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FACULTY OF ELECTRICAL ENGINEERING

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EGOR PUSHKIN

ZADÁNÍ BAKALÁŘSKÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

Příjmení: **Pushkin** Jméno: **Egor** Osobní číslo: **483804**

Fakulta/ústav: **Fakulta elektrotechnická**

Zadávající katedra/ústav: **Katedra ekonomiky, manažerství a humanitních věd**

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Specializace: **Elektrotechnika a management**

II. ÚDAJE K BAKALÁŘSKÉ PRÁCI

Název bakalářské práce:

Vliv moderních trendů na energetickou náročnost veřejného osvětlení

Název bakalářské práce anglicky:

The impact of modern trends on the energy performance of public lighting

Pokyny pro vypracování:

1) Posuďte vliv výměny konvenčních světelných zdrojů a svítidel za moderní na energetickou náročnost veřejného osvětlení.
2) Posuďte vliv nových technických požadavků v oblasti nežádoucích účinků venkovního osvětlení na jeho energetickou náročnost.
3) Na základě 1) a 2) navrhněte postup optimalizace veřejného osvětlení v souladu s aktuálními technickými požadavky.

Seznam doporučené literatury:

[1] HABEL, Jiří. Světlo a osvětlování. Praha: FCC Public, 2013. ISBN 978-80-86534-21-3.
[2] ČSN EN 13201 (360455) Osvětlení pozemních komunikací
[3] ČSN 36 0459 Omezování nežádoucích účinků venkovního osvětlení

Jméno a pracoviště vedoucí(ho) bakalářské práce:

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Jméno a pracoviště druhé(ho) vedoucí(ho) nebo konzultanta(ky) bakalářské práce:

Datum zadání bakalářské práce: **14.02.2023** Termín odevzdání bakalářské práce: **26.05.2023**

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III. PŘEVZETÍ ZADÁNÍ

Student bere na vědomí, že je povinen vypracovat bakalářskou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací.
Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v bakalářské práci.

.

Datum převzetí zadání Podpis studenta

ACKNOWLEDGEMENT

I would like to thank my research supervisor, Ing. Marek Balský, Ph.D. This paper would have never been accomplished without his assistance and dedicated involvement in every step throughout the process. I would like to thank you very much for your support.

DECLARATION

I declare that the presented work was developed independently and that I have listed all sources of information used within it in accordance with the methodical instructions for observing the ethical principles in the preparation of university theses.

Prague, date 21. May 2023

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ABSTRACT

Recent development in LED technology has opened new possibilities in lighting design. Public lighting requirements have become more strict and require individual approach from engineers. This project focuses on different options modern LED technologies provide and discusses challenges engineers face when designing new lighting systems. A city in Czechia was selected to create a case study that proposes LED luminaires based on the results of the calculations. An energy assessment, economic and ecological evaluations were created as part of the solution.

KEYWORDS

Street lighting, LED technology, spill light, lighting design, subsidy, energy assessment, economic evaluation, ecological evaluation

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Reducing energy consumption is one of the main tasks of the European Union and one of the most critical questions of the presence. The EU's goals of energy reduction closely relate to the overall human impact on the environment and global climate change issues. Energy production, distribution, and further consumption are among the most significant ecological burdens on the environment, affecting future generations' lives. Saving energy is one of the most effective ways to reduce the negative effects, which also leads to saving money. Due to geopolitical uncertainty and the ongoing energy crisis shift to sustainable solutions has never been more critical.

Multiple studies [22] show that lighting accounts for almost 20 % of global electricity consumption and 6 % of CO_2 emissions. Some suggestions include turning off lights altogether. However, this solution would cause problems even more severe than it intended to solve. Light is essential for safety, comfort, and well-being overall. Turning lights off during nighttime proved to lead to increased criminality and traffic accidents.

Studies suggest [22] that by switching to energy-efficient LED lighting, lighting consumption could drop to 8 % by 2030 worldwide, even while the total number of light points rises. LED lighting reduces energy consumption over conventional alternatives by over 50 %. When using the benefits of the modern LED lighting control systems to as much as 70 %.

This project focuses on the technical and economic aspects of public lighting renewal in Czechia. It compares the different proposed solutions between each other and the current conventional lamps.

The first chapter gives the reader an understanding of the importance of outdoor lighting and takes a closer look at the lighting systems currently installed.

The second chapter focuses on a topic that is often neglected but is extremely important. Spill light disturbs the residents and increases the newly installed system power. This chapter explains the negative effects of spill light on the environment and guides how to calculate and limit it.

The third and the fourth ones explain the different types of lighting controls commonly found on the market. It also provides a guide on choosing the right LED luminaire.

The last two chapters are a practical example of implementing the technologies discussed, including all the benefits it provides to potential investors. The practical example is structured so that it could potentially be used for a public tender

1. ARTIFICIAL LIGHTING

1.1 Outdoor Lighting

The key responsibility of artificial outdoor lighting is to enable a level of comfort and safety as close as possible to the daytime. This kind of lighting is required for approximately 4100 hours per year. The most common areas which require artificial lighting are industrial and residential zones, parks, different types of roads, and outdoor workplaces such as airports, building sites, farms, gas stations, storage areas, parking areas, railways and tramways, docks, and many others. The whole other section is sports and architectural lighting. The same principles apply to all of them: artificial lighting in the outdoor area aims to create a comfortable environment for the human eye, allowing one to easily distinguish objects from each other. Having good horizontal and vertical illuminance increases overall safety. Due to the variety of application areas, each requires a specific and individual approach and technical solution. Parameters such as reflectance of the surfaces, surroundings, climate, and mechanical vulnerability are important to consider. The key advantages of using LED luminaires are longevity and precise light beam control. LED luminaires have lower maintenance costs since no relamping is needed, and there is a lower chance of moisture getting into the luminaire. Modern technology of beam control of the LEDs significantly minimizes stray light. It is vital in streetlighting, where roads and paths should be illuminated. This also applies to parking areas, sports pitches, and parks where the beam can be directed to the needed area. This leads to a lower level of light pollution and high efficiency.

The natural light during the evening and nighttime is insufficient for safe road traffic. Additional artificial light from vehicles, billboards, and private zones is not permanent; therefore, stable and independent light systems have to be installed. It must improve the reaction time of the drivers as well as increase the ability to distinguish between the traffic signs erected at the side of or above the roads. As technology evolves and motorized vehicles are getting faster, the difficulty of navigation is getting harder, especially in a dense city setup.

1.2 Lighting Systems in the Past

For general outdoor applications, mostly HID lamps, such as sodium-vapor, metal halide, and mercury-vapor lamps, were used [1].

Mercury-vapor lamps proved to be reliable while operating and could be used for basic outdoor applications. They are more energy efficient than incandescent lamps, with average luminous efficacy of 35 – 55 lm/W. Their key advantages are:

- Long lifetime of up to 16 000 h
- Low lumen output depreciation throughout the lifespan – 20 %
- Simple circuit diagram enables easy maintenance
- The low influence of ambient temperature on the lamp parameters
- Reliability while operating in lower temperatures

Metal-halide lamp is a modified version of a mercury-vapor. Additional metal halide compounds improve the efficiency and color rendition of the light. The improved luminous efficacy is up to 100 lm/W. Other key advantages are:

- Long lifetime, depending on the metal halide compound.
- Wide range of initial input power
- High value of CRI

The most used option in the Czech Republic is high-pressure sodium-vapor lamps. High-pressure sodium discharge lamps are light sources in which light is emitted mainly by sodium vapor with a partial operating pressure between 3 and 60 kPa. The luminous efficacy can reach up to 150 lm/W. High-pressure sodium discharge lamps must be operated in a circuit with a choke, a suitable ignition device, or an electronic ballast. While operating under prescribed conditions, the lamps can last up to 30 000 h. They suited well the basic requirements of outdoor lighting. The typical CRI value of these luminaires is 20. A relatively bad ability to differentiate colors was not crucial. Key advantages:

- High luminous efficacy with a good CRI (from 20 – 25)
- Longevity of up to 30 000 h
- Cost-efficient and simple maintenance
- Mass-produced technology pushed down production costs and created a competitive market.

1.3 Outdoor Lighting Design Process

The first step when designing outdoor lighting systems is to obtain data about the current situation. This allows the lighting engineer to compare the solution later and judge the cost efficiency of the proposed solution. To create a detailed solution, it is essential to know the parameters of the calculated area, such as geometrical size, traffic flow, things related to visual difficulties, and many others. The next step is assigning the outdoor area class, which allows us to determine the illumination requirements. However, such parameters are often pre-determined in bigger street lighting projects. When completed, it is up to the investor to choose the best solution from a technical and economic perspective. If the project is subsidized, the investor must arrange a tender with equal requirements and parameters for each contestant.

2. LIGHT POLLUTION

In general, light pollution, also light smog, refers to excessive, unwanted artificial light. It is an indicator of a poorly designed lighting system.

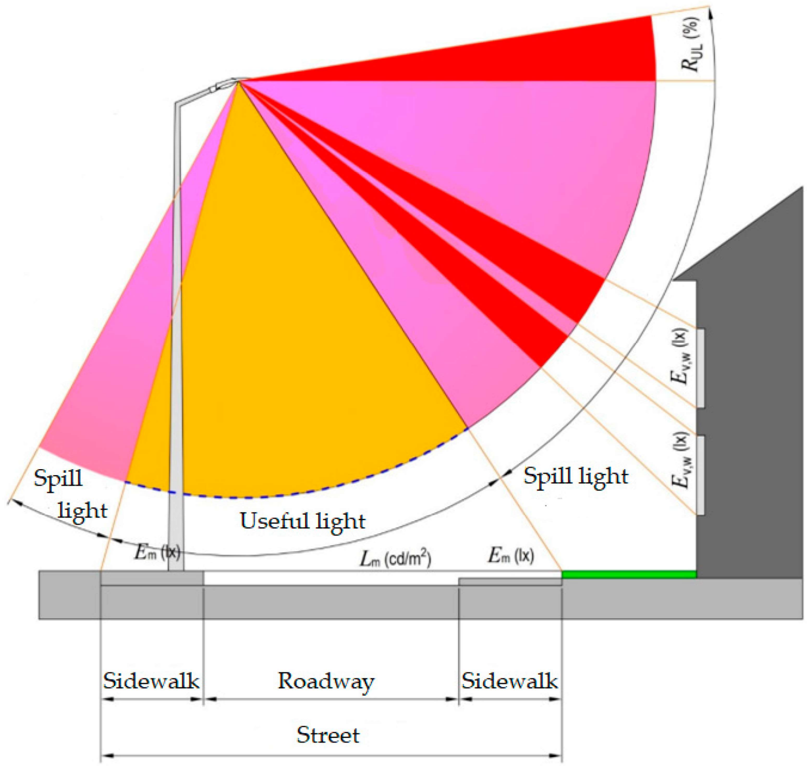

Figure 2-1 Luminous flux distribution [20]

The human body is adapted to a 24-hour rhythm of light and dark as the earth rotates about its axis. The circadian rhythms regulate many processes in the body, including sleep-wake, heart rate, and the rhythm according to which certain hormones are produced. This light and dark mechanism controls the hormones cortisol and melatonin throughout the day and night. They play an essential role in regulating the balance of being alert and asleep. Cortisol levels increase in the morning and gradually decrease during the day till they drop to a minimum at night. On the other side, the sleep hormone is only produced when it's dark. Melatonin level drops in the morning, reducing the feeling of sleepiness. Simple lack of sleep and desynchronization of the natural 24-hour rhythm may cause reduced attention and performance or even lead to more serious health problems. It turns out that the maximum biological sensitivity of living organisms lies in the blue region of the light spectrum, the shorter wavelengths. At the same time, the blue component is heavily emitted by modern LED luminaires. This is the reason one should minimize exposure to light during night hours [2].

2.1 Measurements to prevent light pollution

Firstly, it is important to notice that this topic does not apply to all kinds of outdoor applications. For example, the technical standard does not apply to lighting with a specific purpose, such as traffic signaling, one-time events, or holiday decoration [4], [10].

While operating, the luminaire should emit only into the lower half-space. The only exception should be architectural lighting. This requirement is necessary to limit the light emitted in the wrong directions, for example, residential zone windows or the sky. Unwanted light creates a light haze over metropoles and has a negative effect on living organisms [18]. To achieve that, lighting calculations should be done with minimal to no tilt of the luminaire. Choosing the right optic is one of the most important ways of preventing unnecessary light. Generally, manufacturers produce symmetrical, narrow, medium, and wide optics sufficient for most outdoor cases. Many producers offer an additional backlight shield that limits the beam emitted behind the light fixture. It often happens that the existing light fixture is located too far from the illuminated area. In those cases, an arm should be added.

2.2 Obtrusive Light Calculation

The obtrusive light calculation should be done according to EN12464-2 [5]. The limits of obtrusive light for exterior lighting installations are given in Table 2 of technical standard. The maximum permitted value is divided into four environmental zones, from E1 – E4. The requirements are divided into pre-curfew and post-curfew. The classification is often a part of the "Public lighting passport" provided by the city. The calculation should be done in lighting software using the luminaires from the road calculation. The technical standard provides maximum value for E_v on the properties. In the Czech Republic, people often misunderstand this as a calculation of the values on a facade. It is important to note that the calculations should be done in places where light pollution could be harmful or distracting. For example, it makes sense to calculate obtrusive lighting on the facade of the building with windows. If no direct light passes through the facade, then no calculation seems rational. This assumption is crucial for calculations in the Czech Republic, where there is often a minimum distance between the photometric center of the luminaire and the potentially risky section.

Technical services of major cities in the Czech Republic usually have their city mapped and can provide a passport of the city. It consists of the location of each luminaire, its ''height, tilt, current light fixture name, and wattage. Sometimes they also include environmental zone classification, luminaire standards of the city, or any additional requirements.

2.2.1 ČSN 36 0459

At the time of writing, a new technical standard was introduced [23]. Starting from February 2023, neutral white CCT for newly built lighting systems is banned. One of the most significant changes is a maximum allowed illuminance on facades post-curfew. In most cases, the maximum allowance changed to 5 lx. For a lighting engineer, that means more types of optics can be used, and in many cases, no additional shield has to be installed.

The calculations in this project were done to reach the requirements of the previous technical standard. The NRP subsidy officials [19] have set rules, often more strict than the technical standard dictates. Since the subsidy rules have not been updated at the time of writing, it is assumed that the new standard does not affect the subsidy.

3. LIGHTING CONTROLS

The general public understands lighting controls as specific lighting effects, such as changing colors and scene settings. However, the use of control systems is bigger and is focused on saving energy. Roughly speaking, lighting controls are even more critical than LED technology. Even the most efficient luminaire wastes energy if it's fully ON and can be turned OFF or dimmed.

LED Lighting manufacturers enable multiple features essential for high-cost and energy-efficient solutions for cities while fulfilling modern luminaire installations' safety and comfort requirements. The preferred solution is to dim the artificial lighting when it is less needed, i.e., when the traffic of pedestrians and vehicles is low. LEDs are well suited to using control systems as they always come with an electronic driver. Dimming also extends the longevity of LEDs as the junction temperature goes down.

Historically, the ability to use control systems in outdoor applications was limited. Most luminaires used to be HID lamps which have limited possibility to be dimmed [1], [2]. Most of them have a delayed start in cold conditions and must be restruck when hot. LEDs can be dimmed and switched on and off frequently.

3.1 Common types of professional lighting controls

Choosing the right way of communication protocol is challenging. The differences are in support of one-way or two-way communication, analog or digital, operation speed, number of luminaires that could be controlled, and the cable length between the light and control points. When choosing the right solution, it is important to note that the driver and controls must use the same protocol. This is especially important when using different lighting manufacturers. Among the most common are:

- 1-10 V – This method requires additional low-voltage wiring apart from the main power supply. The low-voltage circuit works as a control signal that varies between 1 and 10 Volts. This technology has certain disadvantages. The communication is one-way, from the controller to the luminaire. Therefore, failed lamps or ballast cannot be detected. It requires separate wiring for every driver, and the control circuit is hardwired as the luminaires have no addresses. Since it is an analog method, achieving distinct control levels is impossible.
- AmpDim – The amplitude of the current is changed to dim the lighting.
- DALI – Digital signaling protocol. The idea is that each luminaire within the system is separately controllable. However, it only requires a single control cable within the system. This method is two-way, so it can also monitor the status of the individual luminaire, detect failure, level dimming, etc. The limitation per channel is 64 luminaires, and this method is widely used in indoor applications. However, the recommended maximum length of 300 m between any two devices on a DALI data bus makes it impractical for street lighting applications.
- StepDim – Dimming to a preprogrammed light level via an external control phase.
- Integrated module – autonomous preprogrammed multi-level dimming module. The pre-defined dimming profile could be referenced to the switch-on time of the LED driver or the annual average middle of the night.
- Smart lighting system – This type of control system combines energy management with inventory information such as location, energy status, and condition of each luminaire. This online connectivity enables instant changes to luminaires.

3.1.1 Multisensor

It is a single hardware device combining multiple types of sensors to support the smart city application:

- Radar motion sensor automatically changes the light level in case of activity, so-called light on demand.
- Allows luminaires grouping via a local mesh radio network to change the light ahead in case of activity-forward triggering.
- Photocell to adapt according to the daytime.
- Tilt and impact sensor to monitor light pole conditions.
- Noise and temperature sensors to monitor ambient conditions around the pole. It allows the city to collect necessary environmental data, which ultimately helps to prevent illnesses connected to excessive heat and noise.

The sensor is mounted to the bottom Zhaga socket and designed for use in Zhaga-D4i-certified outdoor luminaires. It can be used both standalone and in combination with a smart city solution offered by a manufacturer.

Since this solution is relatively new on the market, there is not much historical data to support the long-term assumptions. This sensor undeniably provides an even more individual approach to lighting control. It is possible to assign each luminaire a pre-defined profile that maximizes usage efficiency. As is the problem with many new technologies, this requires a deep understanding from the lighting engineer and the customer. Once installed and commissioned by the field service engineer, the customer gains access to an app that gives the customer control of the luminaires. Since the required function of the luminaire might change over time, the customer could change the setting. It might appear challenging for a customer without prior experience with smart lighting apps.

3.2 Dimming

According to the lighting calculation technical standard CEN/TR 13201-1 [4], [10], it is recommended to change the lumen output of the luminaires during the night. The transportation systems function as living organisms, and the conditions in the evening hours change the later it gets. Visual requirements vary for all the traffic participants. Then, the classification of the road can be adjusted. It is important to note that the road class could be changed only within the same road classification type. For example, an M road cannot be changed into P as the conditions do not modify the general criteria the class is based on. There are exceptions where dimming the luminaires is not advised [10], which is quite logical when using common sense: For example, it is not advised to dim in the areas where it is vital to see the face of the potential suspect. This could be on the square in front of the bank. Also, if the city has historical data which shows that a particular crossroad could be marked as risky and has a high rate of accidents.

4. CHOOSING STREET LIGHT

To have fair competition between the potential lighting manufacturers, a technical standard for a luminaire has to be set. This would eliminate unknown, unreliable manufacturers whose products would have resulted in long-term complications.

4.1 Luminaire standard specification

1) The luminaire should have been originally designed only for an LED light source. It must not be a so-called retrofit; in other words, a light fixture that could be fitted with both conventional and LED sources.
2) The light fixture must be equipped with a universal flange that allows attachment to the polearm and directly to the pole.
3) For the sake of optimization, it must be possible to change the tilt of the lamp on the flange - when mounting on the arm from - 15 ° to + 15 ° (5 ° step); when mounted directly on a pole from 0 ° to + 15 ° (5 ° step).
4) Luminaires for road lighting must emit light corresponding to the correlated color temperature CCT = 2700 K (± 300 K). The Color Rendering Index of the emitted light R_a must be at least 70.
   The widely used standard in the Czech Republic was a sodium-vapor lamp. These yellowish lamps emit relatively small amounts in the blue and green parts of the spectrum. On the other hand, modern LED emits this spectrum significantly.
5) The luminaire for illuminating crosswalks must emit a color of light corresponding to the correlated color temperature CCT = 5700 K (± 300 K). The color rendering index of the emitted light R_a must be at least 70.
   According to additional Czech technical standard TKP:15, the CCT for the crosswalk luminaires should create a color contrast with the rest of the public lighting. The ratio used should be at least 1:1,5. In the case of 5700 K and 2700 K road luminaires, the ratio, therefore, would be 2.1.
6) The manufacturer must guarantee a minimum lifetime of 100,000 hours of lighting.
7) The luminaire must be equipped with a system that compensates for the decrease in the luminous output flux of an LED source during the entire lifetime of the luminaire - CLO. This must be done in such a way that the LED sources emit a constant luminous flux for the specified lifetime (0 % decrease in luminous flux).
8) Cooling must be passive only. The luminaire must not be equipped with fans or fins.
9) The luminaire must comply with the degree of protection against the ingress of dirt, foreign bodies, and water of at least IP 66. The entire light fixture must resist harmful mechanical impacts of at least IK 09. The optical and electrical parts of the light fixture must have their own seals.
   For the older generation of lamps, the requirement was to use enclosed luminaires with a rating of at least IP 54 [1].
10) The optical and electrical parts of the light fixture must be separated from each other so that the LED and the optical part are unreachable when mounting the light fixture.
11) The light fixture must be equipped with a hidden passage for equalizing the pressures inside and outside the light fixture, preventing moisture from entering the light fixture.
12) The entire body of the lamp must be made of highly heat-conductive and corrosion-resistant certified aluminum alloy by high-pressure casting technology
13) 100 % of the emitted light from the fixture must fall into the lower half-space.
14) LED sources must be equipped with temperature protection against overheating.

15) The luminaire diffuser must be made of heat-hardened glass and attached to the frame via a silicone gasket. The lamp diffuser must be replaceable if necessary.
16) Each individual LED must be fitted with an identical optical lens made of UV-resistant material. The light must be distributed without reflections directly out of the fixture.
17) The luminaire must have the option of being equipped with screens that limit the radiation of the luminaire towards the rear. This additional accessory is important for limiting the disturbing light for the individual needs of the population. The shade must be installed inside the light fixture.
18) The lamp must be in protection class I, and it must be possible to connect it directly to the 230 V voltage level.
19) The electronic driver can be removed without the use of tools and without the need to remove other parts of the lamp. Electrical equipment must be connected via removable connectors.
20) The electronic driver must be equipped with thermal protection and integrated overvoltage protection with a value of at least 6 kV.
21) After opening the light fixture, both parts must still be firmly connected so that none of them falls during the service of the light fixture. When opening the luminaire, there must be immediate access to the electronic driver and terminal board.
22) It must be possible to open the luminaire without the need for tools.

4.2 Choosing a smart lighting system

1. Each luminaire must be equipped with its own GSM communication module, GPS localization module, photocell switch, and electrical energy measurement element at the level of the luminaire
2. Intelligent public lighting must include a control system, remote management, and monitoring of operation, status, and online control.
3. A complete public lighting control system must include a graphical user interface, full connectivity between the luminaires and the user interface, and intelligent luminaires with the ability to integrate automatically into the control system. The management system must also include data processing, data transmission, data storage, data backup, and data transmission security. The data transfer security level must be at least a 128-bit AES encryption level. The control system must ensure Full data management, not the user. Communication between the user interface and the luminaires must occur directly, wirelessly, via mobile operators' networks. The system must not require additional control or communication elements at the ground installation level, such as a modem, etc. The system must automatically select the mobile network with the strongest signal in the given area after installing the lights and the first switch-on. Luminaires can be installed independently of the position of other luminaires, i.e., it is not necessary to ensure direct visibility between them. The behavior of the luminaires must not fail even in the event of a mobile operator network failure. The lamps must continue in the last known mode until the network of one of the mobile operators available in the given location is restored.
4. The control system must be accessible from any common office computer anywhere. Each user with a login and password must be able to set the level of their rights in the system. The user interface does not need to be installed on the computer. The user interface must be operated as a web application accessible from a regular internet browser. Access to the user interface must be protected on two levels – by password and by sent code. All interaction between the user and the user environment must take place

at a minimum 128-bit SSL encryption level. The management system must regularly back up all data to at least three physically separate storages, typically in the cloud. In the event of a system failure, the data must be immediately restored from the backup. The entire IT structure of the management system must comply with ISO 27001 certification. All improvements to the user interface must be applied automatically without any request to the user. All improvements to the intelligent unit in the luminaires must take place automatically via wireless transmission without user intervention.

5. After installation, the luminaires must be automatically connected to the control system without the need for user intervention. Luminaires must determine their position and display it in the graphical user interface. Luminaires must import their technical parameters into the control system themselves. The entire procedure of integrating intelligent lighting into the control system must be completely automatic without the need for any user intervention. The capacity of the number of luminaires the system serves must be in the order of millions. Each individual lamp must be controlled independently, separately from the others. The user interface must provide detailed information about each individual light fixture.
6. Luminaires in the graphical user interface must be displayed on a clear map background, incl. an aerial view. The system must display data in real time without the need to refresh the web page. The system must be able to divide luminaires into regions, streets, or interest groups. The user must be able to create his own interest groups of luminaires at will. Each of the luminaires must be able to be integrated into several groups of luminaires simultaneously.
7. The system must allow an immediate change in the luminous flux of each individual luminaire. It must be possible to assign a dimming calendar to each individual luminaire or group of luminaires with individual dimming diagram settings for each individual day of the year. The number of changes in the luminous flux level during one-night dimming must be unlimited. The system must allow the operation of at least fifty different dimming calendars. Each blackout calendar must contain sub-blackout calendars valid for one day. Partial dimming calendars can be repeated during the year based on specified rules.
8. Upon request, the user must receive current information about each individual light fixture. The system must send error messages detected from the previous night to the user every morning if any occur. Current faults in the system must be visualized in the graphical user interface. The delay between the occurrence of a defect and its display in the graphical user interface must not be longer than 30 minutes. The specification of errors registered by the system must be described in detail.
9. The system must enable the monitoring of the history of the actual measured electricity consumption of each individual light fixture or group of light fixtures. The user interface must enable searching in the system of light points based on several parameters. The user interface must enable the generation of reports according to the user's area of interest. The user interface must allow data export in xls/xlsx format.
10. Combining the user interface with the interactive passport of public lighting must be possible. The graphic mark of a smart light and a light without connectivity must be different. The additional integration of the luminaire portfolio must not mean any increased demand for software, hardware, or ground installation components.

5. NPO SUBSIDY

Switching the whole system for the new one on a city scale would require significant investment. New LED luminaires are expensive, and replacing them is often connected with additional construction works, such as replacing older concrete/wood poles for new galvanized steel lighting poles and replacing an old overhead power line. To lessen the initial project investment, the EU has started an initiative that helps to cover the expenses partially.

NRP – (in Czech NPO) National Renovation Plan is a subsidy program financed by the EU. It is intended for the reconstruction and innovation of outdoor public lighting systems to achieve electricity savings and high safety standards. The program applies to reconstructing existing public lighting systems, including adding new light points to meet the requirements of current technical standards. The subsidy only applies to the current lighting systems and cannot be used to construct new ones.

