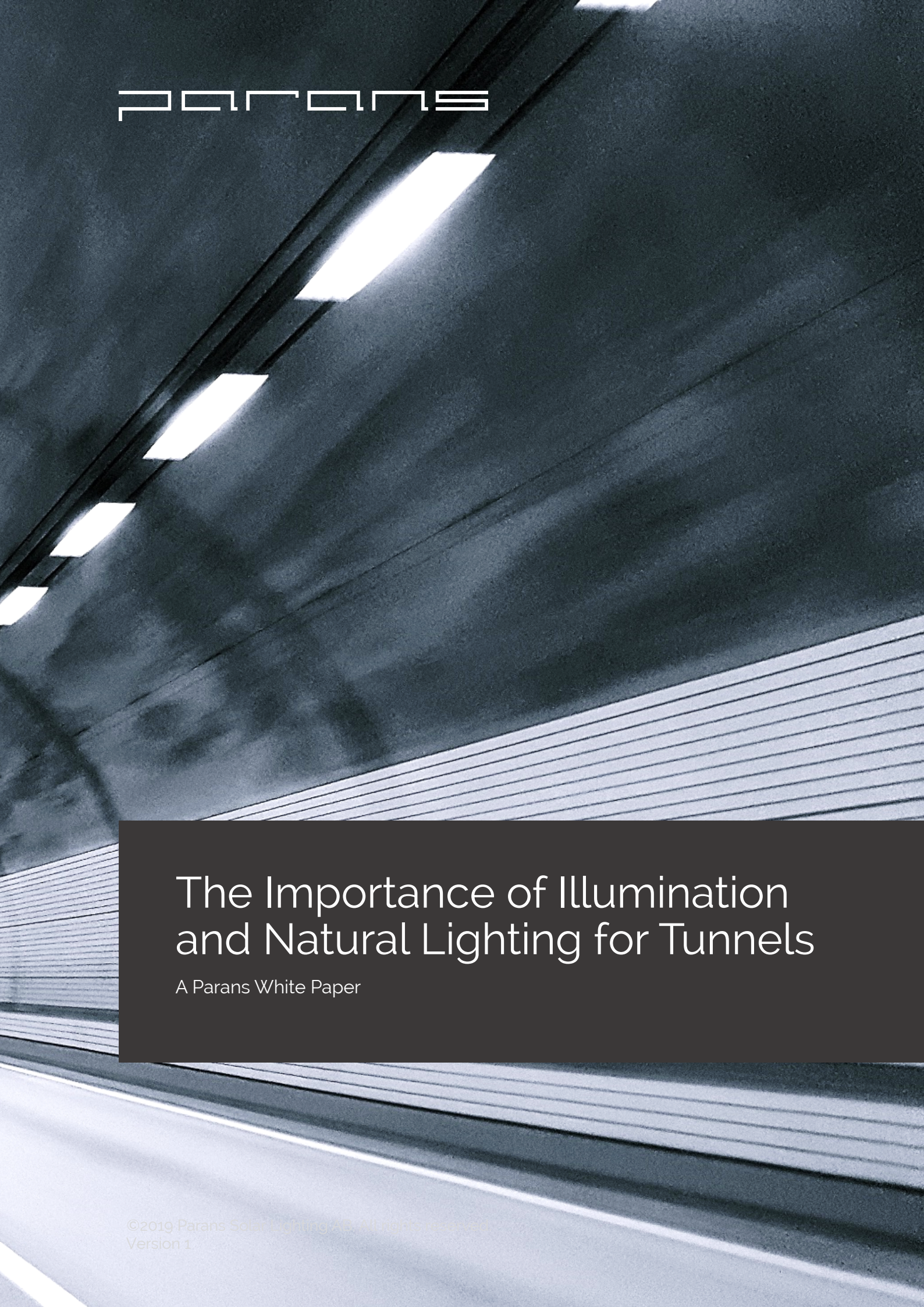


The Importance of Illumination and Natural Lighting for Tunnels

A Parans White Paper

Version 1

Introduction

"Addressing the topic of illumination and lighting in the entrance and exit zone of the tunnel is imperative to improve traffic safety."

Health and safety issues associated with the traffic system, such as improving visibility for drivers, has attracted increasing attention in recent years due to the soaring rates of deaths, injuries, and disabilities resulting from road traffic accidents.

Traffic accidents in tunnels comprise a small share of total road accidents; however, the human and economic losses associated with tunnel accidents are considerably more severe than those on open roads.

The majority of all these accidents occur in the entrance zones of tunnels [1]. In this regard, providing good visual conditions for drivers approaching a tunnel entrance is a crucial factor.

There is thus a need to find solutions that address this issue and that provides the optimum lighting solution for the entrance and exit of tunnels.

This white paper aim to explore the tunnel lighting challenge, outline solutions and specifically provide deeper insights on the value of leading natural sunlight into tunnels, specifically in the critical entrance zone.

Tunnel design and construction

Tunnels play an important role within the transport infrastructure network. They facilitate communication and are thus essential to long distance transport. They also play a decisive role in the functioning and development of regional economies.[2]

The method of tunnel construction depends on such factors as the ground conditions, the ground water conditions, the length and diameter of the tunnel drive, the depth of the tunnel, the logistics of supporting the tunnel excavation, the final use and shape of the tunnel and appropriate risk management.

There are three basic types of tunnel construction in common use. Cut-and-cover tunnels are constructed in a shallow trench and then covered over. Bored tunnels are constructed in situ, without removing the ground above. Finally, a tube can be sunk into a body of water, which is called an immersed tunnel. [3]

The Rijnlands tunnel in the Netherlands will include tunnel entrance sunlight systems from Parans (source: COMOL5)

For all tunnels the lighting designer has limited influence on the orientation the tunnel route forms. This is normally dictated by the site geology and the route required. Having a solid approach on how to design the lighting solution for specific tunnels is vital for the safety of the people driving through the tunnels as will be further discussed in the coming chapters.

Tunnel safety

Driving along a tunnel's dark narrow environment may cause anxiety, uncertainty, and even fear of hitting another vehicle or tunnel walls and/or other dangerous circumstances such as fire or a tunnel collapse. Drivers in tunnels generally reduce their speed and increase their lateral distance to the tunnel wall, which can be interpreted as increased alertness while driving along road tunnels. [4]

"The entrance zone of a tunnel is critical in regard to tunnel safety. Designing and implementing the best possible lighting solution provides the driver with optimum visual comfort and safety."

This change in behavior of drivers generally occurs while approaching the tunnel portals. Amundsen and Ranes believe that driving in a road tunnel causes an "unease" feeling as a result of the darkness and safety concerns. [5]

Transition zones in tunnels are dangerous areas. Drivers approaching tunnels at high speed are exposed to much higher crash risk. These speed variations have a major impact on traffic safety.

Black Hole Effect

Unlike an open road, a tunnel road is a relatively enclosed space where the lighting abruptly changes from bright to dark ("black hole") at the entrance of the tunnel and from dark to bright light ("bright hole") at the exit of the tunnel.

The tunnel black hole effect. (Source: Pexels.com)

One of the major problems associated with road tunnels is the black hole effect. This phenomenon is due to the reflection of sunlight from the surrounding environment to drivers' eyes, especially on sunny days, as well as the lack of adequate lighting at the entrance of tunnels, which reduces the contrast of the barrier at the tunnel entrance and causes some vision problems.

As a result, the risk of traffic accidents may be increased. When the tunnel entrance has the appearance of a black hole, it reduces the

self-confidence of motorists and they may drive in a hesitant manner, negatively affecting traffic safety [6]

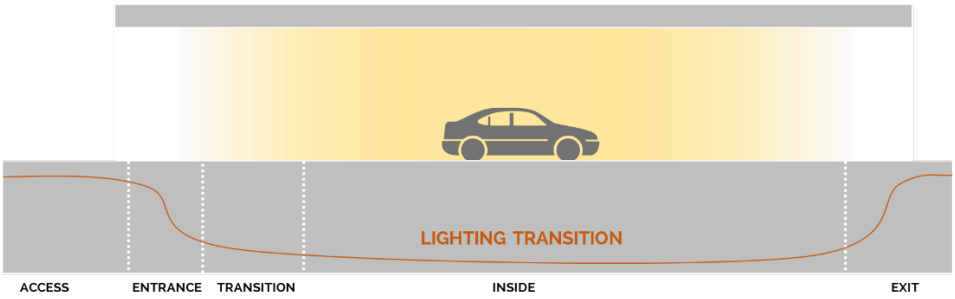
Addressing this issue with smart lighting in the entrance and exit of the tunnel is imperative to improve traffic safety. The lighting solution should provide adequate luminance at the tunnel entrance and the entrance zone to allow time for eye adaptation.

Lighting in tunnels

A well deigned tunnel lighting system must guarantee adequate safety conditions both at night and during daytime, with the aim of providing the driver with the best visual comfort and safety.

Tunnels are divided into transition zones of light:

1- The access zone: Part of the road leading to the tunnel entrance.
2- The entrance zone: The most critical zone in terms of safety.
3- The transition zone: Brightness is slowly reduced towards as traffic enter the tunnel.
4- The inside zone: Often the longest zone. The brightness level depends on traffic and speed.
5- The exit zone: The light is again brighter than in the inside zone.