6. CASE STUDY CITY

6.1 Description

The selected city is a small town in the Czech Republic that meets the criteria of this project. It has about 16 000 inhabitants and is eligible to apply for an NRP subsidy. The town enables to showcase the most common lighting challenges engineers come across in the Czech Republic. The layout consists of a small historical city center where narrow streets with two-story buildings require compromises between illuminating sidewalks and restricting obtrusive light on facades. There are several residential zones with family houses, wide streets, and long spacing between the poles. In many cases, the poles are the same height as nearby trees. Those trees function as a shield for the lighting fixtures and cause difficulties from the lighting engineer's perspective. Other parts of the city are tall blocks of flats with illuminated sidewalks from the poles located right in front of the windows. Complications include irregular pole spacing, missing luminaires, and unreasonable overhangs.

6.2 Street lighting calculation

6.2.1 Crosswalk

Illuminating crosswalks requires special safety measures, and in some countries, the Ministry of Transport releases national standards which provide additional requirements which meet the country's local needs. The idea is to create a contrast between the pedestrian and the background. Creating a negative contrast does not require additional luminaires and could be created with the normal road light. In that way, the pedestrian will be seen as a dark silhouette against a brighter background. The other way is to create a positive contrast by placing additional luminaires. This way, the luminaires aim to directly illuminate pedestrians on or at the crosswalk.

There is a preliminary technical standard in the Czech Republic: "Road Lighting – Additional information ČSN P 36 0455", June 2017 [10]. This technical standard provides additional information on methods and the overall idea behind the crosswalk illumination. Then, there is TKP 15 from 2015: "Chapter 15 – Road Lighting," released by the Department for Transport [11]. The technical standard provides a detailed description of the construction materials, technological work procedure, ecological climate aspects, reconstruction notes, and calculation requirements.

From a construction point of view, the technical standard applies to all correctly built crosswalks in the Czech Republic. The illuminated area is a crosswalk and zones at both ends, where pedestrians stand and wait to enter the main area. It could also be a mid-block in case of arterial roadway crosswalks. Additional illuminated spaces have fixed lengths on both sides, 1 m. For mid-blocks, the fixed calculated length is 3 m. The luminaires must be mounted before the crossing in each direction of the traffic flow, on the side of the traffic flow if conditions allow. No additional lighting is required for the crosswalks regulated with a traffic light. The same applies to the ones where on-road markers are being used. The crosswalk lighting system should be regulated the same way road lighting is. The requirements for the crosswalks are based on road classification [11].

Unlike the road lighting calculations, where horizontal illuminance is important, for the crosswalks, the important parameter is the illuminance of the vertical plane facing the approaching motorized vehicle at the height of 1 m. To achieve that, light poles are placed

shortly before the crosswalks, and the light is directed onto the side of pedestrians facing the traffic drivers. It is a common practice to use asymmetric optics, which provide enough vertical illuminance and do not cause an unacceptable amount of glare to the drivers.
It is advised to keep the same level of average illuminance level for both the main space and additional space. However, in reality, it is impossible, and according to the technical standard, the ratio between the main space and additional space should be between 0.5: 2.0. The overall uniformity of each space should be greater than 0.4.

To create a positive contrast, different color tones should be used. The technical standard requires the minimum CCT ratio of 1:1.5 [11]. Since the subsidy rules require using 2700 K, neutral white color for crosswalks could be used. However, using the cool white color of 5700 K gives a better ratio, meaning contrast, and also provides additional power saving. The ratio, therefore, is 2.11.

The reconstructed part of the case-study city has 18 crosswalks which potentially require additional lighting. Three of them are located on the M3 class road. The road is three lanes both ways, and its' width does not enable it to meet the technical requirements of the technical standard. For a proper solution, 8 m light poles should be installed 2.5 m before the crosswalk on each side. The standard light pole height of the crosswalk luminaires is 6 m with up to 3 m arm. Since the arm length used for the crosswalk is significantly higher than that of the road lighting, using the standard road lighting pole would cause problems with the statics of the fixture. Hardened light poles other than 6m in height are hard to find on the market in the Czech Republic and probably will have to be tailor-made. According to TKP15 [11], in places where it is not possible to set up a crosswalk with additional lighting that meets the technical standard requirements, other measures to increase pedestrian visibility can be used, for example, negative contrast or traffic or construction adjustments. In case of the inappropriate construction arrangement of the existing crosswalk, length in this case, the issue can be resolved by making construction modifications to the crosswalk. Adding a mid-block would solve the problem and enable the use of a 6 m light pole.

The M4 class road has 15 crosswalks located on the road and at junctions. The calculated crosswalks were modeled in lighting design software. The idea behind switching to LED is to minimize the construction works where it is possible. On the crosswalks, no current lighting system existed. In those cases, new light poles must be installed. This additional expense is added to the final BOM. For the crosswalk calculation, two types of luminaires are used (see *Appendix C*). First is a luminaire with an asymmetric right-side-oriented optic with a lumen output of 9600 lm and a wattage of 59 W. Second is also a right-side-oriented optics with a lumen output of 7400 lm and a wattage of 46 W. From these values, it is apparent that this manufacturer offers a high energy efficiency solution, 162 lm/W, and 160 lm/W, respectively. This solution requires an additional 18 pcs of 59 W luminaires and 12 pcs of 46 W luminaires.

For the M5 roads, no crosswalks will be replaced, and there are no crosswalks on the P-class roads that are part of this project.

Additional crosswalk lighting is a modern standard necessity which is not an energy-saving measure. It increases nighttime traffic safety, which is a primary purpose of artificial lighting. This comes with a cost of an additional 1.6 kW of power consumption, a new LED system, and construction works.

6.3 Light pollution

As for the particular calculations, both the current situation and the new LED were done. The lumen output of the LED was adjusted according to the dimming schedule, so the theoretical calculation corresponds to the actual post-curfew situation. Current sodium-vapor lamps are not dimmed at night, so no adjustments were made. It is important to notice that the calculation height is not the height of the pole but the height of the photometric middle of the luminaire. The M-class roads are put into E3 environmental zone, and the P-class ones – are in E2. E3 zones usually represent medium district brightness areas, such as industrial or residential suburbs. E2 zones represent low district brightness areas, such as industrial or residential rural areas.

6.3.1 M3 lighting class

M3 classified roads are often designed for heavy, mostly motor traffic. The roads are often wide multilane. The luminaires used for the calculation typically produce obtrusive light heavily; however, this type of road is often designed to be separated from the city, so there are no living buildings within close distance. This is the case for our city, where the closest buildings are 25 m behind the luminaire and 35 m in front. No calculations for this type are necessary.

6.3.2 M4 lighting class

An M4 sample is a common situation in the Czech Republic, where the sidewalk is located right next to the building. The windowsill height is usually around 1.5 m, and in situations like this, it is up to the lighting technician to decide whether to focus on light pollution on the facade or illuminate the sidewalk according to the technical standards. According to Czech technical standard ČSN P 36 0455: 4.1.13, "There must not be difference larger than two comparable classes according to table 2. The area with the highest illuminance level should be used as a reference. In the case of conflict zones, M classified roads are switched to C according to CEN/TR 13201-1" [4], [10]. The comparable class for M4 is P2 which is 10 lx. Since the minimum and maximum illuminance must not differ more than two classes, this gives a minimum of P4 for the sidewalk. Here comes the tricky situation: the lighting engineer has to reach 5 lx on the sidewalk and 2 lx post-curfew on the facade. To achieve such light levels, narrow beam optics could be used. However, since the illuminated sidewalk is on both sides and the road itself is wide, this solution will not work. In this particular case, the facade behind the pole is 4 m away. An extra backlight louver is added to limit the light pollution behind the luminaire. It limits the overall efficiency of the luminaire; an extra 650 lm should be added to fulfill the requirements for an M4 class. This results in an additional 3.5 W per luminaire used in this sample. The maximum reached level on the facade behind the pole is 1.55 lx and 0.4 lx on the opposite side of the luminaire (see Appendix C). This indicates that the right optic was chosen, and an acceptable amount of excessive light fell on the windowsills.

From the calculation of the current situation, the maximum values reached are 20 lx (see Appendix D). These values are located right behind the pole in height from 1 to 6 m. If the pole is located right in front of the window, the nighttime pollution is extremely disturbing for those living there. Even with 5 m on both sides, the values are still 4 lx.

6.3.3 M5 & M6 lighting classes

M5 and M6 roads are usually illuminated from 5 m and 6 m poles. These mounting heights enable using a variety of optics, often without the addition of a louver. In smaller cities in the Czech Republic, the road width of these classes is usually up to 6 m. This allows using narrow beam optics for the calculations. In our case, the facade on both sides is relatively close. After adding a louver, 1 lx post-curfew is reached (see Appendix C). The luminaire currently in use has double the wattage of the proposed new LED (see Appendix A, B). The old system is not dimmed at night. The values reached behind the pole are 13 lx at the height of the first floor (see Appendix D). 5 lx post-curfew corresponds to the requirements of E4, high district brightness areas, such as town centers and commercial areas. Here, triple the amount is reached in a relatively dark area. The technical standard [5] says that if no curfew regulations are available, the higher values shall not be exceeded, and the lower values should be taken as preferable limits. Pre-curfew value for an E2 environmental zone is 5 lx on properties and 7500 cd luminaire intensity and maximum luminance of 5 cd/m^2 on a building facade. Values reached for the current luminaire system would be sufficient only for an E4 zone representing town centers and commercial areas [5].

6.3.4 P4 & P5 lighting classes

The visual requirements for P-class roads differ from those for M-traffic routes. Since P classes often cover areas with lower movement speeds in residential zones, footways, and cycleways with fewer motorized vehicles, the calculation requirements are significantly lower than for M classes. P areas calculations require maximum and minimum values of E. Sometimes, upon request, also the calculation of TI. For these types of roads, lower-height poles are usually used. Since no TI calculation is needed, a wider variety of optics could be used, increasing the maximum pole distance. The newly proposed LED systems are dimmed according to P6 class requirements. The CEN/TR 13201-1 states that the minimum dimmed class is P6 [4],[10]. The technical standard explicitly states that no P7 class must be used, while the previous, older technical standard enabled an equivalent.

The calculation of P4 local roads, the proposed 4600 lm / 35 W LED luminaires are used (see Appendix B). It is dimmed to P6 class during the night, so the lumen output in the calculation software is adjusted to 40% of the nominal value. The distance between the 5 m poles is 39 m. After the addition of a louver, 1 lx post-curfew is reached both on the side of the pole and the opposite (see Appendix C). The city is currently using 3400 lm / 61 W lamps. The maximum values reached for the same situation are 5.67 lx behind the pole and 1.43 lx in front (see Appendix D). Once again, the maximum values behind the pole do not meet the criteria of the technical standard [5]. It is important to notice that the situation represents a residential zone where such values could potentially cause uncomfortable living conditions.

P classification is used not only for roads designed for motor vehicles but also separated sidewalks and cycleways. New LED systems are installed on separate sidewalks as well. In most cases, the sidewalks are located in front of blocks of the building. The width of the sidewalks is often up to 3 m, and the mounting heights of the luminaires are from 4 to 6 m. The poles are placed next to the road, and since no additional arms are required, the luminaire's overhang is often 0 m. The widths of the sidewalks and long distances between poles lead to narrow beam optics used. The poles are mostly placed on the side of the buildings, and the narrow optics enable easier calculations of light pollution.

High-density areas such as building blocks should be given extra attention when choosing the right artificial light solutions in terms of surrounding pollution. The dense the area, the more potential complaints an investor is going to get. The comparison of the current situation and a new LED perfectly showcases how modern and efficient LED technology is (see Appendix A, B). The calculation surface was placed only on one side, behind the pole; the lowest area is at the height of a windowsill. In the current situation, the maximum values reached at some points are

19 lx (see Appendix D). This indicates that the original lighting system is poorly designed, judging by modern standards. The newly calculated solution uses a 1500 lm / 12.5 W luminaire against 5600 lm / 80 W, which was used initially. An additional louver is added to ensure the maximum pollution on the facade is not exceeded (see Appendix C).

6.4 Case study city dimming

One of the options for this project is to choose different dimming regimes for each M class and a unanimous one for P class roads.

An M3 road is dimmed to M5 during the nighttime. This gives us a change of the minimum maintained luminance of the road from 1.00 cd/m^2 to 0.50 cd/m^2. The regime will be as following: From ON to 22:00 = 100 % / from 22:00 to 23:00 = 75 % / from 23:00 to 04:00 = 50 % / from 04:00 to 05:00 = 75 % / from 05:00 to OFF = 100 %.

The same dimming regime is used for M4 and M5 class roads. The maximum allowed dimming for an M5 road is M6, thus dimming 0.50 cd/m^2 to 0.30 cd/m^2. The following regime will be used: From ON to 23:00 = 100 % / from 23:00 to 05:00 = 60 % / from 05:00 to OFF = 100 %

The local roads are dimmed to P6 level during the nighttime. The level of minimum horizontal illuminance for P4 is 5.00 lx, and for P6 is 2.00 lx. The dimming regime is used as follows: From ON to 23:00 = 100 % / from 23:00 to 05:00 = 40 % / from 05:00 to OFF = 100 %. Using such an aggressive dimming regime while still fulfilling the technical standard requirements [4] is necessary due to the increased energy price.

Choosing the dim regime before the installation is important for two reasons:

1. The needed regime can be added to the luminaire driver during the production phase, and the newly bought luminaires do not require any additional steps during installation. In case of a dim regime change, the certified field service engineer can be summoned upon request.
2. The dim regime coefficients are essential for further calculating the average energy consumption throughout the expected lifetime. Since every kWh saved equals the subsidy the city receives, the regimes should be chosen in advance. In addition, the subsidy program rules dictate that the average consumption of newly installed systems for the first four years must be monitored.

6.5 Energy Assessment

Stages of the reconstruction of the public lighting system

The reconstruction of the public lighting system of the case study city is divided into stages. It is applied gradually by individual stages, as the conditions of the NRP subsidy allow, Call No. 1/2022, component 2.2.2 when the applicant can divide the total subsidy into individual stages.

Stage I: Definition of the public lighting system's reconstruction scope

The subject of this energy assessment is the reconstruction of the selected part of the public lighting system in the Case Study City.

Definition of the Stage I benefit calculation

Within the scope of the solution, the following is defined:

Initial Situation: The state of the relevant light points in the scope of Stage I.

Proposed Situation: The state of the selected part of the public lighting system after reconstruction.

Energy Savings: Calculated as a difference between the Proposed situation and the Initial Situation

Determining electrical energy consumption

The electricity consumption is determined from the consumption according to the billing receipts for 24 months for the relevant EANs, which correspond to the switchboards used for the calculations. It is assumed that the electricity can be used for other purposes apart from public lighting, such as the organization of cultural events, battery charging, radar operation, etc. The mathematical calculation of those is too inaccurate. Therefore, the consumption of the selected part of the public lighting system is calculated using the average operating length in the Czech Republic, which is 4100 hours per year. The calculated consumption must be lower than the value determined from the billing receipts.

6.5.1 Initial Situation

The most used light source for outdoor public lighting in the Czech Republic is the HPS discharge lamp. Thanks to its high luminous efficiency, longevity, and affordable price, it has been a standard in most street lighting applications. Common types are from 50 W to 150 W, also used in the Case Study City.

The selected part of the case study city consists of 20 switchboards. Some parts of the city have already been switched to LED. Those are removed from the calculated data, and the rest is as follows:

Number of light points	920 pcs
Number of luminaires	950 pcs
Number of switchboards	20 pcs
Calculated power	**74 485 W**

Table 6-1 Current situation

Light Source	Quantity
Philips Malaga *150 W*	40
Arthechnic Schreder *100 W*	50
Philips Malaga *100 W*	20
Elektrosvit Opál *70 W*	250
Arthechnic Schreder *70 W*	115
Arthechnic Schreder *50 W*	185
Elektrosvit Opál *50 W*	100
Elektrosvit Sadovka *50 W*	190
Total	**950**

Table 6-2 Current situation – Light Sources

Light Poles:

The majority of the light poles are galvanized and are in perfect condition. However, the steel poles' condition is a point to discuss as they are about 40 years old. A significant part of them has to be replaced due to the high rate of corrosion and increased risk of spontaneous collapse.

Light Pole	Quantity
Galvanized	730
Steel	190
Total	**920**

Light Pole Arm	Quantity
1.5 m Single Arm	40
0.5 m Double Arm	10
1 m Double Arm	20
Total	**70**

Table 6-3 Initial Situation – Light Poles

6.5.1.1 Total electricity consumption for a period of 24 months:

Switchboards combined		Consumption				Costs		
Billing period		Electricity				excl. VAT	VAT rate	incl. VAT
Start Date	End Date	Tariff	HT [MWh]	LT [MWh]	Combined [MWh]	CZK	%	CZK
2020		C62	374.92	0	374.92	1 016 349	21	1 229 782
2021		C62	381.35	0	381.35	1 032 669	21	1 249 529
Average		C62	378.14	0	378.14	1 024 509	21	1 239 656

Table 6-4 Current average electricity consumption

Further calculations are done using the average electricity price:

Average electrical energy price					
Billing period	MWh	GJ	CZK	CZK/MWh	CZK/GJ
24 consecutive months	378.14	1 361.31	1 239 656	3 278.30	910.63

Table 6-5 Average electricity price

6.5.1.2 Luminaires power

Luminaire	Flux	CLO	CCT	DIMMING	System Power (min.)	System Power (max.)	Avg. System Power without Dimming	Avg. System Power incl. Dimming	Qty
HPS 150W - M3	17000 lm	NO	2200 K	NO	169.0 W	169.0 W	169.0 W	169.0 W	40
HPS 100W - M4	10200 lm	NO	2200 K	NO	114.0 W	114.0 W	114.0 W	114.0 W	70
HPS 70W - M5	5600 lm	NO	2200 K	NO	83.0 W	83.0 W	83.0 W	83.0 W	75
HPS 70W - M6	5600 lm	NO	2200 K	NO	83.0 W	83.0 W	83.0 W	83.0 W	40
HPS 50W - P4 type A	3400 lm	NO	2200 K	NO	62.0 W	62.0 W	62.0 W	62.0 W	285
HPS 70W - P4 sidewalk	5600 lm	NO	2200 K	NO	83.0 W	83.0 W	83.0 W	83.0 W	250
HPS 50W - P4 type B	3400 lm	NO	2200 K	NO	62.0 W	62.0 W	62.0 W	62.0 W	190
							74485.0 W	74485 W	950

Table 6-6 HPS system power

6.5.1.3 Electricity consumption for the selected part of the lighting system

Data on the installed system power and operating hours is used to calculate the energy consumption:

Combined System Power:	74 485	W
Lighting System Usage:	4100	hrs/year
Electricity consumption:	305.39	MWh/year
Average price of electricity:	3.278	CZK/kWh
Electrical energy costs:	1 001 068	CZK

6.5.2 Proposed Situation

6.5.2.1 LED system power

Luminaire	Flux	CLO	CCT	DIMMING	System Power (min.)	System Power (max.)	Avg. System Power without Dimming	Avg. System Power incl. Dimming	Qty
LED Luminaire type A	12300 lm	CLO	2700 K	M3	85.0 W	89.0 W	87.0 W	63.8 W	40
LED Luminaire type B	8000 lm	CLO	2700 K	M4 & M5	56.5 W	58.5 W	57.5 W	43.2 W	80
LED Luminaire type C	5100 lm	CLO	2700 K	M4 & M5	39.0 W	40.0 W	39.5 W	29.7 W	80
LED Luminaire type D	3100 lm	CLO	2700 K	NO	22.5 W	23.0 W	23.0 W	23.0 W	50
LED Luminaire type E	4600 lm	CLO	2700 K	P	34.5 W	35.5 W	35.0 W	21.9 W	300
LED Luminaire type F	1500 lm	CLO	2700 K	P	12.5 W	12.5 W	12.5 W	7.8 W	250
LED Luminaire type G	3200 lm	CLO	2700 K	P	23.0 W	24.0 W	23.5 W	14.7 W	200
							30715.0 W	20994 W	1000

Luminaire	Flux	CLO	CCT	DIMMING	System Power (min.)	System Power (max.)	Avg. System Power without Dimming	Avg. System Power incl. Dimming	Qty
LED Luminaire type A	12300 lm	CLO	3000 K	M3	78.0 W	80.0 W	79.0 W	57.9 W	40
LED Luminaire type B	8000 lm	CLO	3000 K	M4 & M5	51.0 W	52.0 W	51.5 W	38.7 W	80
LED Luminaire type C	5100 lm	CLO	3000 K	M4 & M5	34.5 W	35.5 W	35.0 W	26.3 W	80
LED Luminaire type D	3100 lm	CLO	3000 K	NO	20.5 W	21.0 W	21.0 W	21.0 W	50
LED Luminaire type E	4600 lm	CLO	3000 K	P	30.5 W	31.5 W	31.0 W	19.4 W	300
LED Luminaire type F	1500 lm	CLO	3000 K	P	11.0 W	11.2 W	11.0 W	6.9 W	250
LED Luminaire type G	3200 lm	CLO	3000 K	P	21.0 W	21.5 W	21.5 W	13.5 W	200
							27480.0 W	18811 W	1000

Luminaire	Flux	CLO	CCT	DIMMING	System Power (min.)	System Power (max.)	Avg. System Power without Dimming	Avg. System Power incl. Dimming	Qty
LED Luminaire type A	12300 lm	CLO	4000 K	M3	73.0 W	75.0 W	74.0 W	54.2 W	40
LED Luminaire type B	8000 lm	CLO	4000 K	M4 & M5	47.5 W	49.0 W	48.5 W	36.4 W	80
LED Luminaire type C	5100 lm	CLO	4000 K	M4 & M5	32.0 W	33.0 W	32.5 W	24.4 W	80
LED Luminaire type D	3100 lm	CLO	4000 K	NO	19.4 W	19.6 W	19.5 W	19.5 W	50
LED Luminaire type E	4600 lm	CLO	4000 K	P	29.0 W	29.5 W	29.5 W	18.5 W	300
LED Luminaire type F	1500 lm	CLO	4000 K	P	10.4 W	10.6 W	10.5 W	6.6 W	250
LED Luminaire type G	3200 lm	CLO	4000 K	P	20.0 W	20.5 W	20.5 W	12.8 W	200
							25990.0 W	17767 W	1000

Luminaire	Flux	CLO	CCT	DIMMING	System Power (min.)	System Power (max.)	Avg. System Power without Dimming	Avg. System Power incl. Dimming	Qty
Crosswalk LED type A	9600 lm	CLO	5700 K	M4 & M5	58.0 W	59.5 W	59.0 W	44.3 W	18
Crosswalk LED type B	7400 lm	CLO	5700 K	M4 & M5	45.5 W	46.5 W	46.0 W	34.6 W	12
							1614.0 W	1213 W	30

Table 6-7 Proposed luminaires' system power

6.5.2.2 Energy consumption

Energy Consumption				
CCT	Without Dimming		With Dimming	
	MWh/year	CZK/year	MWh/year	CZK/year
2700 K	125.93	412 803	86.08	282 155
3000 K	112.67	369 326	77.13	252 816
4000 K	106.56	349 300	72.84	238 785
5700 K - Crosswalk Luminaires	6.62	21 692	4.97	16 298

Table 6-8 Proposed luminaires' energy consumption

The initial situation is compared with the Proposed situation to evaluate the benefits of the reconstruction.

Balance Sheet						
CCT	Power consumption					
	Initial		Proposed		Difference	
	MWh/year	CZK/year	MWh/year	CZK/year	MWh/year	CZK/year
2700 K			86.08	282 155	219.31	718 913
3000 K	305.39	1 001 068	77.13	252 816	228.26	748 252
4000 K			72.84	238 785	232.55	762 283

Table 6-9 Benefits of the reconstruction with Dimming

6.5.2.3 Calculating the amount of subsidy:

CCT	Initial Situation		Proposed Situation		Savings	
	Combined System Power	Energy Consumption	Combined System Power	Energy Consumption	Energy Consumption	
	W	MWh/year	W	MWh/year	MWh/year	%
2700 K & Crosswalks	74 485	305.39	22 207	91.05	214.34	70.19

Table 6-10 Total energy savings for subsidy

Subsidy		
Energy Savings	214 340	kWh/year
Subsidy	30 CZK	per kWh of savings
Total subsidy	6 430 194	CZK

Table 6-11 Subsidy in total

Achieved savings after reconstructing the selected part of the public lighting system:

Electricity Consumption:	214.34	MWh/year
Electricity Consumption:	70.19	%
Electricity costs:	702 606	CZK/year
Subsidized amount:	6 430 194	CZK

6.5.2.4 Additional informative calculations

CCT	Initial Situation		Proposed Situation		Savings	
	Combined System Power	Energy Consumption	Combined System Power	Energy Consumption	Energy Consumption	
	W	MWh/year	W	MWh/year	MWh/year	%
3000 K	74 485	305.39	20 024	82.10	223.29	73.12
4000 K			18 980	77.82	227.57	74.52

Table 6-12 Savings for other CCT options, incl. Crosswalks

The proposed LED luminaires are equipped with shields to limit obtrusive lighting. To achieve sufficient levels of light additional lumen output have to be added to each luminaire with the shield. The following table compares energy consumptions for a 2700 K solution:

CCT	With Light Shield		No Light Shield		Savings		
	Combined System Power	Energy Consumption	Combined System Power	Energy Consumption	Energy Consumption		Costs
	W	MWh/year	W	MWh/year	MWh/year	%	CZK
2700 K	20 994	86.08	18 804	77.10	8.98	10.43	29 433

Table 6-13 Costs of obtrusive light limitation

Decrease in amount subsidized: 269 370 CZK

6.6 Economic evaluation

The economic evaluation is carried out without consideration of loans, i.e., with own investment funds and funds received as a subsidy. The economic analysis aims to determine the suitability of individual measures from an economic perspective. The economic analysis considers several economic indicators, the most important of which is the net present value, discounted cash flow throughout the project's life.

6.6.1 Input data

Discount rate:

For energy assessments, according to Order No. 141/2021 [21], the discount rate is set to the value of 3 %. This value substantially increases the Discounted Payback Period, which can be compensated by potential energy price growth.

Evaluation period:

The comparison period is usually determined based on the lifetime of the equipment. The lowest lifetime variant is considered.

Price development:

During the lifetime of the equipment, inflation and, thus, prices can change significantly. Usually, especially changes in energy prices significantly affect the financial results of energy projects.

Cost of Investment:

	Allowable costs excl. VAT	Allowable costs incl. VAT
	CZK	
Total	11 939 975.21	14 447 370

Table 6-14 Required financing

6.6.2 Output data

Payback Period:

PP is a secondary indicator when making investment decisions. It does not take into account the real-time value of money (valuation of cash flows through discount rate). Therefore it provides limited information and serves mainly as an orientation. The criterion determines how long the project's income will take to cover the investment costs.

$$\frac{IN}{CF} = PP$$

IN – Cost of Investment

CF – Cash Flow difference after the project realization

Discounted Payback Period:

If considering the present value of cash flows, the time it takes a project to break even is called discounted payback. This indicator gives a good perspective when evaluating the feasibility and profitability of a project.

$$\sum_{t=1}^{T_{DPP}} CF_t * (1+r)^{-t} - IN = 0$$

T_{DPP} – Discounted Payback Period

r – Discount rate

t – Evaluation period

Net Present Value:

NPV is the difference between the present value of cash inflows and outflows over a period of time. The basis for determining the net present value is a determination of cash flows. Cash Flow is the difference between income and expenditure associated with the project in individual years. For the evaluation of cash flows, future streams of payments are adjusted to the current value using a discount rate. The value of the discounted cumulative cash flow in the last year of the evaluation period is NPV and serves as an essential criterion for assessing projects. In general, projects with a positive NPV are economically attractive.

$$\sum_{t=1}^{T_{evaluation}} CF_t * (1+r)^{-t} - IN$$

Internal Rate of Return

IRR of an investment is a discount rate that causes the NPV of a project to be 0.

$$\sum_{t=1}^{T_{evaluation}} CF_t * (1+IRR)^{-t} - IN = 0$$

IRR – Internal Rate of Return

Cash Flow:

Cash flow in a given year for calculations of proposed measures in the energy assessment is determined as follows:

Cash Flow = Savings – Cost of Investment

6.6.3 Results

Measure	Energy savings per year			Investment	Payback Period
	GJ	MWh	CZK	CZK	yrs
Reconstruction of public lighting	771.62	214.34	702 606	14 447 370	20.56

Table 6-15 Cost of investment and energy savings

Two types of calculations were done:

The first one focuses on comparing the benefits of different CCT luminaires. The proposed luminaires use the benefits of modern LED technology: CLO function and driver with a preset dimming regime. The following calculations are done with luminaires equipped with light shields:

Parameter	Unit	Initial Situation	2700K	3000 K	4000 K
			Proposed Situation		
Cost of Investment:	CZK	-	14 447 340		
of which project preparation costs	CZK	-	100 000		
of which cable connector costs	CZK	-	-		
of which materials and construction costs	CZK	-	14 347 340		
Operating costs:	CZK	1 392 816	298 462	269 114	255 083
of which energy costs	CZK	1 001 068	298 462	269 114	255 083
of which personal expenses	CZK	-	-	-	-
of which other operating costs	CZK	391 748	-	-	-
Total project benefits:	CZK		1 094 354	1 123 702	1 137 733
of which energy benefits	CZK	-	702 606	731 954	745 985
of which other benefits	CZK	-	391 748		
Economic evaluation:					
Evaluation period	yrs	-	20		
Discount rate	%	-	3		
Energy price growth rate	%	-	0		
Discounted Payback Period	yrs	-	17.06	16.49	16.22
NPV	CZK	-	1 833 884.12	2 270 508.26	2 479 254.11
IRR	%	-	4.33	4.64	4.78

Table 6-16 Economic evaluation excl. subsidy

The second calculations are done including the subsidy:

Criteria	Value Reached	Explanation
Primary energy savings of at least 30%	70.19 %	The initial situation is compared with the proposed (newly added lighting points included)
Maximum Correlated Color Temperature equals 2700 K	2700 K	CCT according to datasheets
The road calculations should be done according to CEN/TR 13201-1		Documented by reference sections calculations
Obtrusive lighting calculation should be done according to EN 12464-2		
Subsidy amount	6 430 194 CZK	30 CZK received per every kWh of savings

Table 6-17 Subsidy criteria overview

The following calculations were done by decreasing the required investment from the customer by the amount of subsidy:

Parameter	Unit	Initial Situation	Proposed Situation
Cost of Investment:	CZK	-	8 017 146
of which project preparation costs	CZK	-	100 000
of which cable connector costs	CZK	-	-
of which material and construction costs	CZK	-	7 917 146
Operating costs:	CZK	1 392 816	298 462
of which energy costs	CZK	1 001 068	298 462
of which personal expenses	CZK	-	-
of which other operating costs	CZK	391 748	-
Total project benefits:	CZK		1 094 354
of which energy benefits	CZK	-	702 606
of which other benefits	CZK	-	391 748
Economic evaluation:			
Evaluation period	yrs	-	20
Discount rate	%	-	3
Energy price growth rate	%	-	0
Payback Period	yrs	-	7.326
Discounted Payback Period	yrs	-	8.396
NPV	CZK	-	8 264 078.12
IRR	%	-	12.31

Table 6-18 Economic evaluation incl. subsidy

6.7 Ecological evaluation

Ecological evaluation is done according to Order No. 141/2021. [21]

Fuel type	Initial Situation	Proposed Situation	Emission factor	Energy Savings
	MWh/year	MWh/year	t/MWh	MWh/year
Electricity	305.39	91.05	0.86	214.34

Fuel type	Initial Situation	Proposed Situation	Savings	
	t/year	t/year	t/year	%
Electricity	262.64	78.30	184.33	70.19

Table 6-19 CO_2 emissions evaluation

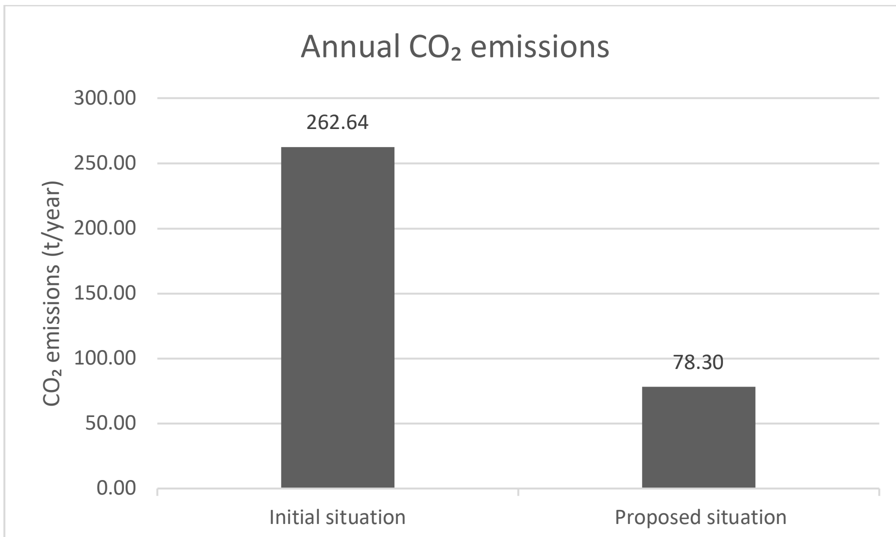

Figure 6-1 Annual CO_2 emissions

6.8 Results overview

Billing data:		
Average energy consumption for a period of 24 months	378.14	MWh/year
Average energy costs for a period of 24 months	1 239 656	CZK
Average electricity price	3.28	CZK/kWh
Initial Situation:		
Total system power	74 485	W
Average energy consumption	305.39	MWh/year
Average energy costs	1 001 068	CZK
Proposed Situation:		
2700 K - Average system power incl. Dimming	20 994	W
Average energy consumption	86.08	MWh/year
3000 K - Average system power incl. Dimming	18 811	W
Average energy consumption	77.13	MWh/year
4000 K - Average system power incl. Dimming	17 767	W
Average energy consumption	72.84	MWh/year
5700 K - Average system power incl. Dimming	1 213	W
Average energy consumption	4.97	MWh/year
Subsidy:		
Energy savings	214.34	MWh/year
	70.19	%
Electricity costs savings	702 606	CZK/year
Subsidy amount	6 430 194	CZK
Economic evaluation: NPV		
2700 K (excl. subsidy)	1 833 884.12	CZK
3000 K	2 270 508.26	CZK
4000 K	2 479 254.11	CZK
2700 K (incl. subsidy)	8 264 078.12	CZK
Ecological evaluation:		
CO_2 savings	184.33	t/year
	70.19	%

CONCLUSION

Outdoor lighting technology has significantly improved in recent years. Transitioning to new technologies always comes with many challenges. The problem should be studied from multiple angles, requiring cooperation between different engineering divisions. Technical requirements are becoming stricter with each generation of technology. Not only are cost and energy efficiency being focused on, but environmental concerns have also been raised. This document focuses on outdoor lighting renovation in smaller cities in Czechia. The condition of these cities is often far from perfect and requires a deep understanding of the topic from the lighting engineer.

Due to the fact that mass production of LED luminaires is relatively new, many misconceptions occur.

This thesis may serve as a guide for potential investors to understand better when considering a switch to a new technology. Many untrustworthy producers tend to lower the prices at the cost of quality and longevity. This creates a certain degree of doubt among the city authorities, thus slowing down the shift.

The Case Study City is calculated according to the technical requirements of the NPO subsidy[19]. The proposed LED system is a big step forward from the current situation. The new system is designed according to modern technical standards and has lower power consumption while achieving a better luminance level.

The disturbing light on the facades was limited by detailed calculation and precise selection of optics best suited for the situation. Modeling the actual situation in lighting design software and placing vertical planes at the height of windows allows for detecting high light pollution values. It ensures that no complaints from the residents would have to be dealt with in the future. The initial thought was that limiting the spill light decreases the system power. However, as shown in Table 6-13 Costs of obtrusive light limitation, this is not always the case and needs context. One of the measures to increase overall efficiency is choosing the right optic for illuminated space, e.g., using narrow optics to illuminate a common sidewalk. However, it is often not enough to prevent disturbing light on the facades. Adding a shield significantly decreases the initial system efficacy [lm/W]. Therefore additional luminous flux has to be added to reach the same values. This leads to the conclusion that limiting spill light does not always save energy.

Crosswalk illumination is another example of a technical standard requirement whose primary goal is safety rather than energy saving. As shown in Table 6-8 Proposed luminaires' energy consumption, illumination of crosswalks results in an additional 4.97 MWh/year in this particular case.

Achieved energy consumption savings as a result of the proposed LED system amounts to 70.19 %. It shows the efficiency of LED lighting with the use of lighting control. The importance of lighting controls is visible in Table 6-7 Proposed luminaires' system power, and Table 6-8 Proposed luminaires' energy consumption. However, this is the outcome of many factors that do not always occur. Firstly, the ratio of the M-class roads to P-class roads is roughly 1 to 4. Bigger savings are often achieved on P-class roads as they represent less-loaded city areas. Secondly, the sidewalks in the Case Study City are illuminated by HPS 70 W lamps. This simply indicates a mistake made previously.

All of the proposed options show positive economic indicators. The most financially attractive option without considering subsidy is a neutral white color. However, using 4000 K in a whole city raises many environmental questions as it heavily emits blue light component. Applying for a subsidy significantly decreases the initial investment. The financial calculations with the subsidy show the most positive indicators.

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[1] HABEL, Jiří. Osvětlování. Vyd. 2. Praha: Vydavatelství ČVUT, 1998. ISBN 80-01-01770-2

[2] HABEL, Jiří. Světlo a osvětlování. Praha: FCC Public, 2013. ISBN 978-80-86534-21-3

[3] JIRAVA, Petr— SLABY, Petr. Dopravní inženýrství. Praha: ČVUT, 1990, 165 s., ISBN 80-01-00213-6

[4]	CEN/TR 13201-1	Road lighting - Part 1: Guidelines on selection of lighting classes
[5]	EN 12464-2	Light and lighting - Lighting of work places - Part 2: Outdoor work places
[6]	EN 13201-2	Road lighting - Part 2: Performance requirements
[7]	EN 13201-3	Road lighting - Part 3: Calculation of performance
[8]	EN 13201-4	Road lighting - Part 4: Methods of measuring lighting perfomance.
[9]	EN 13201-5	Road lighting - Part 5: Energy performance indicators
[10]	ČSN P 36 0455	Road lighting – Additional information
[11]	TKP 15	Road Lighting
[12]	EN 12665	Light and Lighting – Basic terms and criteria for specifying lighting
[13]	CIE S 017/E	ILV: International Lighting Vocabulary
[14]	CIE 115	Lighting of roads for motor and pedestrian traffic
[15]	CIE 140	Road lighting calculations
[16]	CIE 154	Maintenance of outdoor lighting systems
[17]	CIE 196	CIE Guide to increasing accessibility in light and lighting
[18]	CIE 126	Guidelines for minimizing sky glow
[19]	NRP	Official website of NRP subsidy (https://www.planobnovycr.cz/)
[20]	ČSN 36 0459	Reducing the Undesirable Side Effects of Outdoor Lighting
[21]	Order No. 141/2021	Energy Assessment and the data kept in the energy consumption monitoring system
[22]	UNEP	Official report by UNEP (https://www.unep.org/)
[23]	ČSN 36 0459	Reducing the undesirable side effects of outdoor lighting

SUPPLEMENTARY A: LIST OF ABBREVIATIONS AND SYMBOLS

A.1 List of symbols

$\bar{L}$	$(\mathrm{cd} \cdot \mathrm{m}^{-2})$	average road surface luminance (of a carriageway of a road)
U_I		longitudinal uniformity (of road surface luminance of a carriageway)
f_{TI}		threshold increment of TI (of an object at the road surface)
$\bar{E}$	(lx)	average illuminance (on a road area)
E_{min}	(lx)	minimum illuminance (on a road area)
E_{max}	(lx)	maximum illuminance (on a road area)
E_v	(lx)	vertical illuminance
U_0		overall uniformity (of road surface luminance, illuminance on a road area or hemispherical illuminance)
R_{EI}		edge illuminance ratio EIR (of illumination of a strip adjacent to the carriageway of a road)
R_{UL}	(%)	proportion of the flux of the luminaire(s) that is emitted above the horizontal, when the luminaire(s) is (are) mounted in its' (their) installed position and attitude
R_a		Color rendering index. The maximum value of R_a is 100

A.2 List of abbreviations

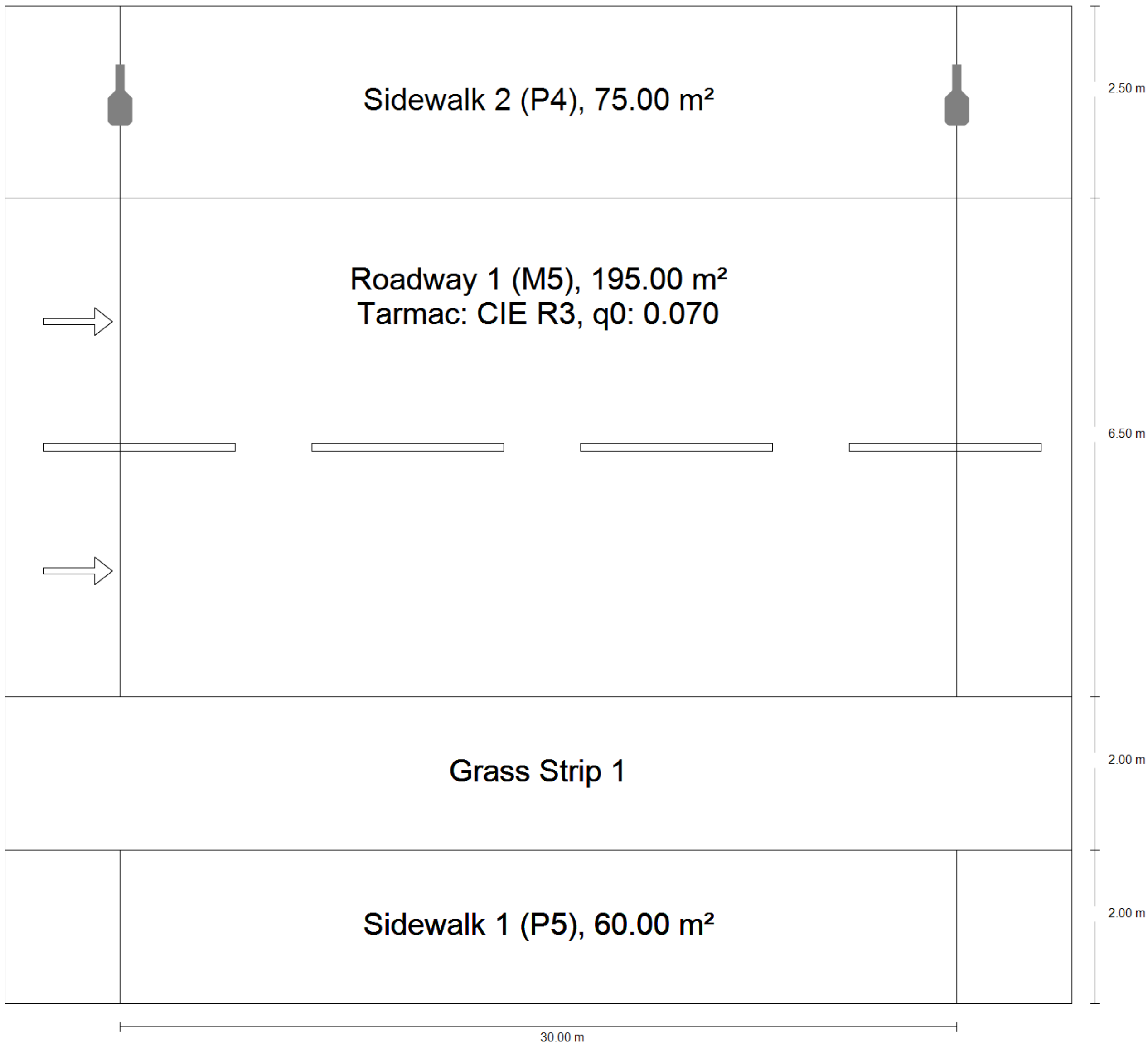
TI	measure of the effect of disability glare, described as an equivalent veiling luminance caused by scattering of light in the human eye
CCT	Correlated Color Temperature refers to the apparent color (chromacity) of the light emitted
CRI	Color Rendering Index
HID	High Intensity Discharge
LED	Light-emitting Diode
HPS	High-pressure Sodium
NRP	National Renovation Plan
NPO	National Renovation Plan (in Czech)
IP Rating	Ingress Protection Rating
GSM	Global System for Mobile Communications
GPS	Global Positioning System
DALI	Digital Addressable Lighting Interface
BOM	Bill of Materials

Appendix A - Case Study City - HPS

Content

Collector - Class M5

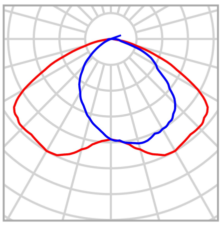
Summary (according to EN 13201:2015)



Collector - Class M5

Summary (according to EN 13201:2015)

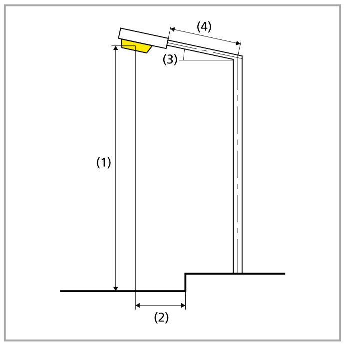
PHILIPS



Manufacturer	
Article name	SGS101 MR SON-I CONV
Fitting	1x SON-I-70W-CO

P	80.0 W
Φ_{Lamp}	5600 lm
$\Phi_{Luminaire}$	3696 lm
η	66.00 %

SGS101 MR SON-I CONV (single side top)



Pole distance	30.000 m
(1) Light spot height	6.000 m
(2) Light point overhang	-1.200 m
(3) Boom inclination	10.0°
(4) Boom length	0.500 m
Annual operating hours	4000 h: 100.0 %, 80.0 W
Consumption	2640.0 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 202 cd/klm ≥ 80°: 92.4 cd/klm ≥ 90°: 27.3 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	G*2
Glare index class	D.6

Collector - Class M5

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P4)	E_{av}	9.79 lx	[5.00 - 7.50] lx	✗
	E_{min}	1.31 lx	≥ 1.00 lx	✓
Roadway 1 (M5)	L_{av}	0.35 cd/m²	≥ 0.50 cd/m²	✗
	U_o	0.26	≥ 0.35	✗
	U_l	0.30	≥ 0.40	✗
	TI	10 %	≤ 15 %	✓
	R_{EI}	0.45	≥ 0.30	✓
Sidewalk 1 (P5)	E_{av}	1.53 lx	[3.00 - 4.50] lx	✗
	E_{min}	0.77 lx	≥ 0.60 lx	✓

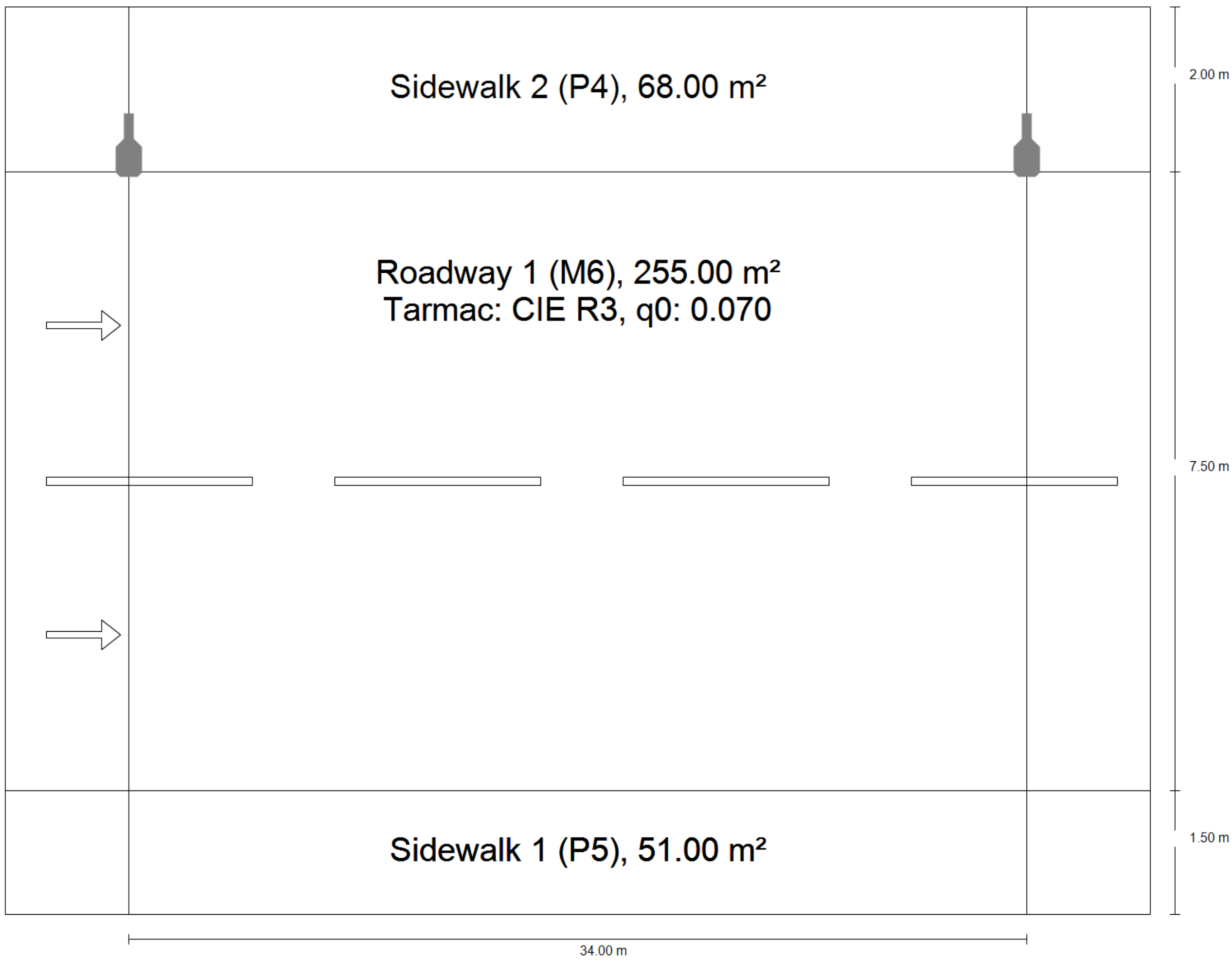
A maintenance factor of 0.87 was used for calculating for the installation.

Results for energy efficiency indicators

	Symbol	Calculated	Consumption
Collector - Class M5	D_p	0.036 W/lx*m²	-
SGS101 MR SON-I CONV (single side top)	D_e	1.0 kWh/m² yr,	320.0 kWh/yr

Collector - Class M6

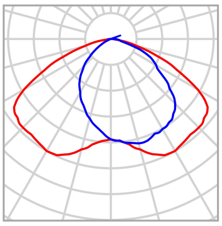
Summary (according to EN 13201:2015)



Collector - Class M6

Summary (according to EN 13201:2015)

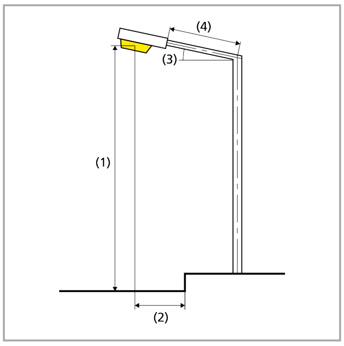
PHILIPS



Manufacturer	
Article name	SGS101 MR SON-I CONV
Fitting	1x SON-I-70W-CO

P	80.0 W
Φ_{Lamp}	5600 lm
$\Phi_{Luminaire}$	3696 lm
η	66.00 %

SGS101 MR SON-I CONV (single side top)



Pole distance	34.000 m
(1) Light spot height	5.500 m
(2) Light point overhang	-0.200 m
(3) Boom inclination	0.0°
(4) Boom length	0.500 m
Annual operating hours	4000 h: 100.0 %, 80.0 W
Consumption	2320.0 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 158 cd/klm ≥ 80°: 45.5 cd/klm ≥ 90°: 6.06 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	G*5
Glare index class	D.6

Collector - Class M6

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P4)	E_{av}(1)	9.59 lx	-	-
	E_{min}(1)	0.69 lx	-	-
Roadway 1 (M6)	L_{av}	0.33 cd/m²	≥ 0.30 cd/m²	✓
	U_o	0.11	≥ 0.35	✗
	U_l	0.15	≥ 0.40	✗
	TI	12 %	≤ 20 %	✓
	R_{EI}(1)	0.30	-	-
Sidewalk 1 (P5)	E_{av}(1)	1.40 lx	-	-
	E_{min}(1)	0.34 lx	-	-

(1) Informative, not part of the valuation

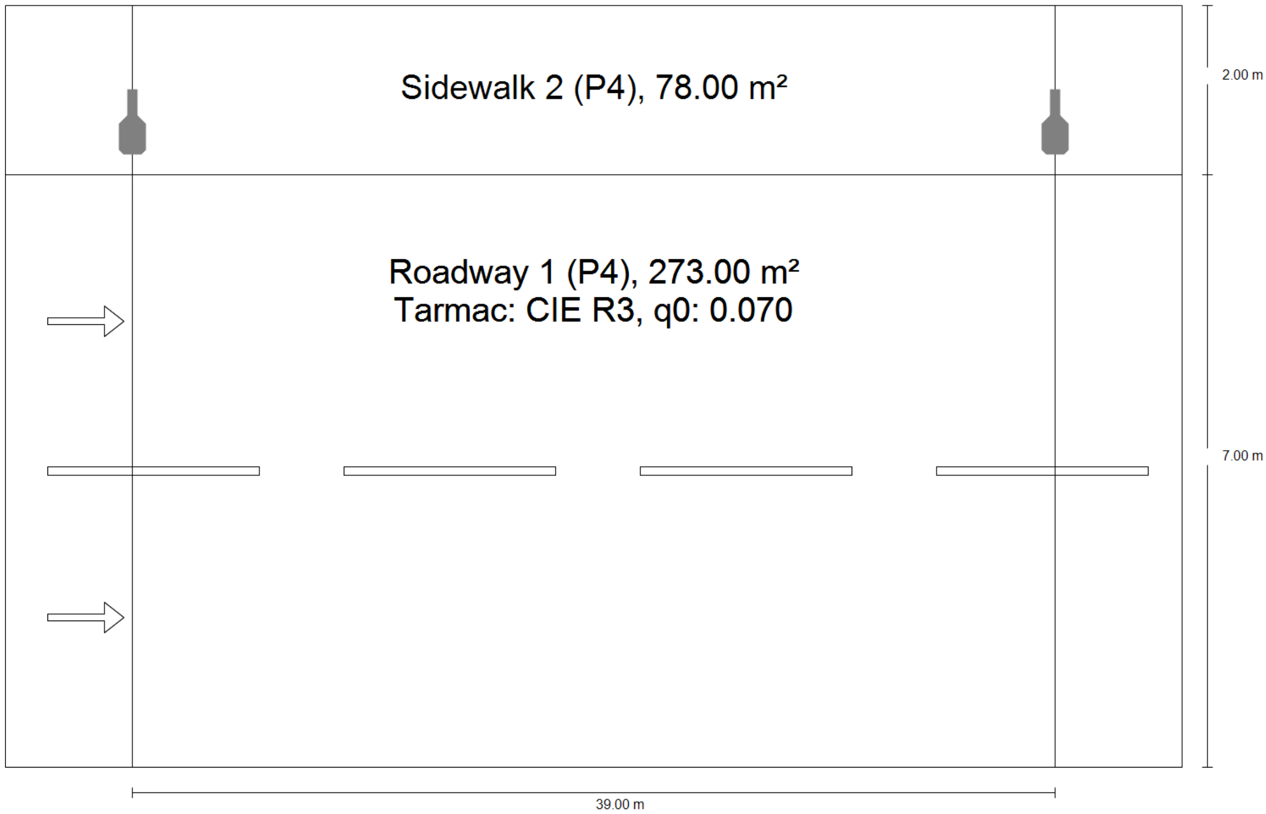
A maintenance factor of 0.87 was used for calculating for the installation.