In daylight, road safety rules require that drivers' eyes adapt from lighting conditions outside of tunnel entrances to levels applied inside the tunnel.

The initial adjustment occurs in the entrance zone. When drivers' eyesight adjust as they move inside the tunnel, brightness levels can be slowly reduced to ensure that eyesight adaptation is not affected.

A novel solution - sunlight in tunnels

Good tunnel lighting allows users to enter, pass through and exit the tunnel safely and comfortably.

WHAT IS SUNLIGHT AND DAYLIGHT?

"Sunlight has an immense impact on our wellbeing. It makes us feel better, learn faster, achieve more and become more productive."

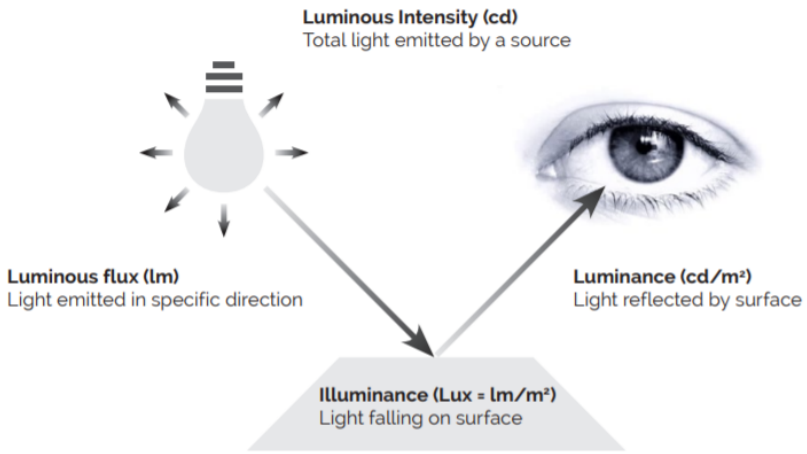
We often distinguish between daylight and sunlight. Daylight refers to the diffuse natural light that comes from the sky or that gets reflected off surrounding surfaces. ‘

Sunlight is the direct light from the sun and is much stronger than daylight. Sunlight is also much harder to utilize than daylight. This partly due that the sun is constantly changing position and it is also often hindered by clouds, trees or surrounding buildings. In addition, it is also way too strong. Daylight can also fluctuate during the course of the day but never so much that it results in blinding.

Other advantages with direct light is that it renders contrasts, clear colors, variation during the day and warmth during winter.

To measure and quantify light

There are many ways to measure and quantify natural light. Some carries a larger weight than others in terms of energy matters, physical traits and the human eye.



luminous intensity (cd)

Luminous intensity is measured in candela (cd) and is the unit of the flow a light that radiates out in space within a certain space angle, i.e. in a certain direction. A light candle with a diameter of 25 mm has a luminosity of around 1 cd.

Luminance (cd/m^2)

Luminance describe the amount of light that passes through or gets emitted from a surface and falls against a certain space angle. This corresponds to the amount of light that the eye perceives when looking in a certain direction. I e how light the surfaces in your surrounding is. In this case the space angle becomes the field of vision of the pupil.

Luminous flux (lm)

Luminous flux is the measure of the perceived power of light. It accounts for the sensitivity of the eye by weighting the power at each wavelength with the luminosity function, which represents the eye's response to different wavelengths.

Illuminance (Lux)

Illuminance indicates how much light that falls on a certain surface and is measured in lux. (or lumen per square meter). If a certain amount of light hits a surface the illuminance has a certain value and if the surface is larger but still hit by the same amount of light the illuminance decreases.

Luminous efficacy [lm/W]

Luminous efficacy defines the relationship between lumen and watts for a light source. The light exchange for daylight, especially for diffuse sun is better than most kinds of electric light. Normally you want an as high light exchange as possible as this will bring the electricity cost down. You also avoid an unnecessary heat spill.

Light source	Luminous efficacy (lm/W)
Light bulb 150w	16-40
Fluorescent lamp (40w, CWX)	50-80
Natrium high pressure lamp	40-140
LED light	60-100
Parans (SP4-20)	1800-2600

A comparison of luminous efficacy for different lighting solutions.

Better light quality for tunnels

Natural light has perfect color rendering without flicker. People are also tolerant of wide variations in natural light in compare with electric lighting.

In a large survey from 2012, "Daylight Metrics, PIER Daylighting Research Program Plus" no correlation was found between glare and high levels of illuminance.