Results for energy efficiency indicators

	Symbol	Calculated	Consumption
Collector - Class M6	D_p	0.034 W/lx*m²	-
SGS101 MR SON-I CONV (single side top)	D_e	0.9 kWh/m² yr,	320.0 kWh/yr

Local - Class P4 - type A

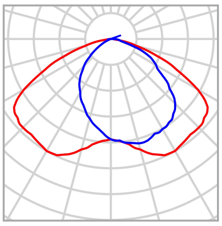
Summary (according to EN 13201:2015)



Local - Class P4 - type A

Summary (according to EN 13201:2015)

PHILIPS

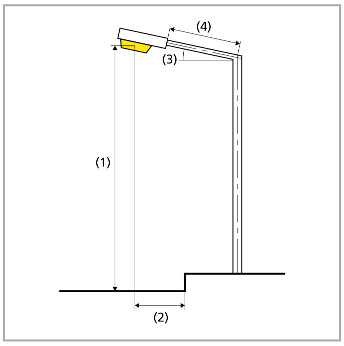


Manufacturer	
Article name	SGS101 MR SON-I CONV
Fitting	1x SON-I-50W-CO

P	61.0 W
Φ_{Lamp}	3400 lm
$\Phi_{Luminaire}$	2244 lm
η	66.00 %

SGS101 MR SON-I CONV (single side top)

Pole distance	39.000 m
(1) Light spot height	5.000 m
(2) Light point overhang	-0.500 m
(3) Boom inclination	0.0°
(4) Boom length	0.500 m
Annual operating hours	4000 h: 100.0 %, 61.0 W
Consumption	1586.0 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 158 cd/klm ≥ 80°: 45.5 cd/klm ≥ 90°: 6.06 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	G*5
Glare index class	D.6



Local - Class P4 - type A

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P4)	E_{av}	5.92 lx	[5.00 - 7.50] lx	✓
	E_{min}	0.17 lx	≥ 1.00 lx	✗
Roadway 1 (P4)	E_{av}	3.45 lx	[5.00 - 7.50] lx	✗
	E_{min}	0.14 lx	≥ 1.00 lx	✗

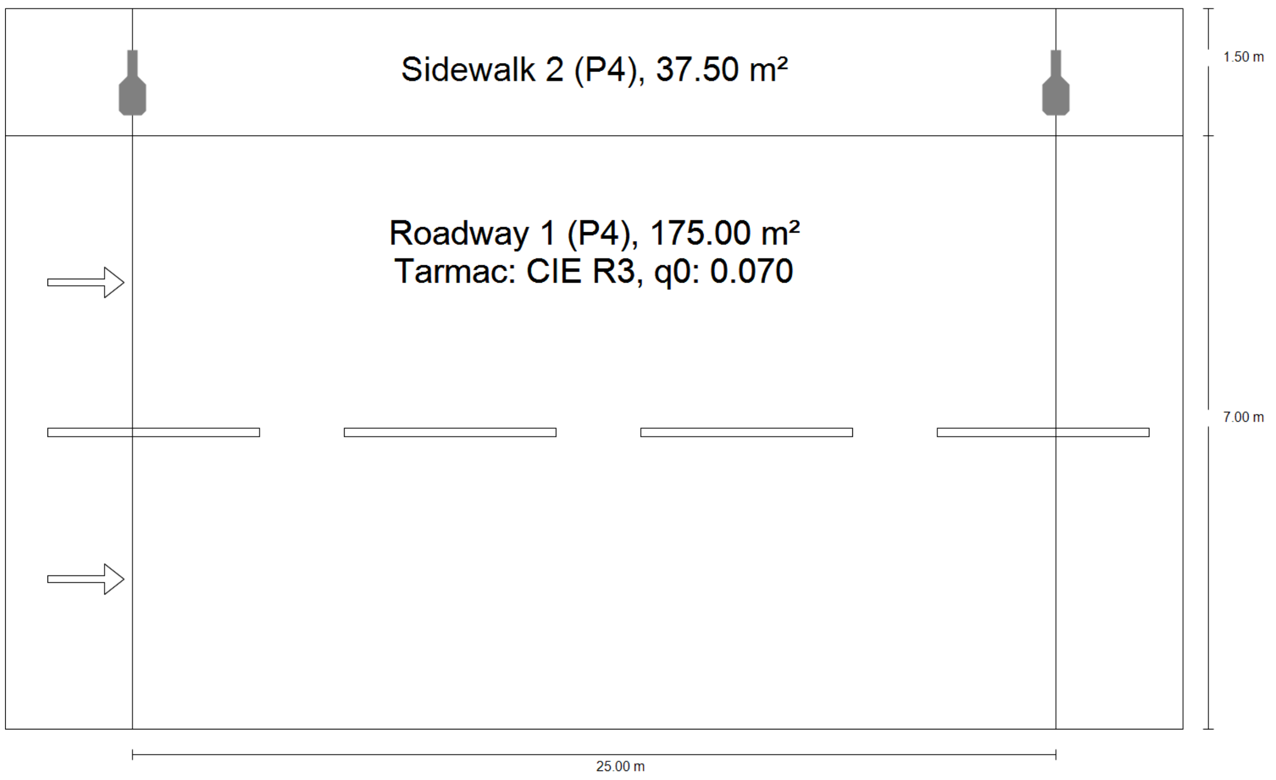
A maintenance factor of 0.87 was used for calculating for the installation.

Results for energy efficiency indicators

	Symbol	Calculated	Consumption
Local - Class P4 - type A	D_p	0.043 W/lx*m²	-
SGS101 MR SON-I CONV (single side top)	D_e	0.7 kWh/m² yr,	244.0 kWh/yr

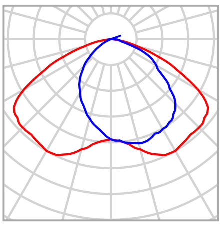
Local - Class P4 - type B

Summary (according to EN 13201:2015)



Local - Class P4 - type B

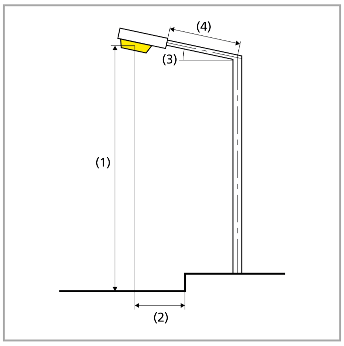
Summary (according to EN 13201:2015)



Manufacturer	
Article name	SGS101 MR SON-I CONV
Fitting	1x SON-I-50W-CO

P	61.0 W
Φ_{Lamp}	3400 lm
$\Phi_{Luminaire}$	2244 lm
η	66.00 %

SGS101 MR SON-I CONV (single side top)



Pole distance	25.000 m
(1) Light spot height	4.000 m
(2) Light point overhang	-0.500 m
(3) Boom inclination	0.0°
(4) Boom length	0.500 m
Annual operating hours	4000 h: 100.0 %, 61.0 W
Consumption	2440.0 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 158 cd/klm ≥ 80°: 45.5 cd/klm ≥ 90°: 6.06 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	G*5
Glare index class	D.6

Local - Class P4 - type B

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P4)	E_{av}	11.98 lx	[5.00 - 7.50] lx	✗
	E_{min}	0.82 lx	≥ 1.00 lx	✗
Roadway 1 (P4)	E_{av}	5.48 lx	[5.00 - 7.50] lx	✓
	E_{min}	0.35 lx	≥ 1.00 lx	✗

A maintenance factor of 0.87 was used for calculating for the installation.

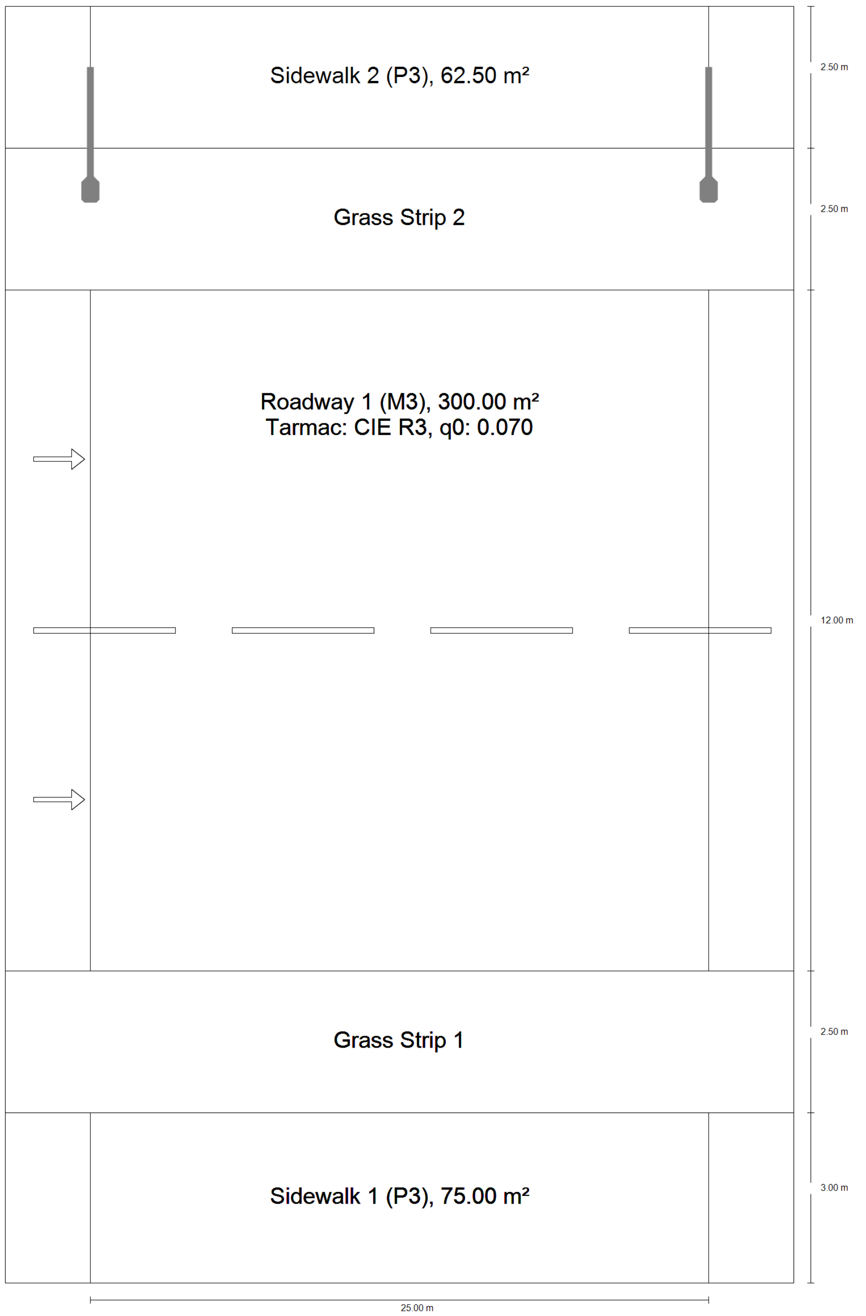
Results for energy efficiency indicators

	Symbol	Calculated	Consumption
Local - Class P4 - type B	D_p	0.043 W/lx*m²	-
SGS101 MR SON-I CONV (single side top)	D_e	1.1 kWh/m² yr,	244.0 kWh/yr

DIALux

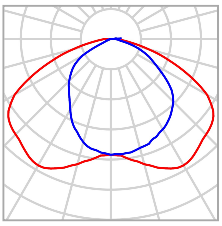
Major - Class M3

Summary (according to EN 13201:2015)



Major - Class M3

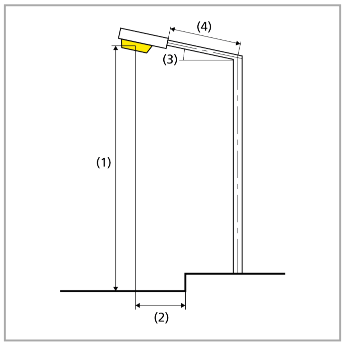
Summary (according to EN 13201:2015)



Manufacturer	
Article name	SGS102 MR SON-PP CONV
Fitting	1x SON-PP150W

P	169.0 W
Φ_{Lamp}	17000 lm
$\Phi_{Luminaire}$	11426 lm
η	67.21 %

SGS102 MR SON-PP CONV (single side top)



Pole distance	25.000 m
(1) Light spot height	10.000 m
(2) Light point overhang	-1.800 m
(3) Boom inclination	10.0°
(4) Boom length	2.100 m
Annual operating hours	4000 h: 100.0 %, 169.0 W
Consumption	6760.0 W/km
ULR / ULOR	0.01 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 182 cd/klm ≥ 80°: 78.9 cd/klm ≥ 90°: 27.6 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	G*2
Glare index class	D.4

Major - Class M3

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P3)	E_{av}	19.38 lx	[7.50 - 11.25] lx	✗
	E_{min}	12.17 lx	≥ 1.50 lx	✓
Roadway 1 (M3)	L_{av}	0.68 cd/m²	≥ 1.00 cd/m²	✗
	U_o	0.34	≥ 0.40	✗
	U_l	0.89	≥ 0.60	✓
	TI	11 %	≤ 15 %	✓
	R_{EI}	0.43	≥ 0.30	✓
Sidewalk 1 (P3)	E_{av}	3.09 lx	[7.50 - 11.25] lx	✗
	E_{min}	2.58 lx	≥ 1.50 lx	✓

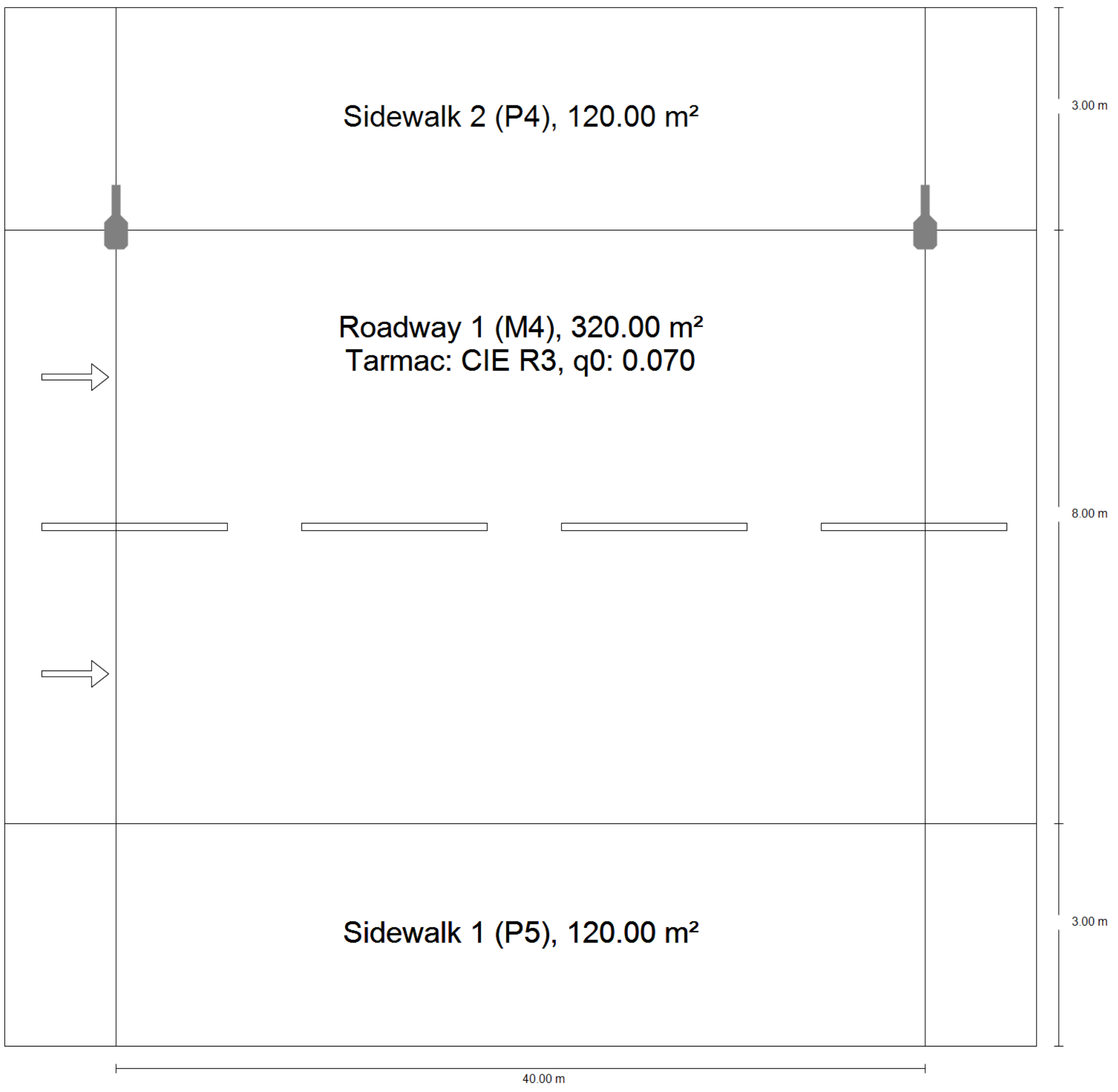
A maintenance factor of 0.87 was used for calculating for the installation.

Results for energy efficiency indicators

	Symbol	Calculated	Consumption
Major - Class M3	D_p	0.031 W/lx*m²	-
SGS102 MR SON-PP CONV (single side top)	D_e	1.5 kWh/m² yr,	676.0 kWh/yr

Major - Class M4

Summary (according to EN 13201:2015)

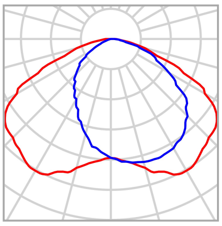


DIALux

Major - Class M4

Summary (according to EN 13201:2015)

PHILIPS

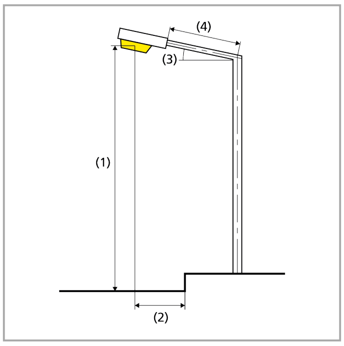


Manufacturer	
Article name	SGS102 MR SON-PP CONV
Fitting	1x SON-PP100W

P	114.0 W
Φ_{Lamp}	10200 lm
$\Phi_{Luminaire}$	7056 lm
η	69.18 %

SGS102 MR SON-PP CONV (single side top)

Pole distance	40.000 m
(1) Light spot height	8.000 m
(2) Light point overhang	0.000 m
(3) Boom inclination	0.0°
(4) Boom length	0.600 m
Annual operating hours	4000 h: 100.0 %, 114.0 W
Consumption	2850.0 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 175 cd/klm ≥ 80°: 53.5 cd/klm ≥ 90°: 17.3 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	G*3
Glare index class	D.5



Major - Class M4

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P4)	E_{av}	9.71 lx	[5.00 - 7.50] lx	✗
	E_{min}	1.38 lx	≥ 1.00 lx	✓
Roadway 1 (M4)	L_{av}	0.47 cd/m²	≥ 0.75 cd/m²	✗
	U_o	0.23	≥ 0.40	✗
	U_l	0.28	≥ 0.60	✗
	TI	10 %	≤ 15 %	✓
	R_{EI}(1)	0.44	-	-
Sidewalk 1 (P5)	E_{av}(1)	3.26 lx	-	-
	E_{min}(1)	1.05 lx	-	-

(1) Informative, not part of the valuation

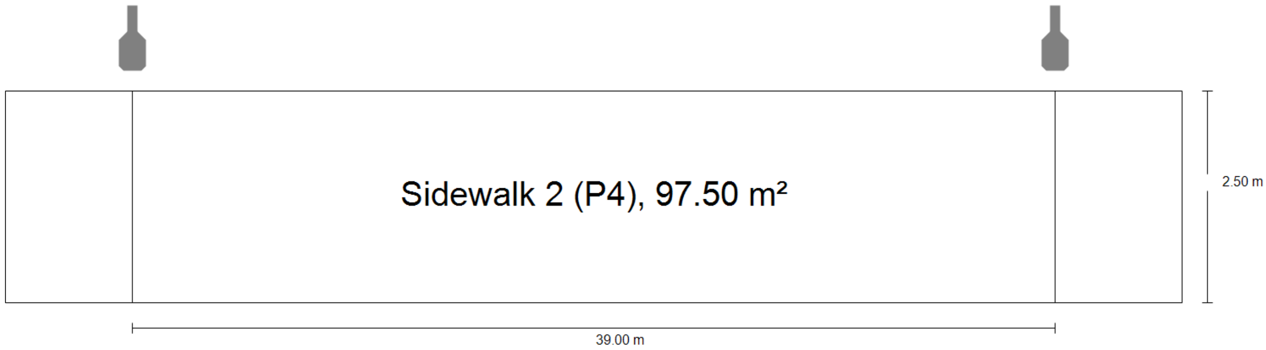
A maintenance factor of 0.87 was used for calculating for the installation.

Results for energy efficiency indicators

	Symbol	Calculated	Consumption
Major - Class M4	D_p	0.026 W/lx*m²	-
SGS102 MR SON-PP CONV (single side top)	D_e	0.8 kWh/m² yr,	456.0 kWh/yr

Sidewalk - Class P4

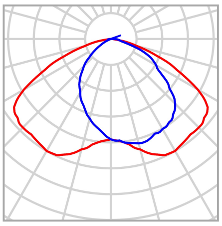
Summary (according to EN 13201:2015)



Sidewalk - Class P4

Summary (according to EN 13201:2015)

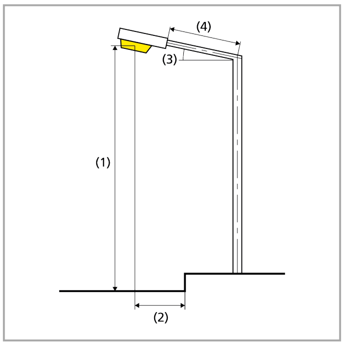
PHILIPS



Manufacturer	
Article name	SGS101 MR SON-I CONV
Fitting	1x SON-I-70W-CO

P	80.0 W
Φ_{Lamp}	5600 lm
$\Phi_{Luminaire}$	3696 lm
η	66.00 %

SGS101 MR SON-I CONV (single side top)



Pole distance	39.000 m
(1) Light spot height	5.500 m
(2) Light point overhang	-0.500 m
(3) Boom inclination	0.0°
(4) Boom length	0.500 m
Annual operating hours	4000 h: 100.0 %, 80.0 W
Consumption	2080.0 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 158 cd/klm ≥ 80°: 45.5 cd/klm ≥ 90°: 6.06 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	G*5
Glare index class	D.6

Sidewalk - Class P4

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P4)	E_{av}	8.85 lx	[5.00 - 7.50] lx	✗
	E_{min}	0.40 lx	≥ 1.00 lx	✗

A maintenance factor of 0.87 was used for calculating for the installation.

Results for energy efficiency indicators

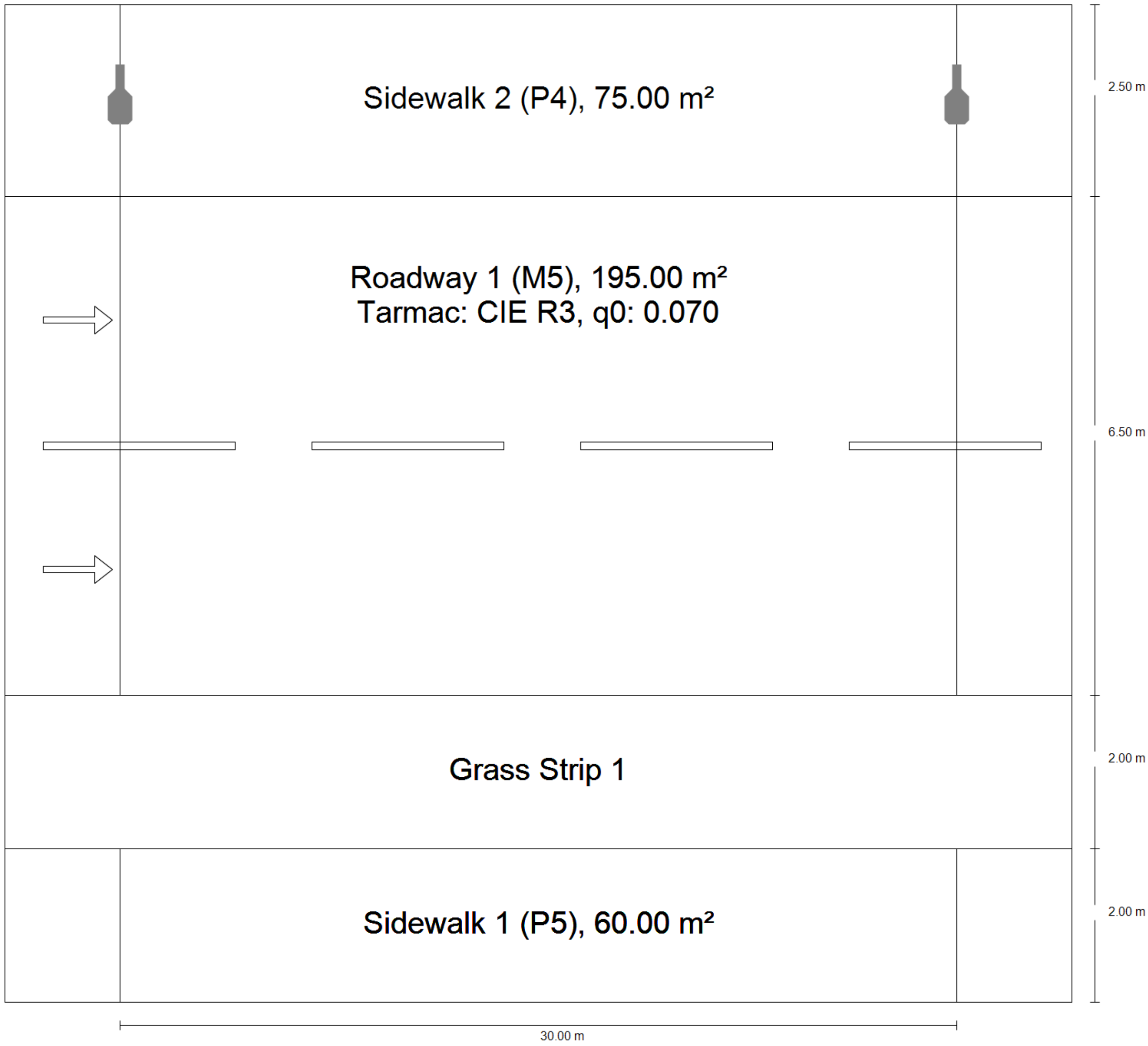
	Symbol	Calculated	Consumption
Sidewalk - Class P4	D_p	0.093 W/lx*m²	-
SGS101 MR SON-I CONV (single side top)	D_e	3.3 kWh/m² yr,	320.0 kWh/yr

Appendix B - Case Study City - LED

Content

Collector - Class M5

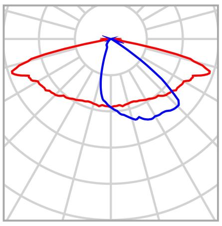
Summary (according to EN 13201:2015)



DIALux

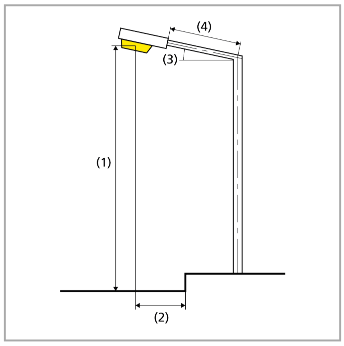
Collector - Class M5

Summary (according to EN 13201:2015)



Manufacturer		P	39.5 W
Article No.		Φ_{Lamp}	5100 lm
Article name	LED Luminaire type C /727	$\Phi_{Luminaire}$	3486 lm
Fitting	user-defined	η	68.36 %

LED Luminaire type C /727 (single side top)



Pole distance	30.000 m
(1) Light spot height	6.000 m
(2) Light point overhang	-1.200 m
(3) Boom inclination	10.0°
(4) Boom length	0.500 m
Annual operating hours	4000 h: 100.0 %, 39.5 W
Consumption	1303.5 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 751 cd/klm ≥ 80°: 443 cd/klm ≥ 90°: 6.00 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	-
Glare index class	D.6

Collector - Class M5

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P4)	E_{av}	7.32 lx	[5.00 - 7.50] lx	✓
	E_{min}	2.31 lx	≥ 1.00 lx	✓
Roadway 1 (M5)	L_{av}	0.50 cd/m²	≥ 0.50 cd/m²	✓
	U_o	0.51	≥ 0.35	✓
	U_l	0.69	≥ 0.40	✓
	TI	15 %	≤ 15 %	✓
	R_{EI}	0.63	≥ 0.30	✓
Sidewalk 1 (P5)	E_{av}	3.47 lx	[3.00 - 4.50] lx	✓
	E_{min}	2.73 lx	≥ 0.60 lx	✓

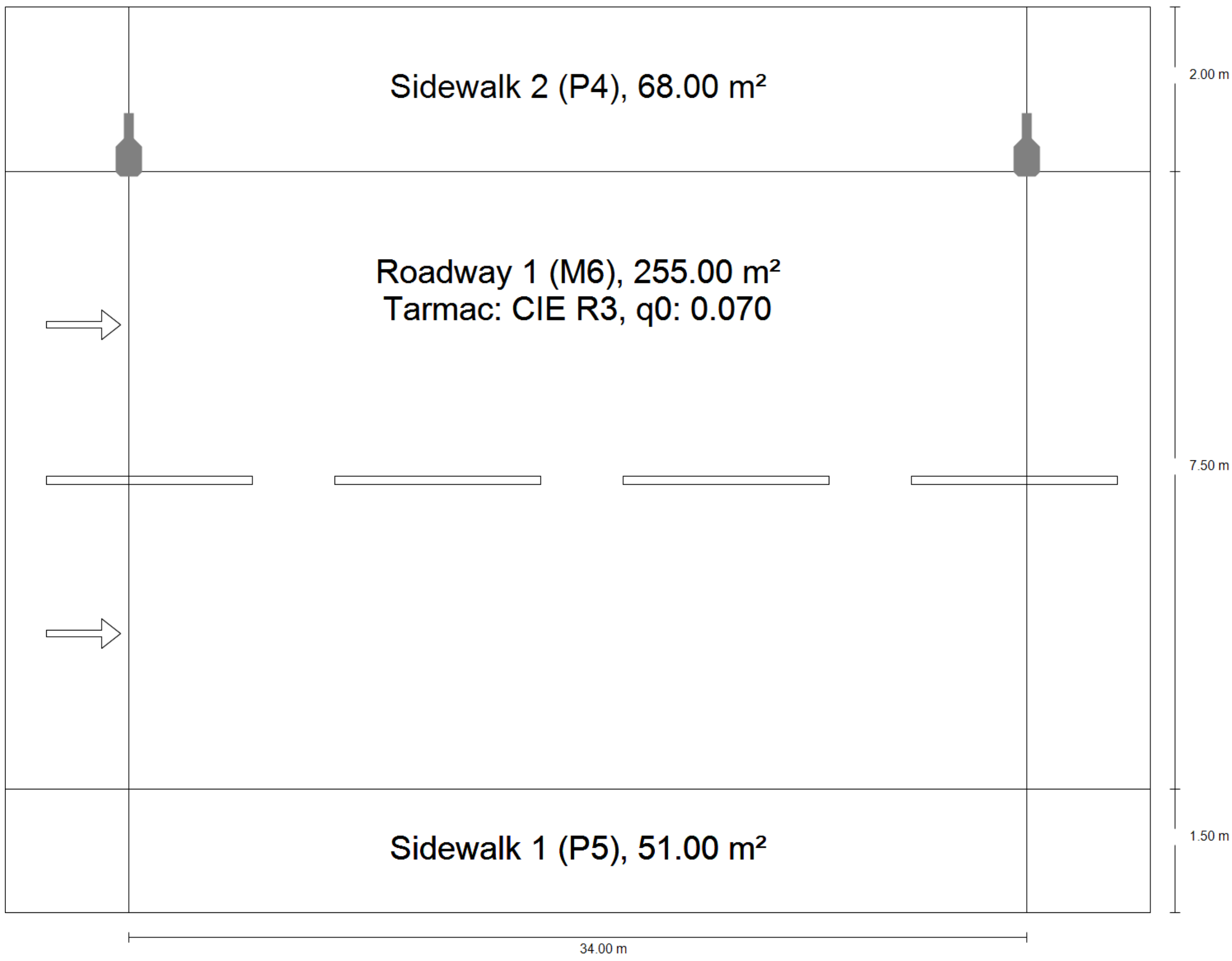
A maintenance factor of 0.87 was used for calculating for the installation.

Results for energy efficiency indicators

	Symbol	Calculated	Consumption
Collector - Class M5	D_p	0.016 W/lx*m²	-
BGP760 T25 DM10 BL1 /727 (single side top)	D_e	0.5 kWh/m² yr,	158.0 kWh/yr

Collector - Class M6

Summary (according to EN 13201:2015)

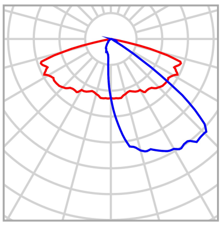


DIALux

Collector - Class M6

Summary (according to EN 13201:2015)

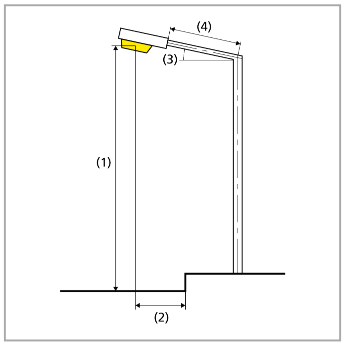
PHILIPS



Manufacturer	
Article No.	
Article name	LED Luminaire type D /727
Fitting	user-defined

P	23.0 W
Φ_{Lamp}	3100 lm
$\Phi_{Luminaire}$	1764 lm
η	56.90 %

LED Luminaire type D /727 (single side top)



Pole distance	34.000 m
(1) Light spot height	5.500 m
(2) Light point overhang	-0.200 m
(3) Boom inclination	0.0°
(4) Boom length	0.500 m
Annual operating hours	4000 h: 100.0 %, 23.0 W
Consumption	667.0 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 911 cd/klm ≥ 80°: 147 cd/klm ≥ 90°: 0.00 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	G*2
Glare index class	D.6

DIALux

Collector - Class M6

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P4)	E_{av}(1)	1.52 lx	-	-
	E_{min}(1)	0.19 lx	-	-
Roadway 1 (M6)	L_{av}	0.30 cd/m²	≥ 0.30 cd/m²	✓
	U_o	0.35	≥ 0.35	✓
	U_l	0.43	≥ 0.40	✓
	TI	20 %	≤ 20 %	✓
	R_{EI}(1)	0.16	-	-
Sidewalk 1 (P5)	E_{av}(1)	1.51 lx	-	-
	E_{min}(1)	0.46 lx	-	-

(1) Informative, not part of the valuation

A maintenance factor of 0.87 was used for calculating for the installation.

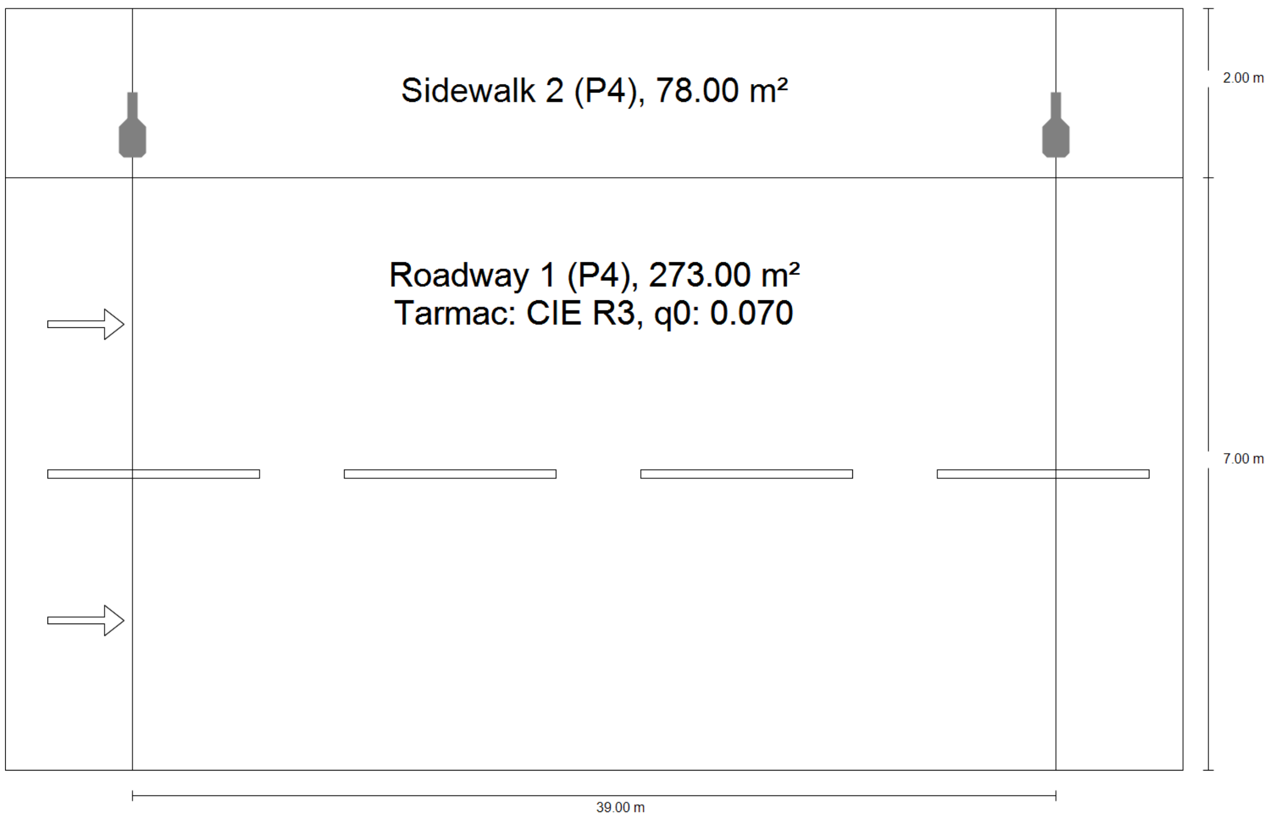
Results for energy efficiency indicators

	Symbol	Calculated	Consumption
Collector - Class M6	D_p	0.016 W/lx*m²	-
BGP760 T25 DM10 BL2 /727 (single side top)	D_e	0.2 kWh/m² yr,	92.0 kWh/yr

DIALux

Local - Class P4 - type A

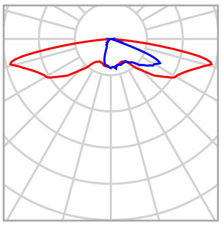
Summary (according to EN 13201:2015)



Local - Class P4 - type A

Summary (according to EN 13201:2015)

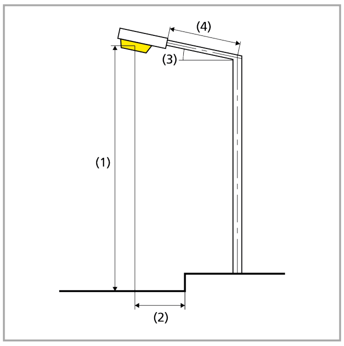
PHILIPS



Manufacturer	
Article No.	
Article name	LED Luminaire type E
Fitting	user-defined

P	35.0 W
Φ_{Lamp}	4600 lm
$\Phi_{Luminaire}$	2900 lm
η	63.04 %

LED Luminaire type E (single side top)



Pole distance	39.000 m
(1) Light spot height	5.000 m
(2) Light point overhang	-0.500 m
(3) Boom inclination	0.0°
(4) Boom length	0.500 m
Annual operating hours	4000 h: 100.0 %, 35.0 W
Consumption	910.0 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 777 cd/klm ≥ 80°: 732 cd/klm ≥ 90°: 0.00 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	-
Glare index class	D.0

Local - Class P4 - type A

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P4)	E_{av}	6.56 lx	[5.00 - 7.50] lx	✓
	E_{min}	1.71 lx	≥ 1.00 lx	✓
Roadway 1 (P4)	E_{av}	5.08 lx	[5.00 - 7.50] lx	✓
	E_{min}	1.49 lx	≥ 1.00 lx	✓

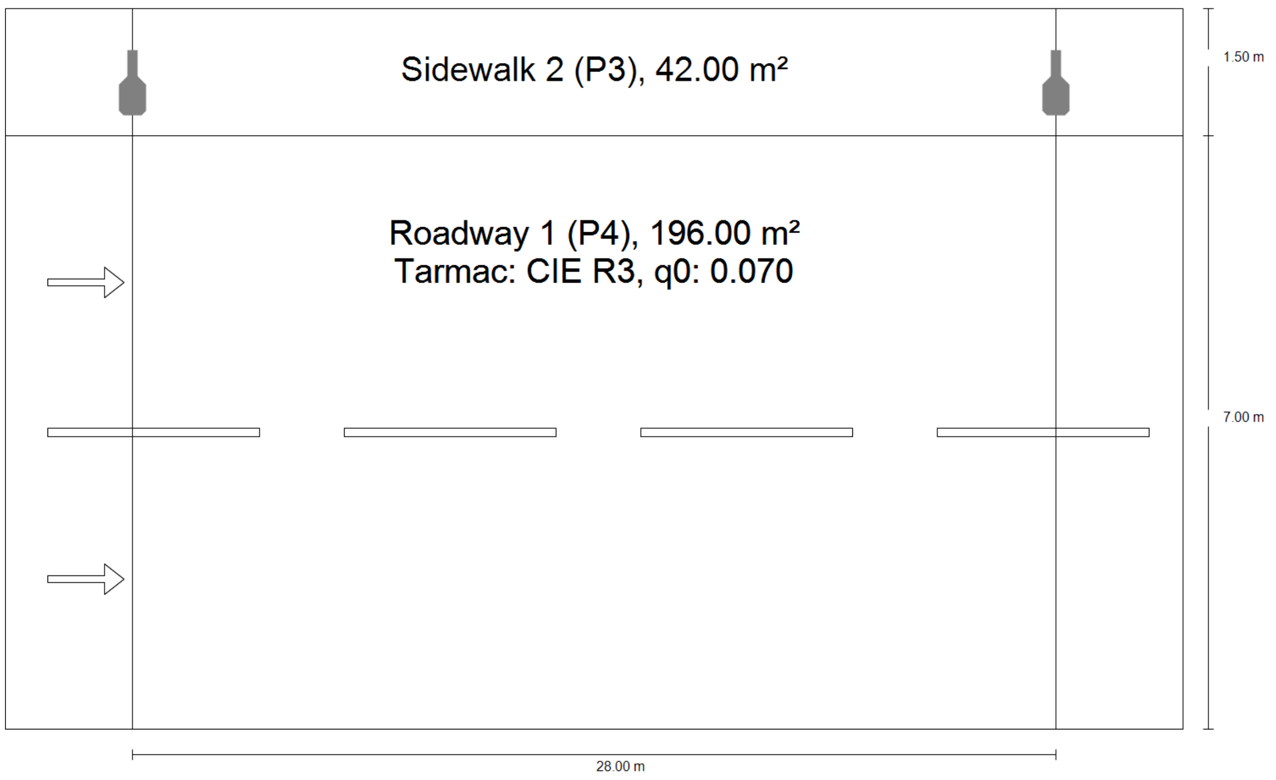
A maintenance factor of 0.87 was used for calculating for the installation.

Results for energy efficiency indicators

	Symbol	Calculated	Consumption
Local - Class P4 - type A	D_p	0.018 W/lx*m²	-
BGP760 T25 DM70 BL1 /727 (single side top)	D_e	0.4 kWh/m² yr,	140.0 kWh/yr

Local - Class P4 - type B

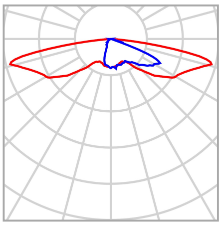
Summary (according to EN 13201:2015)



Local - Class P4 - type B

Summary (according to EN 13201:2015)

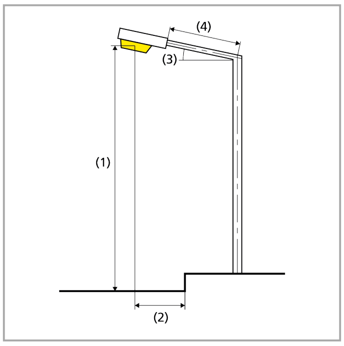
PHILIPS



Manufacturer	
Article No.	
Article name	LED Luminaire type G /727
Fitting	user-defined

P	23.5 W
Φ_{Lamp}	3200 lm
$\Phi_{Luminaire}$	2017 lm
η	63.04 %

LED Luminaire type G /727 (single side top)



Pole distance	28.000 m
(1) Light spot height	4.000 m
(2) Light point overhang	-0.500 m
(3) Boom inclination	0.0°
(4) Boom length	0.500 m
Annual operating hours	4000 h: 100.0 %, 23.5 W
Consumption	846.0 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 777 cd/klm ≥ 80°: 732 cd/klm ≥ 90°: 0.00 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	-
Glare index class	D.1

Local - Class P4 - type B

Summary (according to EN 13201:2015)

esults for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P4)	E_{av}	8.12 lx	7.50- 11.25 lx	✓
	E_{min}	2.73 lx	≥ 1.50 lx	✓
Roadway 1 (P4)	E_{av}	5.42 lx	5.00- 7.50 lx	✓
	E_{min}	1.47 lx	≥ 1.00 lx	✓

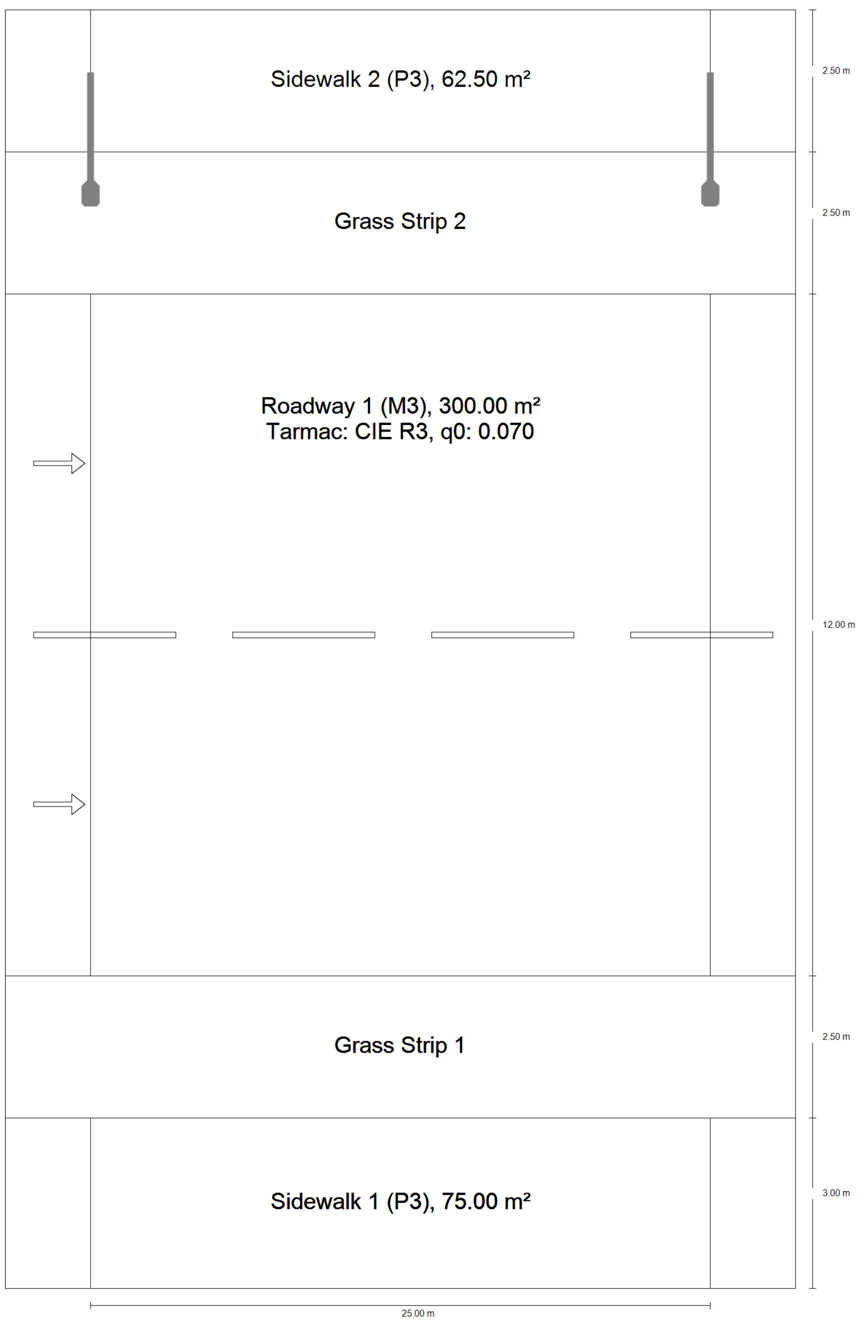
A maintenance factor of 0.87 was used for calculating for the installation.

esults for energy efficiency indicators

	Symbol	Calculated	Consumption
Local - Class P4 - type B	D_p	0.017 W/lxm^2	-
BGP760 T25 DM70 BL1 /727 (single side top)	D_e	0.4 kWh/m^2 yr,	94.0 kWh/yr

Major - Class M3

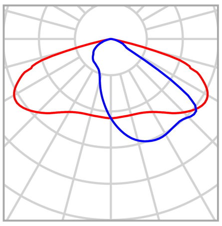
Summary (according to EN 13201:2015)



DIALux

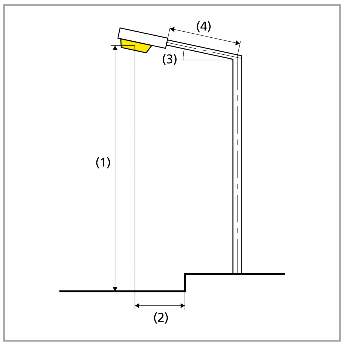
Major - Class M3

Summary (according to EN 13201:2015)



Manufacturer		P	87.0 W
Article No.		Φ_{Lamp}	12000 lm
Article name	LED Luminaire type A /727	$\Phi_{Luminaire}$	11179 lm
Fitting	user-defined	η	93.16 %

LED Luminaire type A /727 (single side top)



Pole distance	25.000 m
(1) Light spot height	10.000 m
(2) Light point overhang	-1.800 m
(3) Boom inclination	10.0°
(4) Boom length	2.100 m
Annual operating hours	4000 h: 100.0 %, 87.0 W
Consumption	3480.0 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 675 cd/klm ≥ 80°: 169 cd/klm ≥ 90°: 10.3 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	G□1
Glare index class	D.6

Major - Class M3

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P3)	E_{av}	7.67 lx	[7.50 - 11.25] lx	✓
	E_{min}	4.33 lx	≥ 1.50 lx	✓
Roadway 1 (M3)	L_{av}	1.01 cd/m²	≥ 1.00 cd/m²	✓
	U_o	0.48	≥ 0.40	✓
	U_l	0.83	≥ 0.60	✓
	TI	8 %	≤ 15 %	✓
	R_{EI}	0.49	≥ 0.30	✓
Sidewalk 1 (P3)	E_{av}	7.61 lx	[7.50 - 11.25] lx	✓
	E_{min}	6.48 lx	≥ 1.50 lx	✓

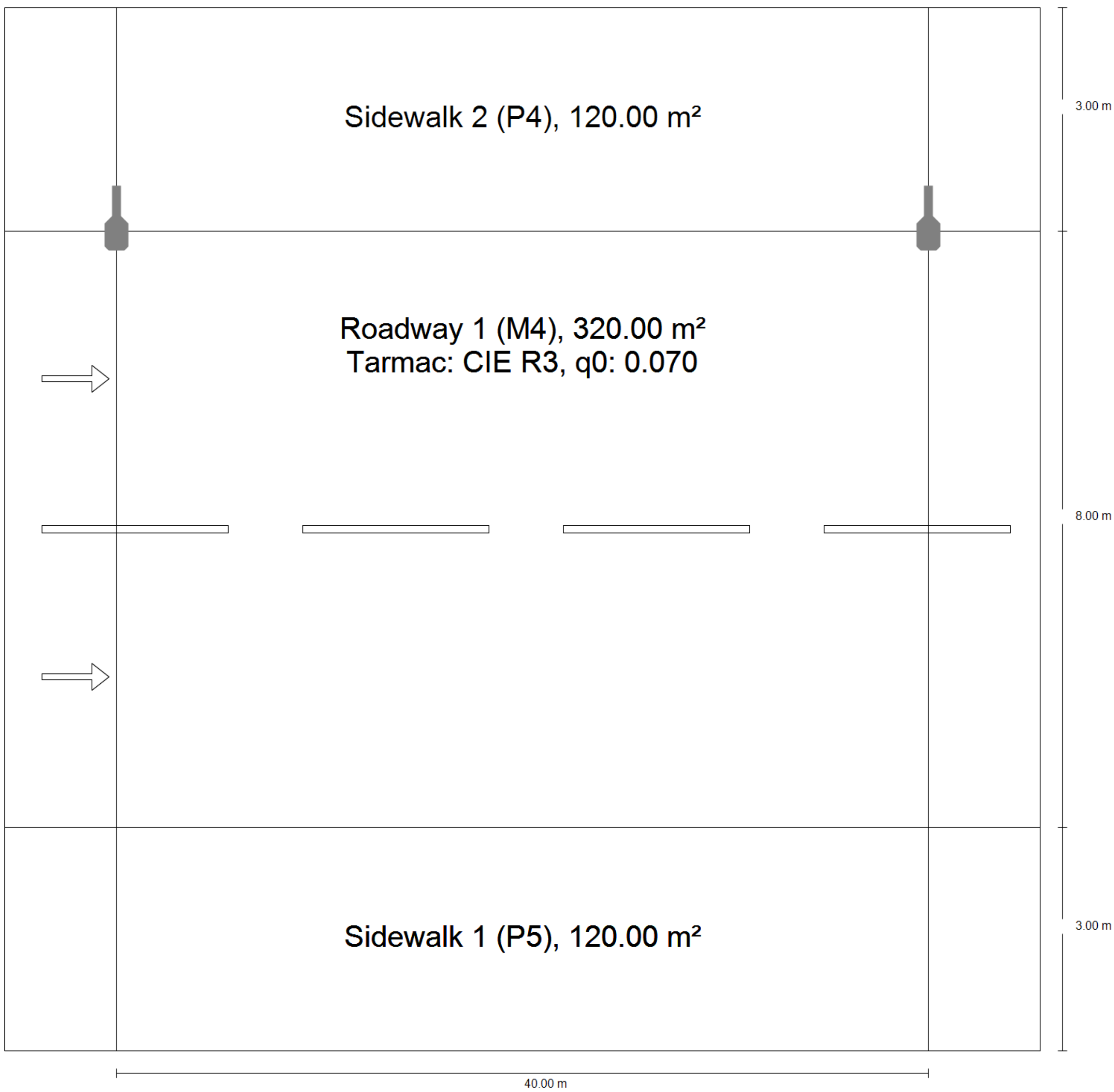
A maintenance factor of 0.87 was used for calculating for the installation.