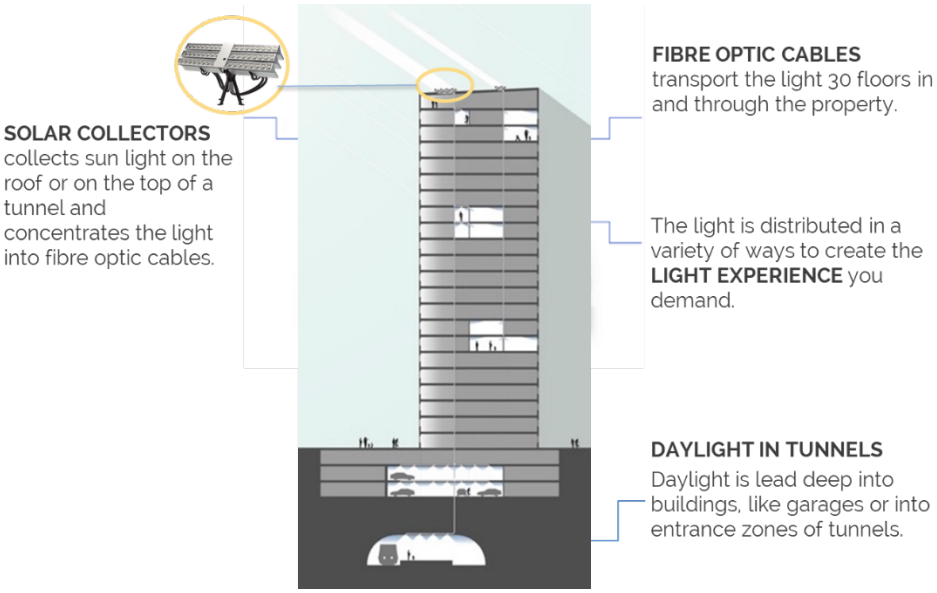
Parans Solar Lighting for a tunnel entrance zone. (Source: COMOL5)

"The founders of Parans had a strong passion for innovation and how technology can improve the world. We build on that strong heritage with every project we embark upon."

How the Parans system works

Since 2003 Parans has brought natural light to various environments with the help of its green Swedish innovation – the Parans system. Fiber optic cables transport the sunlight in and through properties and constructions.

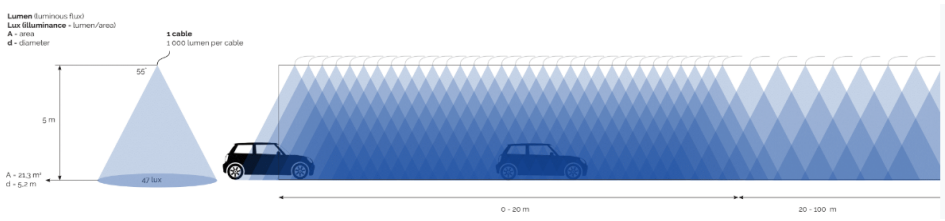
With the new 4th generation system the light is transported up to 100 meters. Both the high light quality and intensity is retained all the 100 meters. This way sunlight can be distributed deep into tunnels.



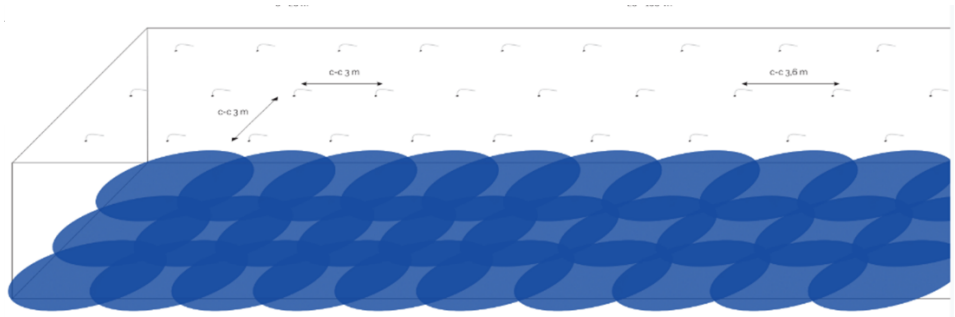
Parans for tunnel entrance zones

As previously described, the entrance zone of a tunnel is critical in regard to tunnel safety. Designing and implementing the best possible lighting solution provides the driver optimum visual comfort and safety.

At Parans we work together with architects, designers and engineering companies to bring innovations to tunnel constructions. Getting a seamless transfer of natural light from the access zone to the entrance zone aids companies to not only provide better illumination and safety, but also to save energy cost.