Results for energy efficiency indicators

	Symbol	Calculated	Consumption
Major - Class M3	D_p	0.013 W/lx*m²	-
BGP762 T25 DM32 /727 (single side top)	D_e	0.8 kWh/m² yr,	348.0 kWh/yr

Major - Class M4

Summary (according to EN 13201:2015)

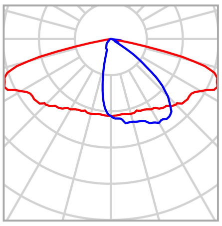


DIALux

Major - Class M4

Summary (according to EN 13201:2015)

PHILIPS

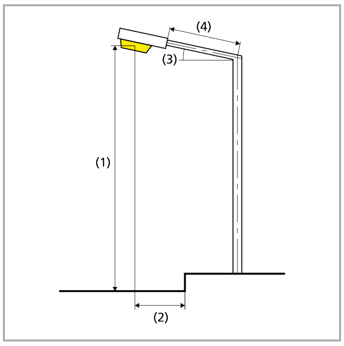


Manufacturer	
Article No.	
Article name	LED Luminaire type B /727
Fitting	user-defined

P	57.5 W
Φ_{Lamp}	8000 lm
$\Phi_{Luminaire}$	5793 lm
η	72.41 %

LED Luminaire type B /727 (single side top)

Pole distance	40.000 m
(1) Light spot height	8.000 m
(2) Light point overhang	0.000 m
(3) Boom inclination	0.0°
(4) Boom length	0.600 m
Annual operating hours	4000 h: 100.0 %, 57.5 W
Consumption	1437.5 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 950 cd/klm ≥ 80°: 101 cd/klm ≥ 90°: 0.00 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	G*2
Glare index class	D.6



Major - Class M4

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P4)	E_{av}	6.08 lx	[5.00 - 7.50] lx	✓
	E_{min}	1.53 lx	≥ 1.00 lx	✓
Roadway 1 (M4)	L_{av}	0.75 cd/m²	≥ 0.75 cd/m²	✓
	U_o	0.43	≥ 0.40	✓
	U_l	0.61	≥ 0.60	✓
	TI	15 %	≤ 15 %	✓
	R_{EI} (1)	0.28	-	-
Sidewalk 1 (P5)	E_{av} (1)	3.78 lx	-	-
	E_{min} (1)	1.28 lx	-	-

(1) Informative, not part of the valuation

A maintenance factor of 0.87 was used for calculating for the installation.

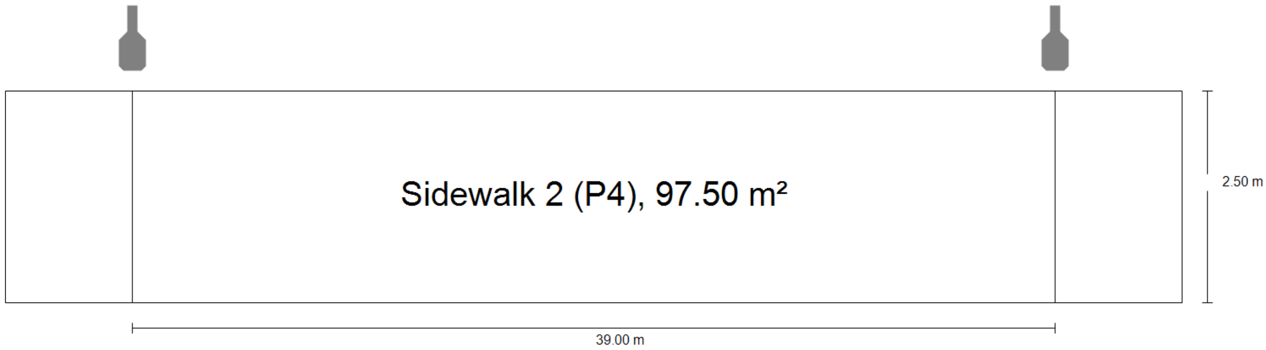
Results for energy efficiency indicators

	Symbol	Calculated	Consumption
Major - Class M4	D_p	0.012 W/lx*m²	-
BGP761 T25 DM12 BL1 /727 (single side top)	D_e	0.4 kWh/m² yr,	230.0 kWh/yr

DIALux

Sidewalk - Class P4

Summary (according to EN 13201:2015)

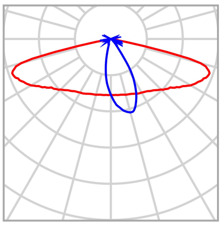


DIALux

Sidewalk - Class P4

Summary (according to EN 13201:2015)

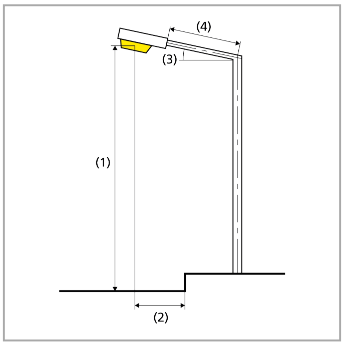
PHILIPS



Manufacturer	
Article No.	
Article name	LED Luminaire type F /727
Fitting	user-defined

P	12.5 W
Φ_{Lamp}	1500 lm
$\Phi_{Luminaire}$	1106 lm
η	73.74 %

BLED Luminaire type F /727 (single side top)



Pole distance	39.000 m
(1) Light spot height	5.500 m
(2) Light point overhang	-0.500 m
(3) Boom inclination	0.0°
(4) Boom length	0.500 m
Annual operating hours	4000 h: 100.0 %, 12.5 W
Consumption	325.0 W/km
ULR / ULOR	0.00 / 0.00
Max. luminous intensities Any direction forming the specified angle from the downward vertical, with the luminaire installed for use.	≥ 70°: 953 cd/klm ≥ 80°: 92.7 cd/klm ≥ 90°: 0.00 cd/klm
Luminous intensity class The luminous intensity values in [cd/klm] for calculation of the luminous intensity class refer to the luminaire luminous flux according to EN 13201:2015.	G*3
Glare index class	D.6

Sidewalk - Class P4

Summary (according to EN 13201:2015)

Results for valuation fields

	Symbol	Calculated	Target	Check
Sidewalk 2 (P4)	E_{av}	5.17 lx	[5.00 - 7.50] lx	✓
	E_{min}	1.00 lx	≥ 1.00 lx	✓

A maintenance factor of 0.87 was used for calculating for the installation.

Results for energy efficiency indicators

	Symbol	Calculated	Consumption
Sidewalk - Class P4	D_p	0.025 W/lx*m²	-
BGP760 T25 DN25 BL1 /727 (single side top)	D_e	0.5 kWh/m² yr,	50.0 kWh/yr

Appendix C - Crosswalk and Light Pollution - LED

Date: 12.01.2023
Operator:

Operator
Telephone
Fax
e-Mail

Table of contents

Operator
Telephone
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e-Mail

Table of contents

Operator
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Fax
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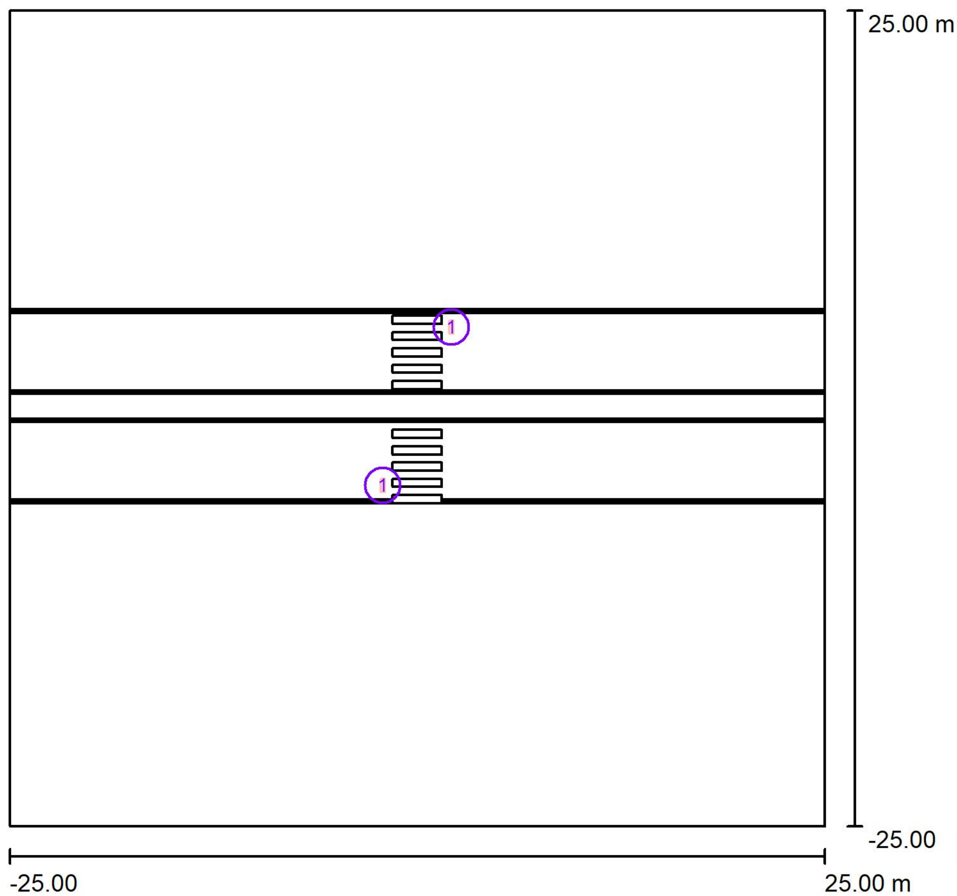
Crosswalk - Road Class M4 - A / Planning data



Light loss factor: 0.87, ULR (Upward Light Ratio): 0.0%

Scale 1:464

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)		Φ (Luminaire) [lm]		Φ (Lamps) [lm]	P [W]
1	2	Crosswalk LED type A (Type 1)* (1.000)		8776		9600	59.0
			Total:	17552	Total:	19200	118.0

*Modified Technical Specifications

Operator
Telephone
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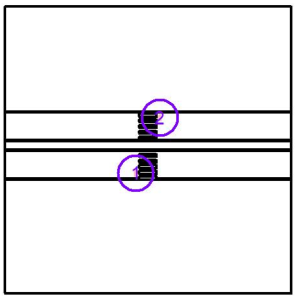
e-Mail

Crosswalk - Road Class M4 - A / Luminaires (coordinates list)

Crosswalk LED /757 (Type 1)

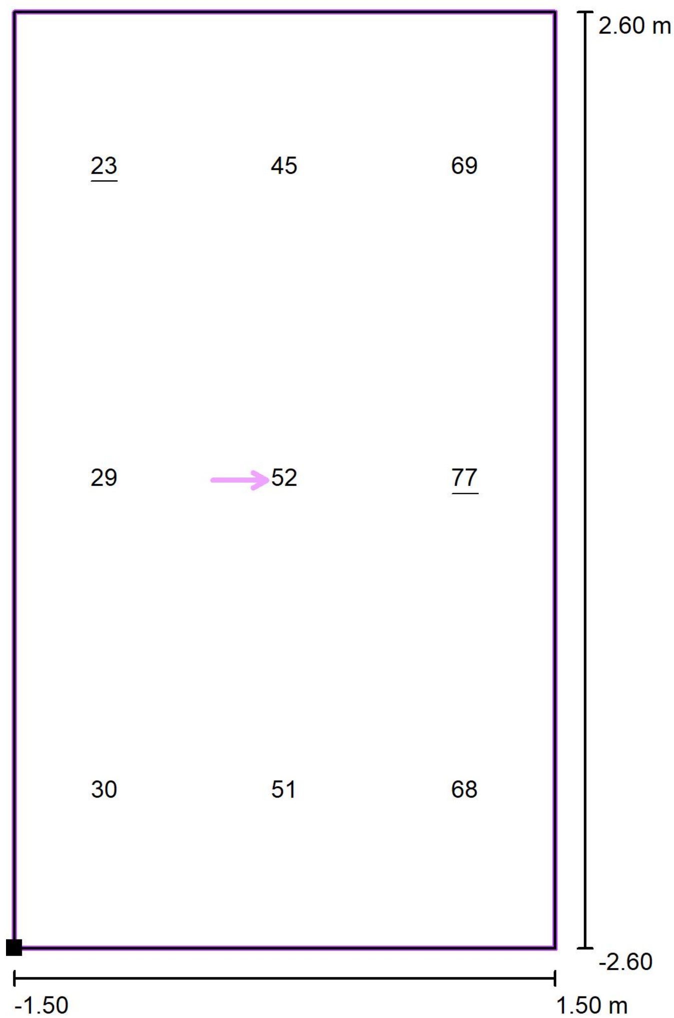
8776 lm, 59.0 W, 1 x 1 x Definováno uživatelem (Correction Factor 1.000).



No.	Position [m]			Rotation [°]		
	X	Y	Z	X	Y	Z
1	-2.100	-4.100	6.107	0.0	0.0	0.0
2	2.100	5.600	6.107	0.0	0.0	-180.0

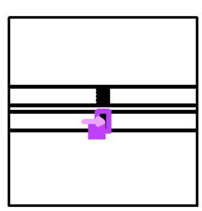
Operator
Telephone
Fax
e-Mail

Crosswalk - Road Class M4 - A / Vertical Illuminance of the main space / Value Chart (E, Vertical)



Values in Lux, Scale 1 : 42

Position of surface in external scene:
Marked point: (-1.500 m, -5.200 m, 1.000 m)

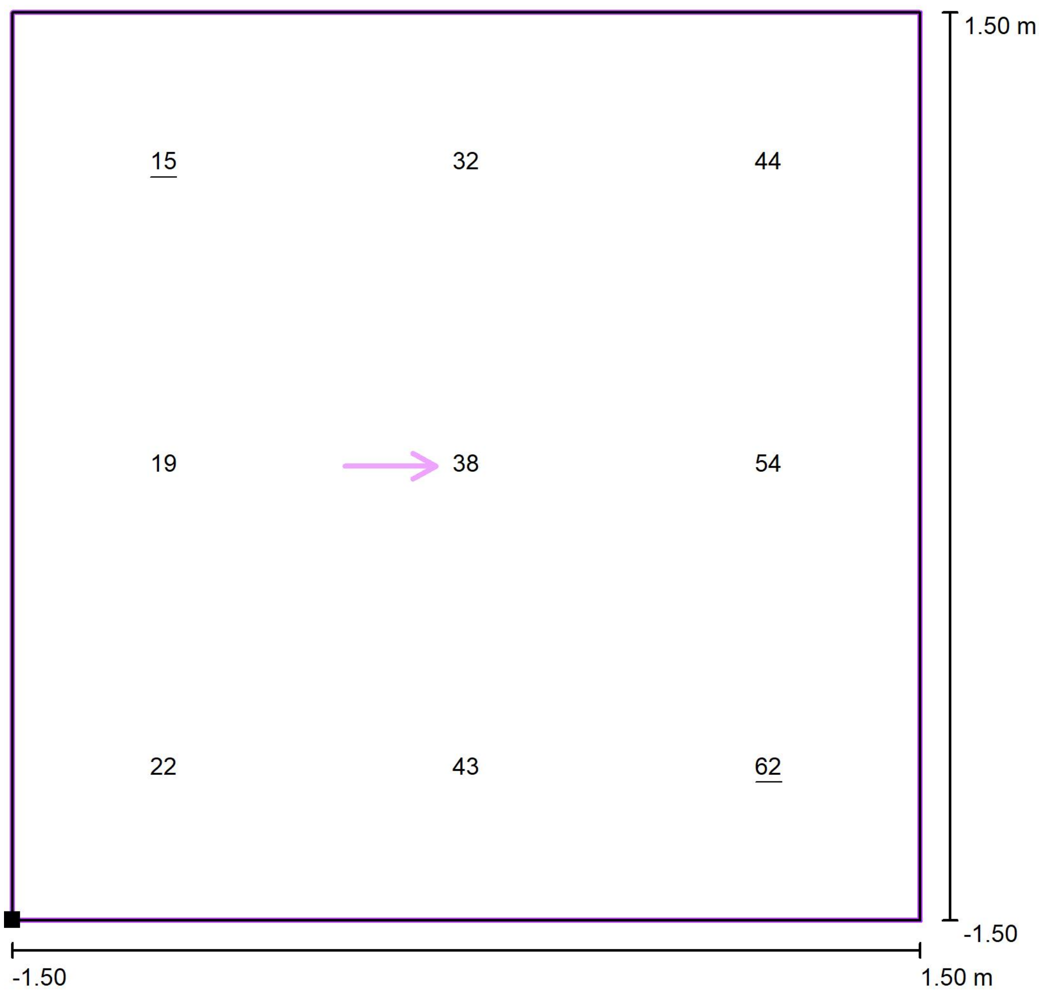


Grid: 3 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
50	23	77	0.47	0.31

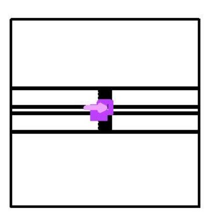
Operator
Telephone
Fax
e-Mail

Crosswalk - Road Class M4 - A / Vertical Illuminance of the additional space, extended / Value Chart (E, Vertical)



Values in Lux, Scale 1 : 25

Position of surface in external scene:
Marked point: (-1.500 m, 0.000 m, 1.000 m)

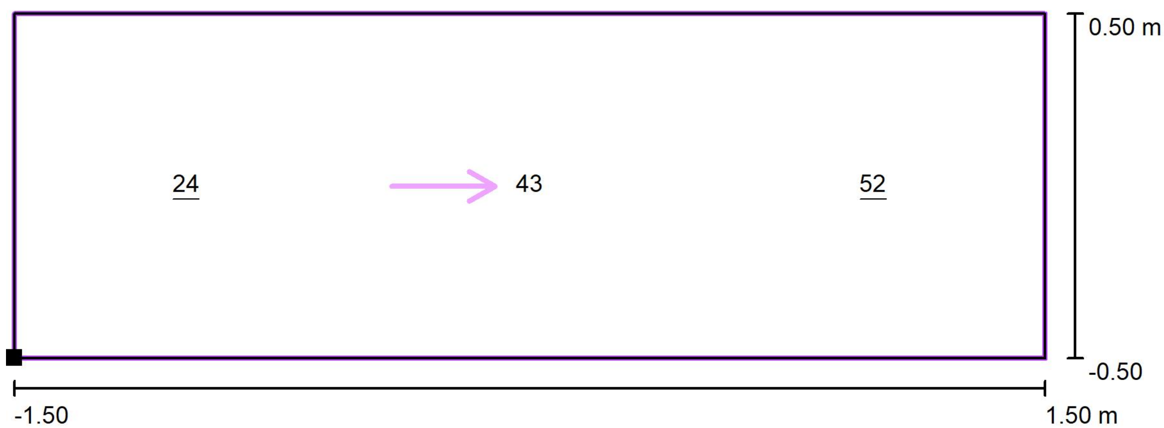


Grid: 3 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
37	15	62	0.41	0.24

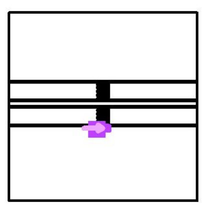
Operator
Telephone
Fax
e-Mail

Crosswalk - Road Class M4 - A / Vertical Illuminance of the additional space, not extended / Value Chart (E, Vertical)



Values in Lux, Scale 1 : 22

Position of surface in external scene:
Marked point: (-1.500 m, -6.200 m, 1.000 m)

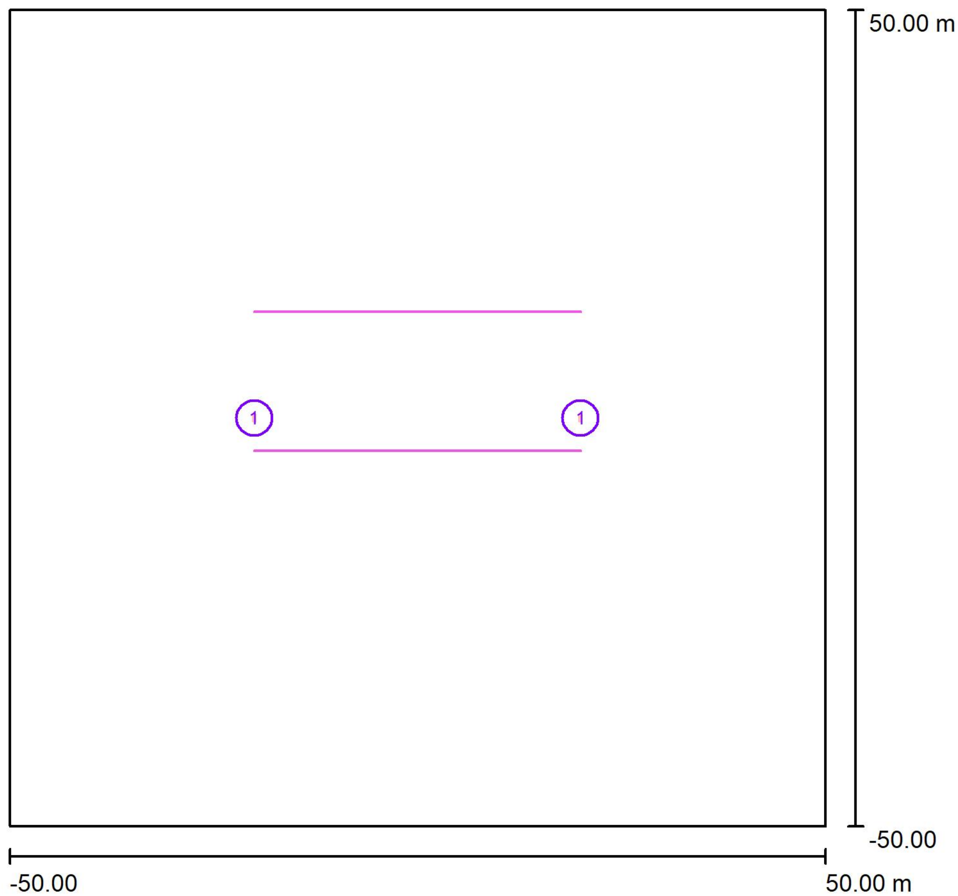


Grid: 3 x 1 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
40	24	52	0.61	0.46

Operator
Telephone
Fax
e-Mail

Light Pollution - M4 / Planning data



Light loss factor: 1.00, ULR (Upward Light Ratio): 0.0%

Scale 1:927

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	LED Luminaire type B /727 (Type 1)* (0.600)	5793	8000	57.5
			Total: 11585	Total: 16000	115.0

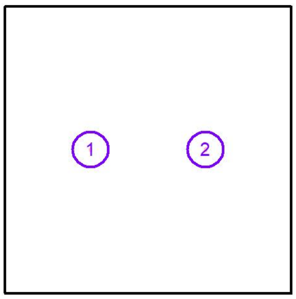
*Modified Technical Specifications

Operator
Telephone
Fax
e-Mail

Light Pollution - M4 / Luminaires (coordinates list)

LED Luminaire type B /727 (Type 1)

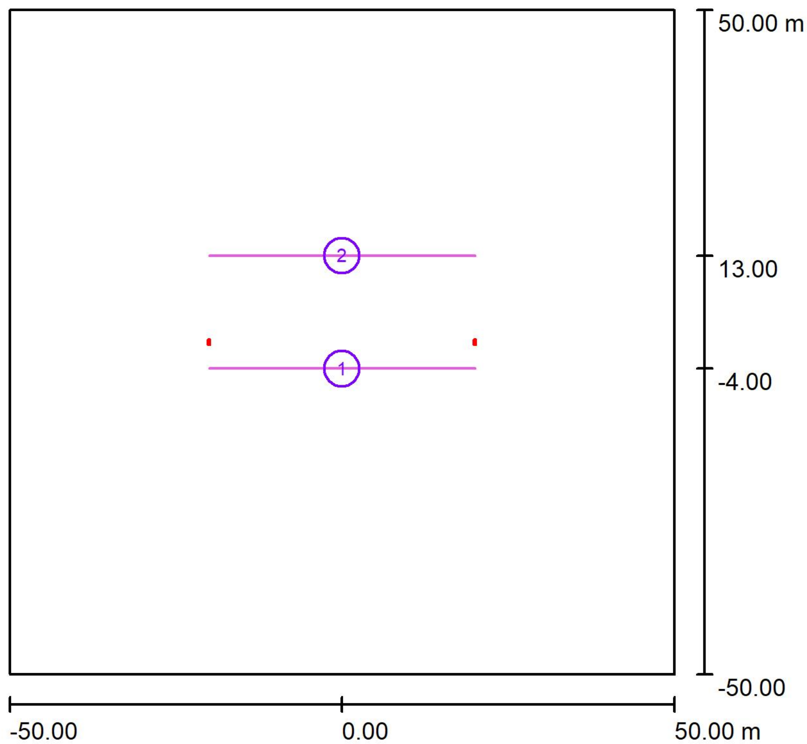
5793 lm, 57.5 W, 1 x 1 x User defined (Correction Factor 0.600).



No.	Position [m]			Rotation [°]		
	X	Y	Z	X	Y	Z
1	-20.000	0.000	8.107	0.0	0.0	0.0
2	20.000	0.000	8.107	0.0	0.0	0.0

Operator
Telephone
Fax
e-Mail

Light Pollution - M4 / Calculation surfaces (results overview)



Scale 1 : 1138

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Facade behind the light pole	perpendicular	128 x 32	0.22	0.00	1.55	0.010	0.001
2	Facade in front of the light pole	perpendicular	64 x 16	0.09	0.00	0.38	0.005	0.001

Summary of Results

Type	Quantity	Average [lx]	Min [lx]	Max [lx]	u0	E_{min} / E_{max}
perpendicular	2	0.15	0.00	1.55	0.00	0.00

Operator
Telephone
Fax
e-Mail

Light Pollution - M4 / Facade behind the light pole / Value Chart (E, Perpendicular)

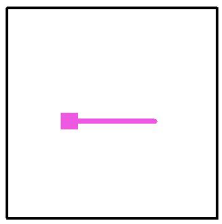
0.29	0.09	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.04	0.10	0.29
0.65	0.34	0.15	0.06	0.06	0.04	0.03	0.02	0.01	0.02	0.02	0.03	0.06	0.04	0.07	0.18	0.39	0.75
0.94	0.43	0.20	0.08	0.09	0.09	0.06	0.03	0.03	0.03	0.03	0.06	0.10	0.07	0.11	0.25	0.52	0.96
1.25	0.65	0.32	0.12	0.07	0.10	0.07	0.04	0.03	0.03	0.04	0.07	0.11	0.08	0.15	0.38	0.75	1.32

6.00 m
0.00
0.00
40.00 m

Values in Lux, Scale 1 : 286

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-20.000 m, -4.000 m, 8.000 m)



Grid: 128 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.22	0.00	1.55	0.010	0.001

Operator
Telephone
Fax
e-Mail

Light Pollution - M4 / Facade in front of the light pole / Value Chart (E, Perpendicular)

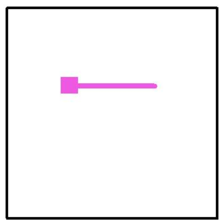
0.03	0.03	0.03	0.02	0.02	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.05
0.09	0.13	0.13	0.08	0.05	0.04	0.03	0.02	0.02	0.03	0.03	0.04	0.07	0.10	0.12	0.14
0.17	0.18	0.22	0.16	0.09	0.07	0.07	0.05	0.05	0.06	0.07	0.07	0.13	0.21	0.17	0.17
0.29	0.38	0.29	0.18	0.14	0.12	0.10	0.09	0.09	0.09	0.11	0.13	0.16	0.27	0.34	0.30

6.00 m
0.00
0.00
40.00 m

Values in Lux, Scale 1 : 286

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-20.000 m, 13.000 m, 2.000 m)

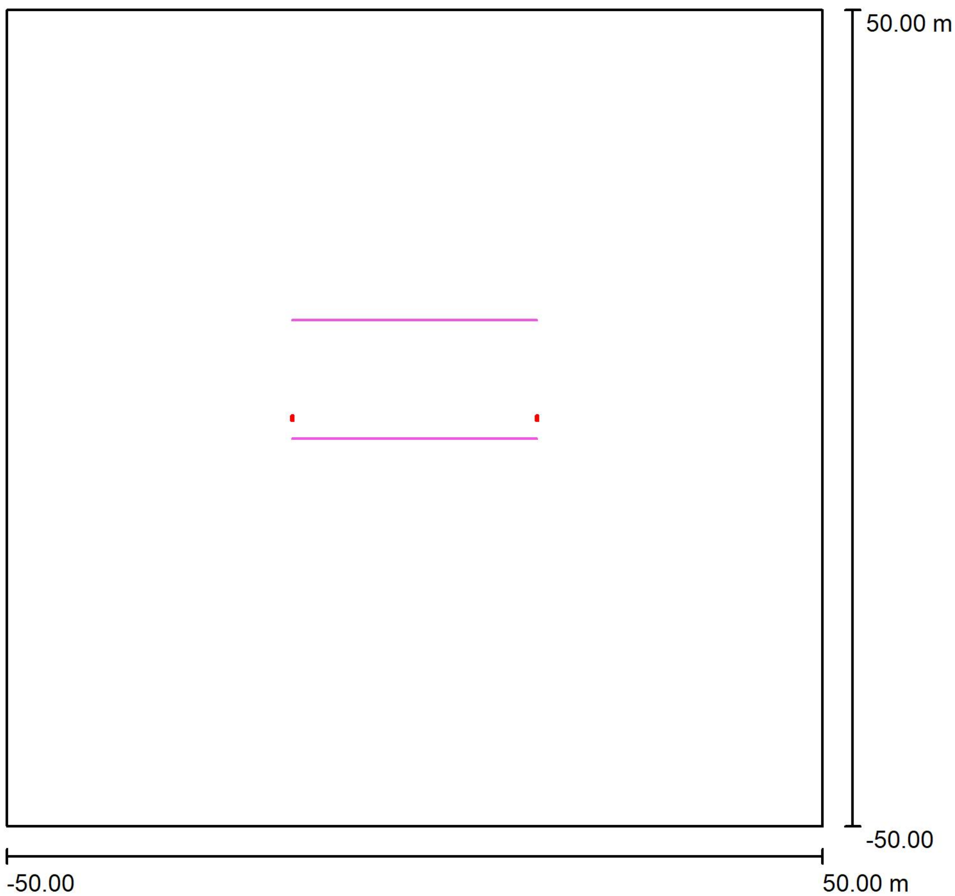


Grid: 64 x 16 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.09	0.00	0.38	0.005	0.001

Operator
Telephone
Fax
e-Mail

Light Pollution - M5 / Planning data



Light loss factor: 1.00, ULR (Upward Light Ratio): 0.0%

Scale 1:927

Luminaire Parts List

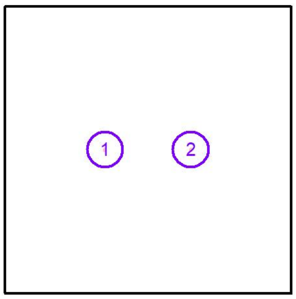
No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	LED Luminaire type C /727 (Type 1)* (0.600)	3486	5100	39.5
			Total: 6973	Total: 10200	79.0

*Modified Technical Specifications

Operator
Telephone
Fax
e-Mail

Light Pollution - M5 / Luminaires (coordinates list)

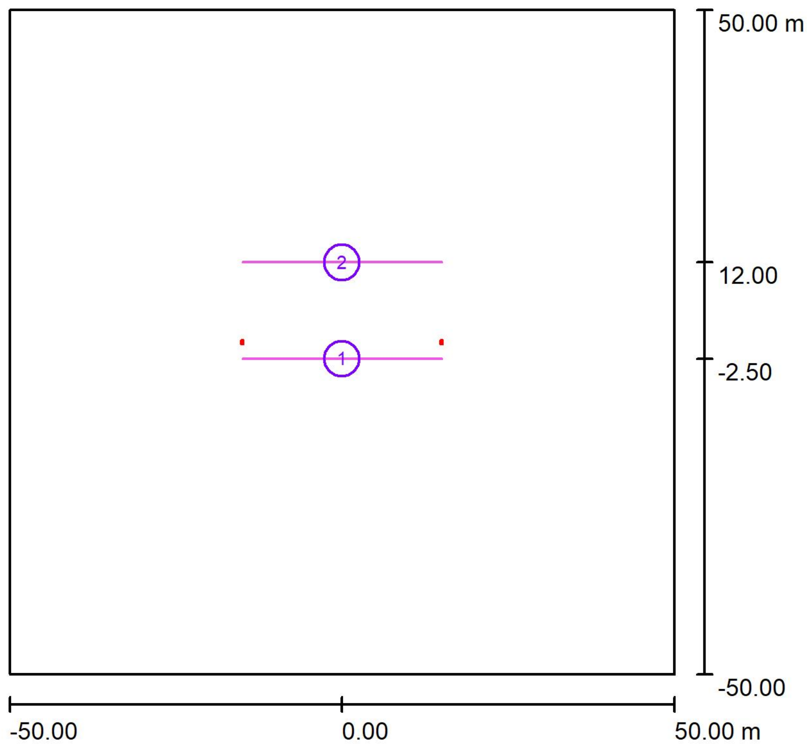
LED Luminaire type C /727 (Type 1)
3486 lm, 39.5 W, 1 x 1 x User defined (Correction Factor 0.500).



No.	Position [m]			Rotation [°]		
	X	Y	Z	X	Y	Z
1	-15.000	0.000	6.103	10.0	0.0	0.0
2	15.000	0.000	6.103	10.0	0.0	0.0

Operator
Telephone
Fax
e-Mail

Light Pollution - M5 / Calculation surfaces (results overview)



Scale 1 : 1138

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Facade behind the light pole	perpendicular	128 x 32	0.06	0.00	0.90	0.000	0.000
2	Facade in front of the light pole	perpendicular	128 x 64	0.12	0.00	1.19	0.007	0.001

Summary of Results

Type	Quantity	Average [lx]	Min [lx]	Max [lx]	u0	E_{min} / E_{max}
perpendicular	2	0.09	0.00	1.19	0.00	0.00

Operator
Telephone
Fax
e-Mail

Light Pollution - M5 / Facade behind the light pole / Value Chart (E, Perpendicular)

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.06	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.05
0.32	0.16	0.11	0.03	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.12	0.24	0.35
0.57	0.32	0.14	0.04	0.03	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.02	0.03	0.07	0.18	0.33	0.65

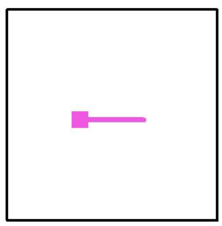
6.00 m
0.00

0.00 — 30.00 m

Values in Lux, Scale 1 : 215

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-15.000 m, -2.500 m, 8.000 m)



Grid: 128 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.06	0.00	0.90	0.000	0.000

Operator
Telephone
Fax
e-Mail

Light Pollution - M5 / Facade in front of the light pole / Value Chart (E, Perpendicular)

0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.03
0.07	0.06	0.04	0.04	0.04	0.04	0.03	0.02	0.02	0.02	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.06
0.12	0.10	0.09	0.08	0.08	0.08	0.05	0.05	0.05	0.05	0.05	0.05	0.07	0.08	0.08	0.10	0.10	0.12
0.15	0.19	0.18	0.20	0.20	0.16	0.12	0.08	0.08	0.07	0.08	0.11	0.15	0.20	0.21	0.19	0.19	0.16
0.18	0.21	0.24	0.37	0.45	0.53	0.49	0.49	0.48	0.45	0.52	0.52	0.54	0.49	0.40	0.29	0.25	0.21

6.00 m

0.00

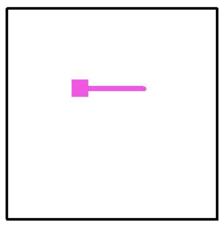
0.00

30.00 m

Values in Lux, Scale 1 : 215

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-15.000 m, 12.000 m, 2.000 m)

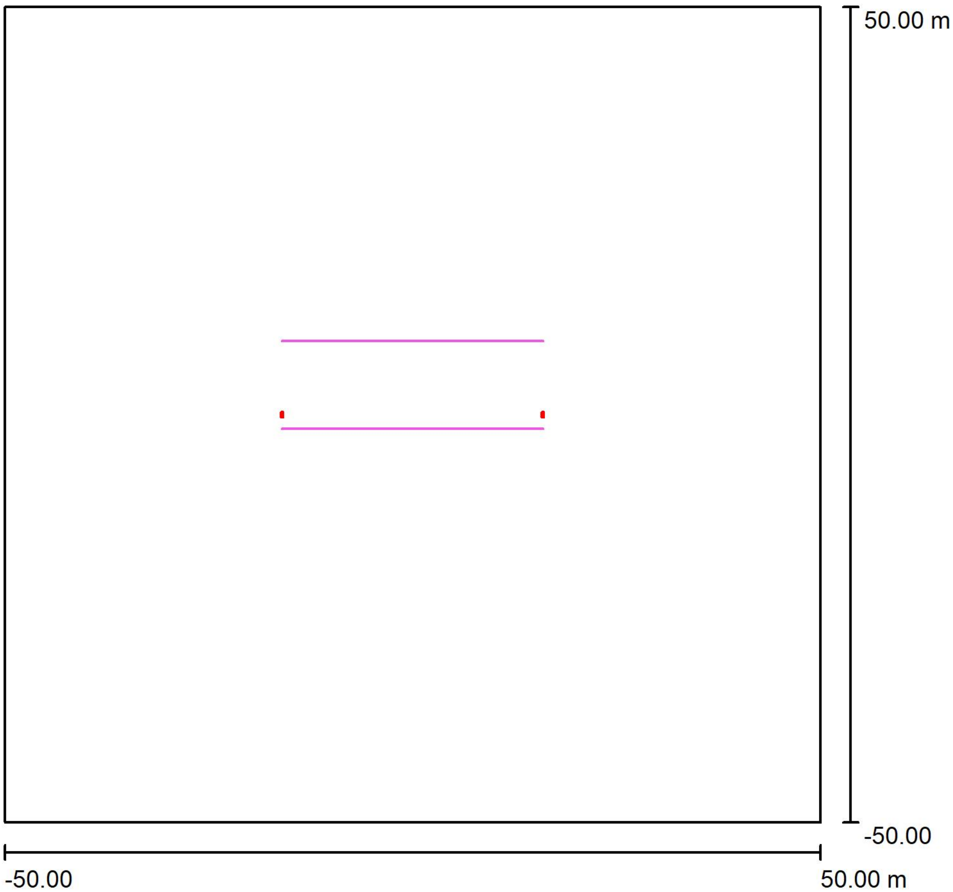


Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.12	0.00	1.19	0.007	0.001

Operator
Telephone
Fax
e-Mail

Light Pollution - M6 / Planning data



Light loss factor: 1.00, ULR (Upward Light Ratio): 0.0%

Scale 1:927

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	LED Luminaire type D /727 (Type 1)* (1.000)	1764	3100	23.0
			Total: 3528	Total: 6200	46.0

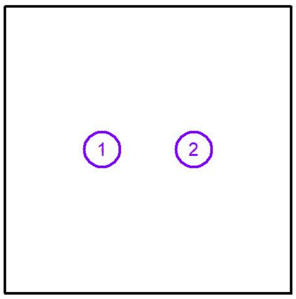
*Modified Technical Specifications

Operator
Telephone
Fax
e-Mail

Light Pollution - M6 / Luminaires (coordinates list)

LED Luminaire type D /727 (Type 1)

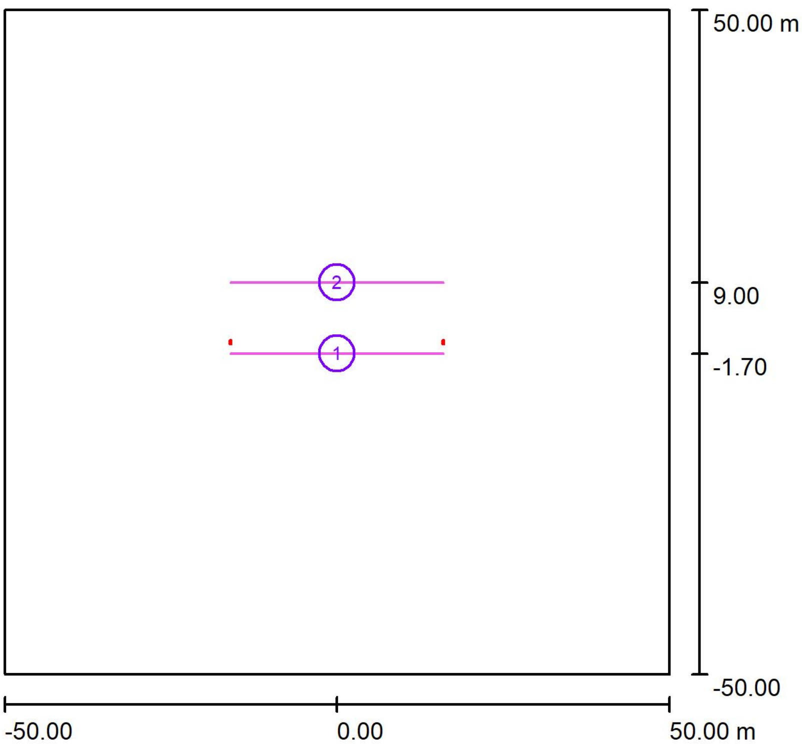
1764 lm, 23.0 W, 1 x 1 x User defined (Correction Factor 0.500).



No.	Position [m]			Rotation [°]		
	X	Y	Z	X	Y	Z
1	-16.000	0.000	5.603	0.0	0.0	0.0
2	16.000	0.000	5.603	0.0	0.0	0.0

Operator
Telephone
Fax
e-Mail

Light Pollution - M6 / Calculation surfaces (results overview)



Scale 1 : 1138

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Facade behind the light pole	perpendicular	128 x 16	0.15	0.00	1.41	0.004	0.000
2	Facade in front of the light pole	perpendicular	128 x 64	0.06	0.01	0.16	0.168	0.069

Summary of Results

Type	Quantity	Average [lx]	Min [lx]	Max [lx]	u0	E_{min} / E_{max}
perpendicular	2	0.11	0.00	1.41	0.01	0.00

Operator
Telephone
Fax
e-Mail

Light Pollution - M6 / Facade behind the light pole / Value Chart (E, Perpendicular)

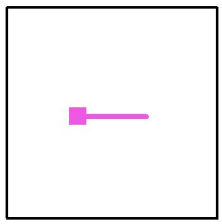
0.72	0.23	0.07	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.10	0.31	1.00
0.59	0.23	0.10	0.04	0.02	0.02	0.01	0.01	0.00	0.00	0.01	0.02	0.02	0.03	0.05	0.13	0.30	0.73

Height: 0.00 – 2.00 m; Length: 0.00 – 32.00 m

Values in Lux, Scale 1 : 229

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-16.000 m, -1.700 m, 3.500 m)



Grid: 128 x 16 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.15	0.00	1.41	0.004	0.000

Operator
Telephone
Fax
e-Mail

Light Pollution - M6 / Facade in front of the light pole / Value Chart (E, Perpendicular)

0.12	0.09	0.06	0.06	0.05	0.04	0.04	0.02	0.02	0.02	0.02	0.03	0.04	0.04	0.06	0.05	0.09	0.07
0.11	0.12	0.13	0.11	0.08	0.07	0.08	0.07	0.07	0.07	0.07	0.08	0.07	0.08	0.10	0.12	0.12	0.13

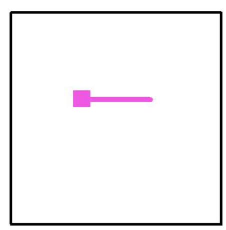
2.00 m
0.00

0.00
32.00 m

Values in Lux, Scale 1 : 229

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-16.000 m, 9.000 m, 1.500 m)

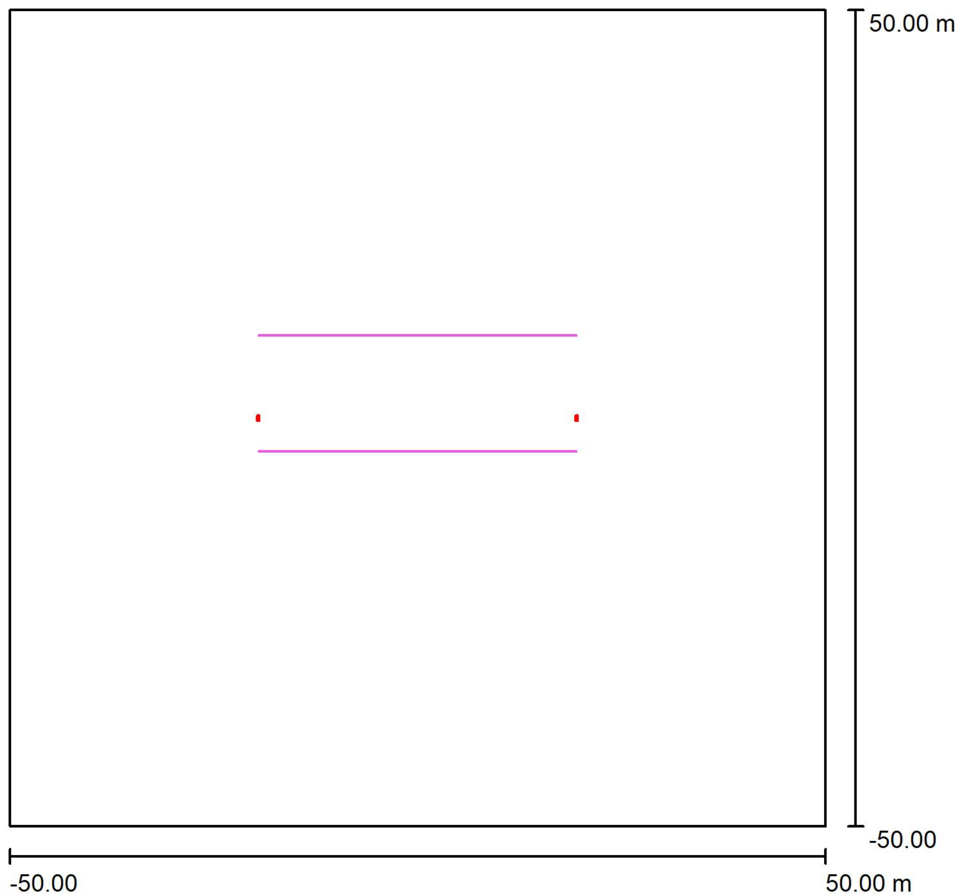


Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.06	0.01	0.16	0.168	0.069

Operator
Telephone
Fax
e-Mail

Light Pollution - P4 / Planning data



Light loss factor: 1.00, ULR (Upward Light Ratio): 0.0%

Scale 1:927

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	LED Luminaire type E /727 (Type 1)* (0.400)	2900	4600	35.0
			Total: 5800	Total: 9200	70.0

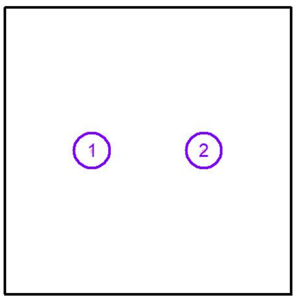
*Modified Technical Specifications

Operator
Telephone
Fax
e-Mail

Light Pollution - P4 / Luminaires (coordinates list)

LED Luminaire type E /727 (Type 1)

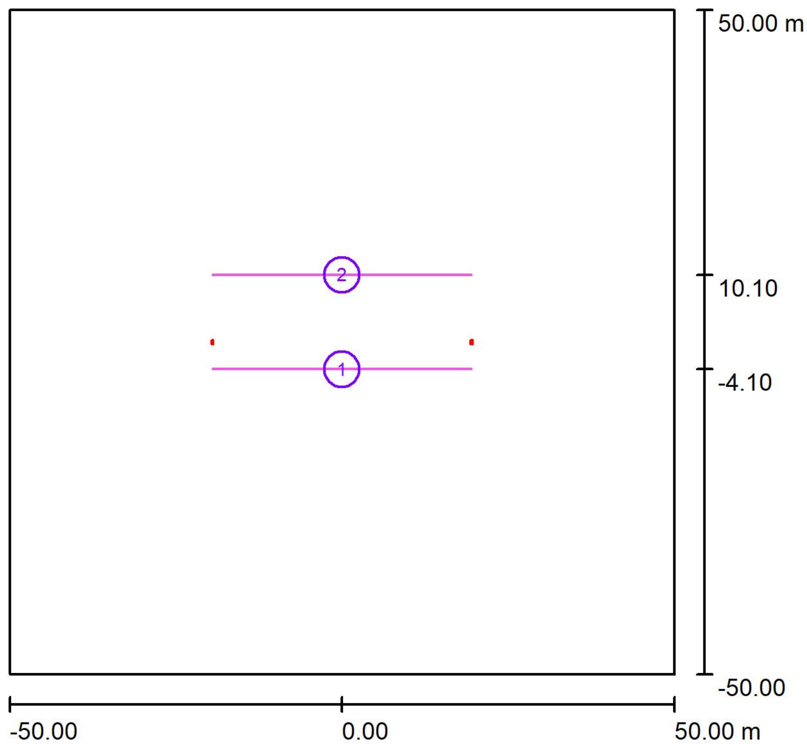
2900 lm, 35.0 W, 1 x 1 x User defined (Correction Factor 0.500).