The concept of solar lighting in the tunnel entrance providing a seamless and natural lighting experience from the outside, into the tunnel.



Bundling fiber cables to transfer the sunlight to point lighting mounted in the ceiling of the tunnel.

Sun collectors

The collectors are modular which means they come with either 4,6,8,12 or 20 cables depending on the need. Every cable can have an individual length. This way they can meet your need for natural light in best possible way. That means you can optimize both the number of cables and their length on every installation.

Parans sun collectors.

Fiber optic cables

The fiber optic cables transport the natural light up to 100 meters while retaining both a high level of light quality and light intensity, important for the safety of tunnels.

Luminaires

Our luminaire spreads the natural sunlight into the tunnel. The luminaire is integrated into the construction and is integrated with the tunnel lighting control system.

Always connected to the cloud

The Parans system is constantly connected to the cloud in order to provide performance data. It's for example possible to receive information on the number of hours of sunlight in the building,

The service organization can monitor the system to ensure maximum up-time.

A case from the Netherlands

Parans and COMOL5 have signed an agreement whereby Parans will deliver systems in an innovative infrastructure project, where the end customer is the Province of Zuid-Holland.

Both tunnel entrances of the Rijnlands tunnel will have Parans natural light in the entrance zones. The tunnel is under construction and the preliminary plan is to do part deliveries 2019 with main deliveries taking place 2020.

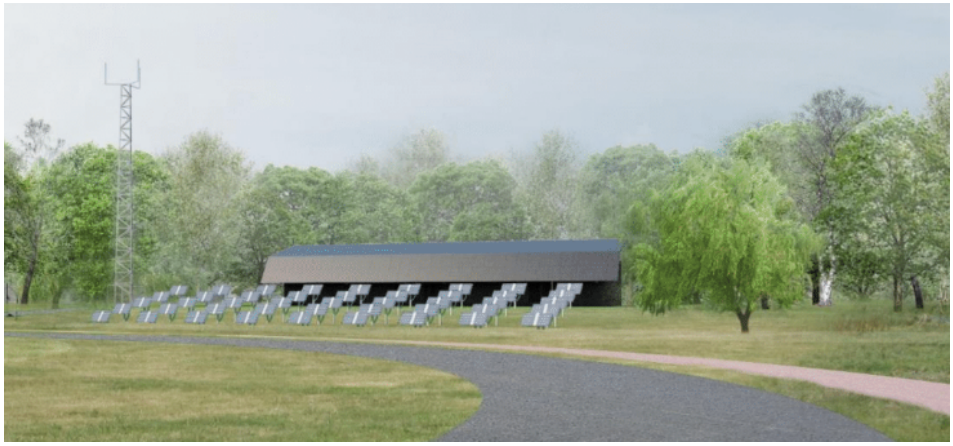
The Parans system will lead the sunlight into the tunnel in a way that previously has been impossible, minimizing the risk of "black holes" thus ensuring the best possible safety for the road traffic.

The key reasons selecting Parans was:

- Regulation
  - There is strong regulation in place imposing entrance lights in tunnels.
- Energy savings
  - The consortium will manage the tunnel for 15 years, thus making it important to run a lean operation to maximize financial benefits. Saving energy also means a reduction in CO2 emissions.
- Innovation
  - Both COMOL5 and the end-customer viewed the Parans system as innovative which matched their view on the project in whole. This tunnel is expected to set a new bar for other tunnels to match.

One of the project team members was a top finalist in the nationwide competition The Challenge Engineering for the Rijnlands tunnel project's innovative design, largely due to The Parans system's ability to lead light deep into the tunnel.

Parans work closely with COMOL5 regarding the light solution and the upcoming software integration.



Parans sun collector cluster situated above the tunnel. (Source: COMOL5)

About Parans

"With Parans, architectural lighting designers can now lead the sunlight deep into buildings and into tunnels, to allow everyone to benefit of the natural daylight."

Sunlight has an immense impact on our wellbeing. It makes us feel better, learn faster, achieve more and become more productive.

With Parans, architectural lighting designers can now lead the sunlight deep into buildings, far away from windows to allow everyone to enjoy the natural daylight.

Parans Solar Lighting offers sunlight for indoor environments and constructions through innovative technology and design. The system captures and leads the rays of the sun in and through the property – deep into buildings and far away from windows – and spreads the light in a way giving people a memorable experience.

The system is also well adapted to support novel lighting design for tunnels, providing high quality illumination for improved road safety.

Today when the world aim to reduce its footprint, Parans' solution is more topical than ever. To use the sun as a light source is healthy, sustainable and smart.

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https://www.parans.com/get-parans-light-guide/


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