No.	Position [m]			Rotation [°]		
	X	Y	Z	X	Y	Z
1	-19.500	0.000	5.103	0.0	0.0	0.0
2	19.500	0.000	5.103	0.0	0.0	0.0

Operator
Telephone
Fax
e-Mail

Light Pollution - P4 / Calculation surfaces (results overview)



Scale 1 : 1138

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Facade behind the light pole	perpendicular	128 x 16	0.09	0.00	0.97	0.001	0.000
2	Facade in front of the light pole	perpendicular	128 x 64	0.06	0.00	0.85	0.000	0.000

Summary of Results

Type	Quantity	Average [lx]	Min [lx]	Max [lx]	u0	E_{min} / E_{max}
perpendicular	2	0.07	0.00	0.97	0.00	0.00

Operator
Telephone
Fax
e-Mail

Light Pollution - P4 / Facade behind the light pole / Value Chart (E, Perpendicular)

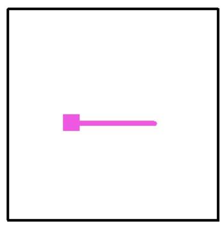
0.09	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.11
0.40	0.20	0.13	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.15	0.26	0.46

Height: 0.00 – 4.00 m; Length: 0.00 – 39.00 m

Values in Lux, Scale 1 : 279

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-19.500 m, -4.100 m, 5.000 m)



Grid: 128 x 16 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.09	0.00	0.97	0.001	0.000

Operator
Telephone
Fax
e-Mail

Light Pollution - P4 / Facade in front of the light pole / Value Chart (E, Perpendicular)

0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
0.12	0.08	0.06	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.05	0.07	0.12
0.19	0.17	0.14	0.10	0.08	0.07	0.06	0.05	0.05	0.06	0.06	0.05	0.07	0.07	0.08	0.12	0.16	0.19

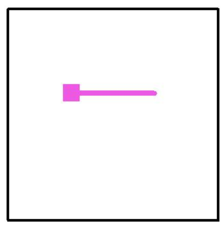
4.00 m
0.00

0.00 39.00 m

Values in Lux, Scale 1 : 279

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-19.500 m, 10.100 m, 1.500 m)

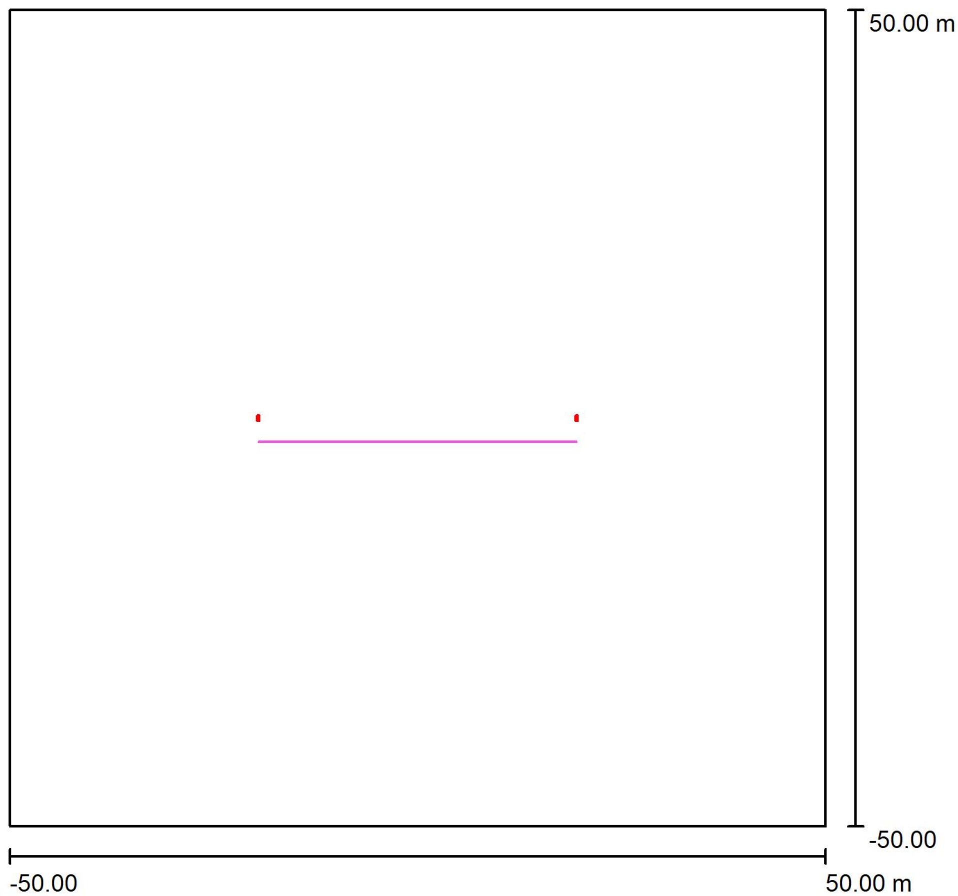


Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.06	0.00	0.85	0.000	0.000

Operator
Telephone
Fax
e-Mail

Light Pollution - Sidewalk / Planning data



Light loss factor: 1.00, ULR (Upward Light Ratio): 0.0%

Scale 1:927

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	LED Luminaire type F /727 (Type 1)* (0.400)	1106	1500	12.5
			Total: 2212	Total: 3000	25.0

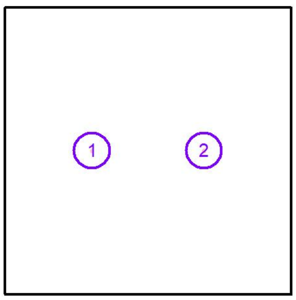
*Modified Technical Specifications

Operator
Telephone
Fax
e-Mail

Light Pollution - Sidewalk / Luminaires (coordinates list)

LED Luminaire type F /727 (Type 1)

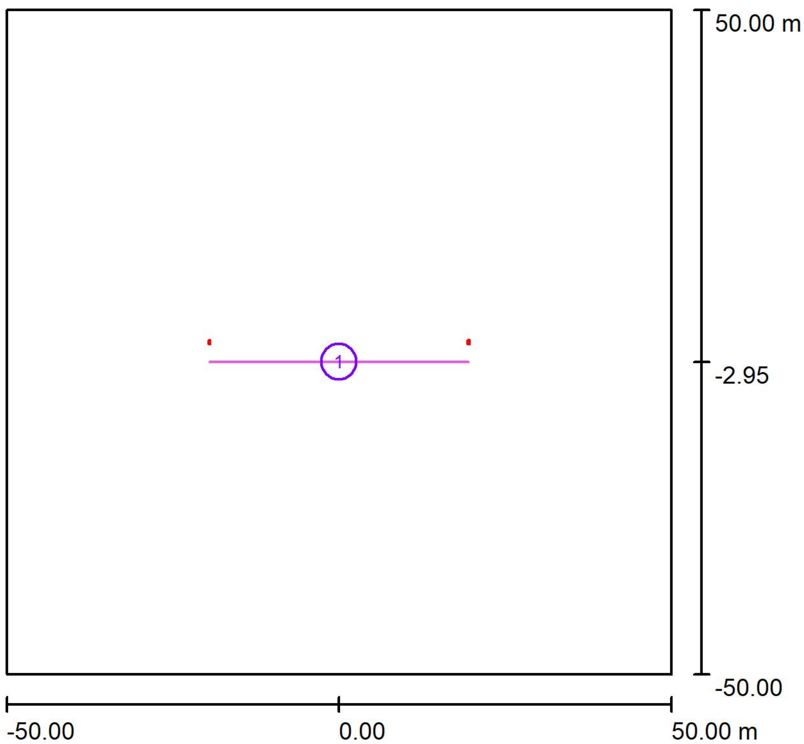
1106 lm, 12.5 W, 1 x 1 x User defined (Correction Factor 0.500).



No.	Position [m]			Rotation [°]		
	X	Y	Z	X	Y	Z
1	-19.500	0.000	5.603	0.0	0.0	0.0
2	19.500	0.000	5.603	0.0	0.0	0.0

Operator
Telephone
Fax
e-Mail

Light Pollution - Sidewalk / Calculation surfaces (results overview)



Scale 1 : 1138

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Facade behind the light pole	perpendicular	128 x 16	0.07	0.00	0.95	0.007	0.001

Operator
Telephone
Fax
e-Mail

Light Pollution - Sidewalk / Facade behind the light pole / Value Chart (E, Perpendicular)

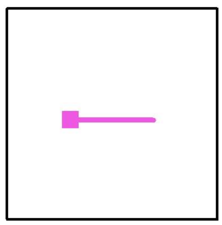
0.17	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.27
0.38	0.13	0.04	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.05	0.17	0.59

4.00 m
0.00
0.00
39.00 m

Values in Lux, Scale 1 : 279

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-19.500 m, -2.950 m, 5.000 m)

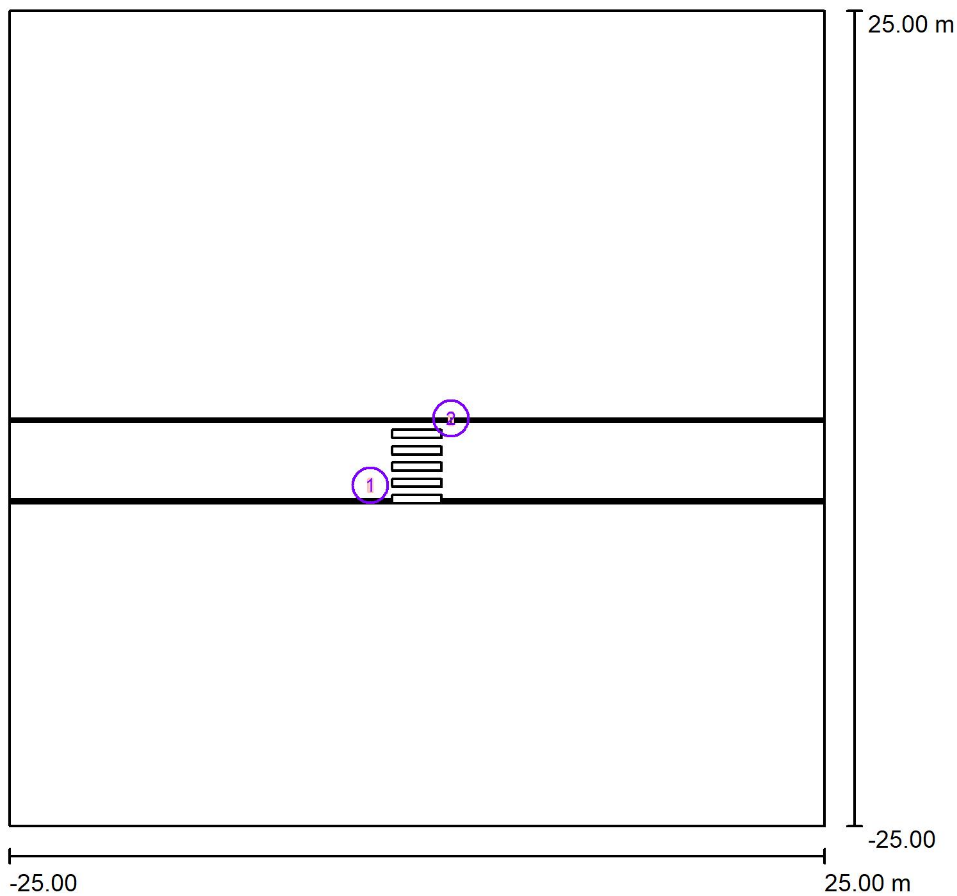


Grid: 128 x 16 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.07	0.00	0.95	0.007	0.001

Operator
Telephone
Fax
e-Mail

Crosswalk - Road Class M4 - B / Planning data



Light loss factor: 0.87, ULR (Upward Light Ratio): 0.0%

Scale 1:464

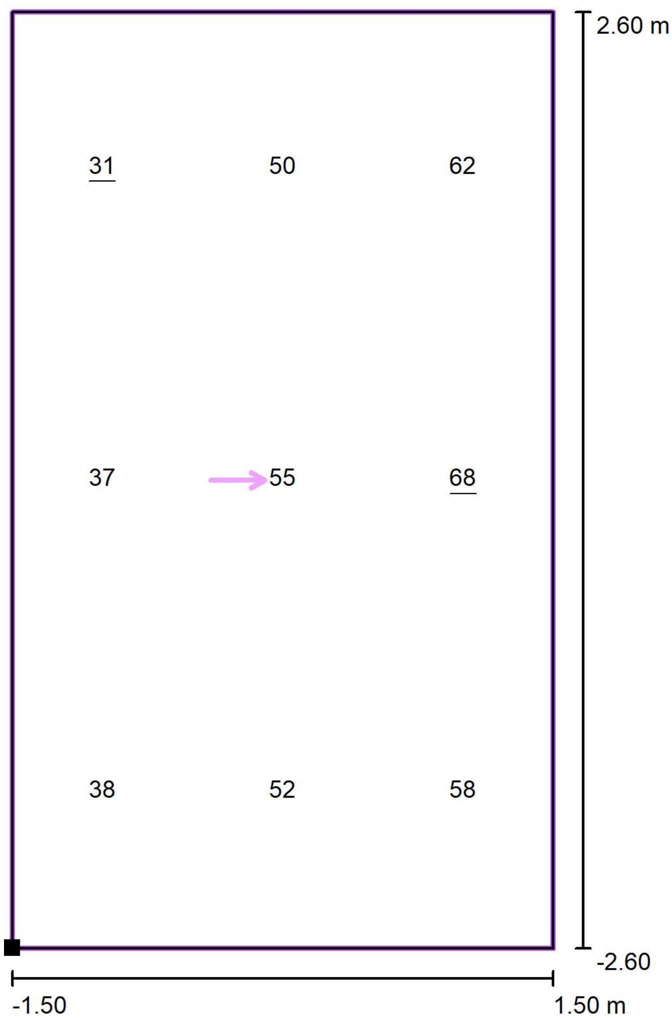
Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	1	Crosswalk Luminaire type B /757 (Type 1)* (1.000)	6765	7400	46.0
2	1	Crosswalk Luminaire type B /757 (Type 2)* (1.000)	6765	7400	46.0
			Total: 13530	Total: 14800	92.0

*Modified Technical Specifications

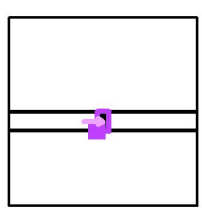
Operator
Telephone
Fax
e-Mail

Crosswalk - Road Class M4 - B / Vertical Illuminance of the main space / Value Chart (E, Vertical)



Values in Lux, Scale 1 : 42

Position of surface in external scene:
Marked point: (-1.500 m, -5.200 m, 1.000 m)

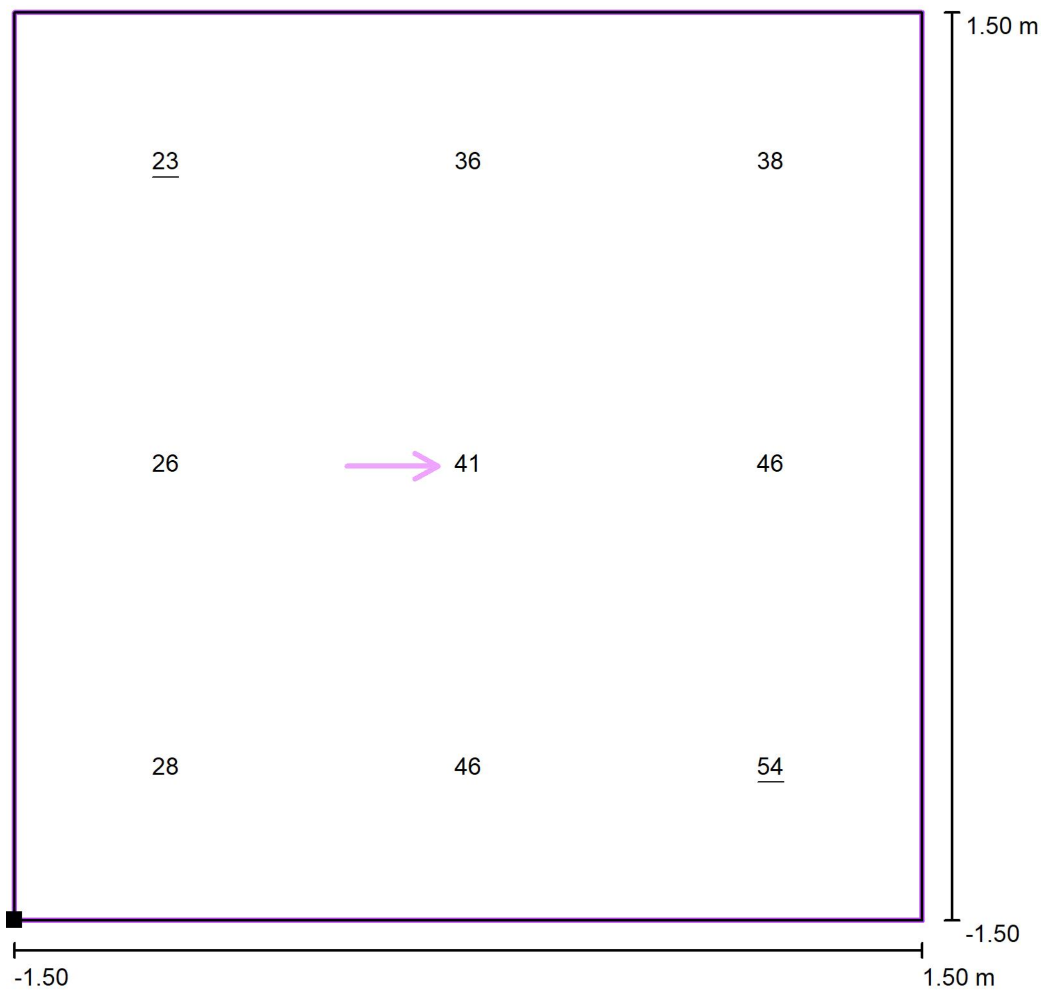


Grid: 3 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
50	31	68	0.62	0.45

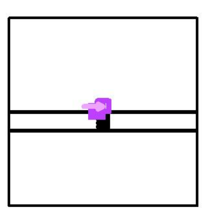
Operator
Telephone
Fax
e-Mail

Crosswalk - Road Class M4 - B / Vertical Illuminance of the additional space, extended / Value Chart (E, Vertical)



Values in Lux, Scale 1 : 25

Position of surface in external scene:
Marked point: (-1.500 m, 0.000 m, 1.000 m)

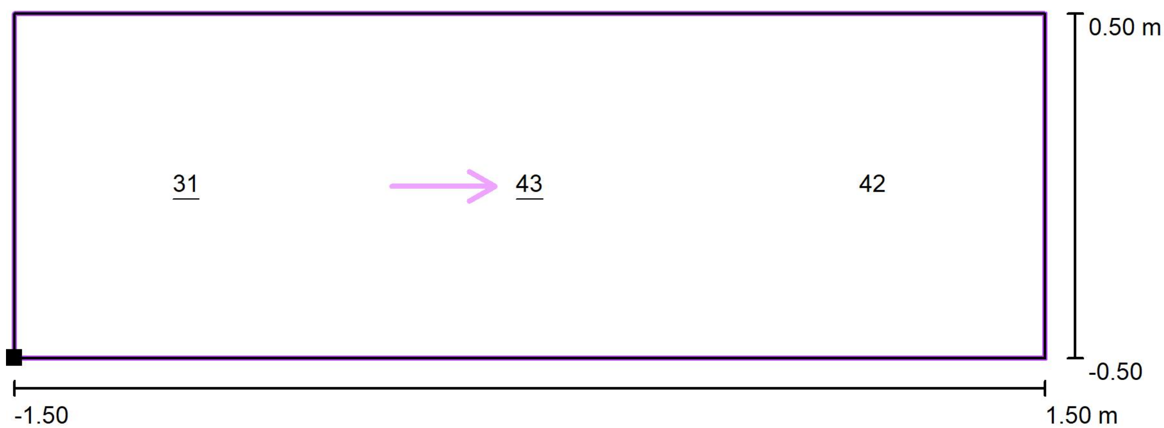


Grid: 3 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
38	23	54	0.61	0.42

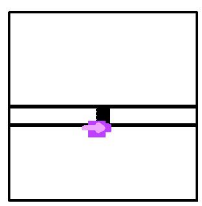
Operator
Telephone
Fax
e-Mail

Crosswalk - Road Class M4 - B / Vertical Illuminance of the additional space, not extended / Value Chart (E, Vertical)



Values in Lux, Scale 1 : 22

Position of surface in external scene:
Marked point: (-1.500 m, -6.200 m, 1.000 m)



Grid: 3 x 1 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
39	31	43	0.81	0.74

Appendix D - Light Pollution - HPS

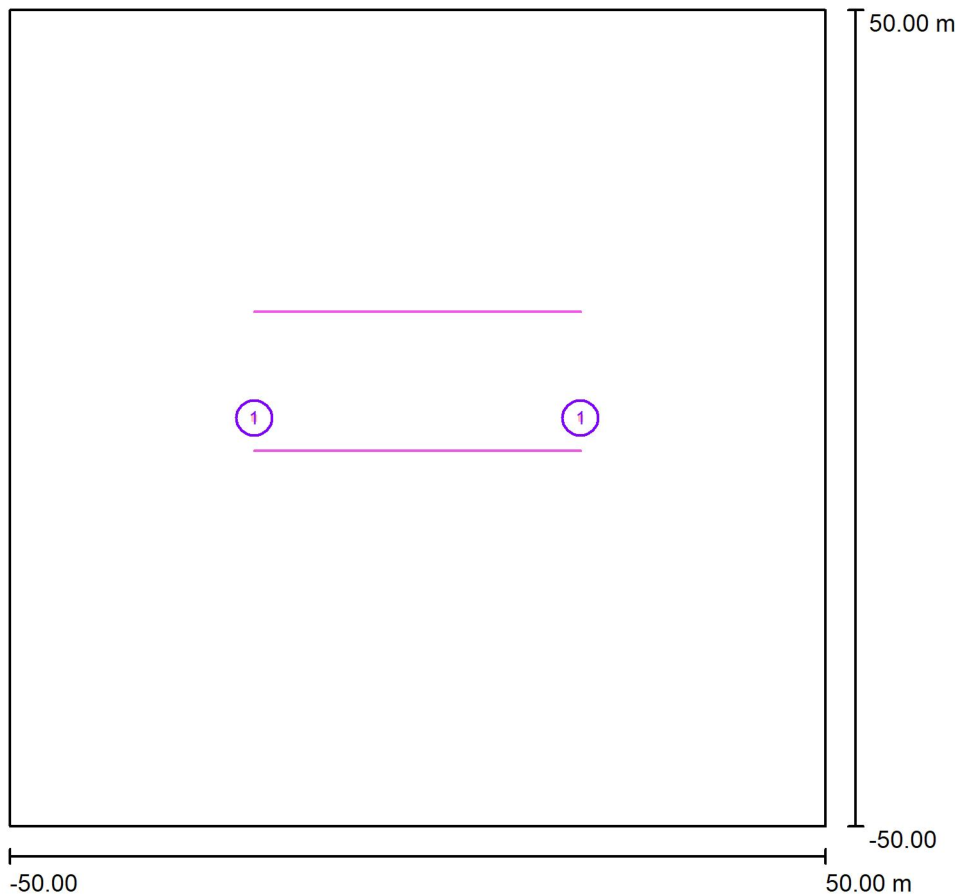
Date: 12.01.2023
Operator:

Operator
Telephone
Fax
e-Mail

Table of contents

Operator
Telephone
Fax
e-Mail

Light Pollution - M4 / Planning data



Light loss factor: 1.00, ULR (Upward Light Ratio): 0.0%

Scale 1:927

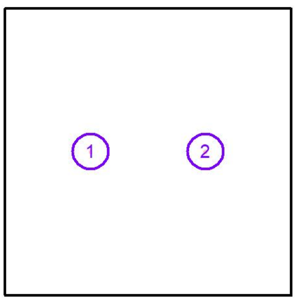
Luminaire Parts List

No.	Pieces	Designation (Correction Factor)		Φ (Luminaire) [lm]		Φ (Lamps) [lm]	P [W]
1	2	SGS102 MR SON-PP CONV (1.000)		7053		10200	114.0
			Total:	14106	Total:	20400	228.0

Light Pollution - M4 / Luminaires (coordinates list)

SGS102 MR SON-PP CONV

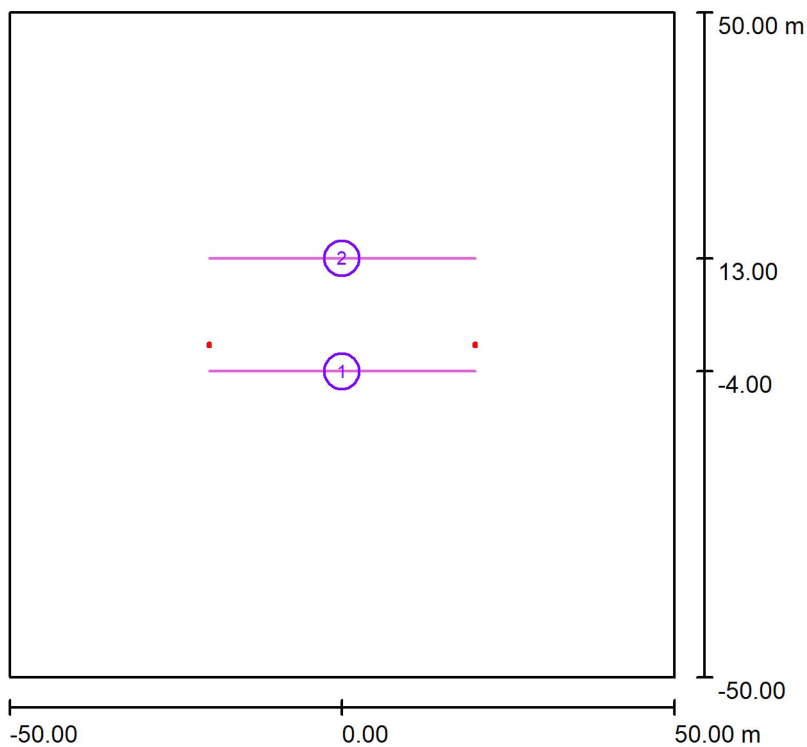
7053 lm, 114.0 W, 1 x 1 x SON-PP100W (Correction Factor 1.000).



No.	Position [m]			Rotation [°]		
	X	Y	Z	X	Y	Z
1	-20.000	0.000	8.107	0.0	0.0	0.0
2	20.000	0.000	8.107	0.0	0.0	0.0

Operator
Telephone
Fax
e-Mail

Light Pollution - M4 / Calculation surfaces (results overview)



Scale 1 : 1138

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Facade behind the light pole	perpendicular	128 x 64	2.99	0.01	20	0.002	0.000
2	Facade in front of the light pole	perpendicular	128 x 32	0.99	0.15	3.89	0.157	0.040

Summary of Results

Type	Quantity	Average [lx]	Min [lx]	Max [lx]	u0	E_{min} / E_{max}
perpendicular	2	1.99	0.01	20	0.00	0.00

Operator
Telephone
Fax
e-Mail

Light Pollution - M4 / Facade behind the light pole / Value Chart (E, Perpendicular)

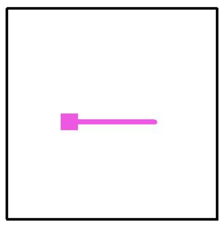
0.96	0.95	0.54	0.26	0.17	0.11	0.09	0.07	0.06	0.07	0.07	0.09	0.13	0.19	0.32	0.59	1.16	0.35
6.93	4.12	1.74	0.82	0.36	0.20	0.14	0.12	0.10	0.10	0.12	0.16	0.23	0.46	1.01	2.18	5.43	7.63
12	9.39	3.67	1.41	0.70	0.45	0.26	0.19	0.18	0.19	0.23	0.35	0.59	1.04	2.26	6.30	12	17
12	10	5.71	2.73	1.04	0.66	0.38	0.29	0.23	0.25	0.34	0.49	0.85	1.99	4.06	8.28	11	17

6.00 m
0.00
0.00
40.00 m

Values in Lux, Scale 1 : 286

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-20.000 m, -4.000 m, 8.000 m)



Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
2.99	0.01	20	0.002	0.000

Operator
Telephone
Fax
e-Mail

Light Pollution - M4 / Facade in front of the light pole / Value Chart (E, Perpendicular)

6.00 m

0.80	0.66	0.59	0.48	0.40	0.31	0.27	0.20	0.18	0.18	0.20	0.25	0.30	0.37	0.45	0.56	0.64	0.77
1.38	1.23	0.94	0.77	0.65	0.50	0.42	0.33	0.30	0.32	0.31	0.39	0.48	0.61	0.73	0.88	1.14	1.36
2.67	2.38	1.76	1.29	0.94	0.71	0.60	0.53	0.49	0.48	0.51	0.56	0.68	0.81	1.19	1.61	2.20	2.64
3.75	3.47	2.90	2.18	1.49	1.21	0.92	0.75	0.69	0.67	0.73	0.83	1.13	1.38	1.98	2.70	3.32	3.71

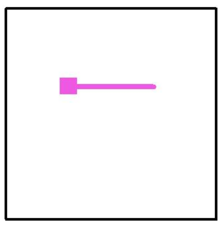
0.00

0.00 — 40.00 m

Values in Lux, Scale 1 : 286

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-20.000 m, 13.000 m, 2.000 m)

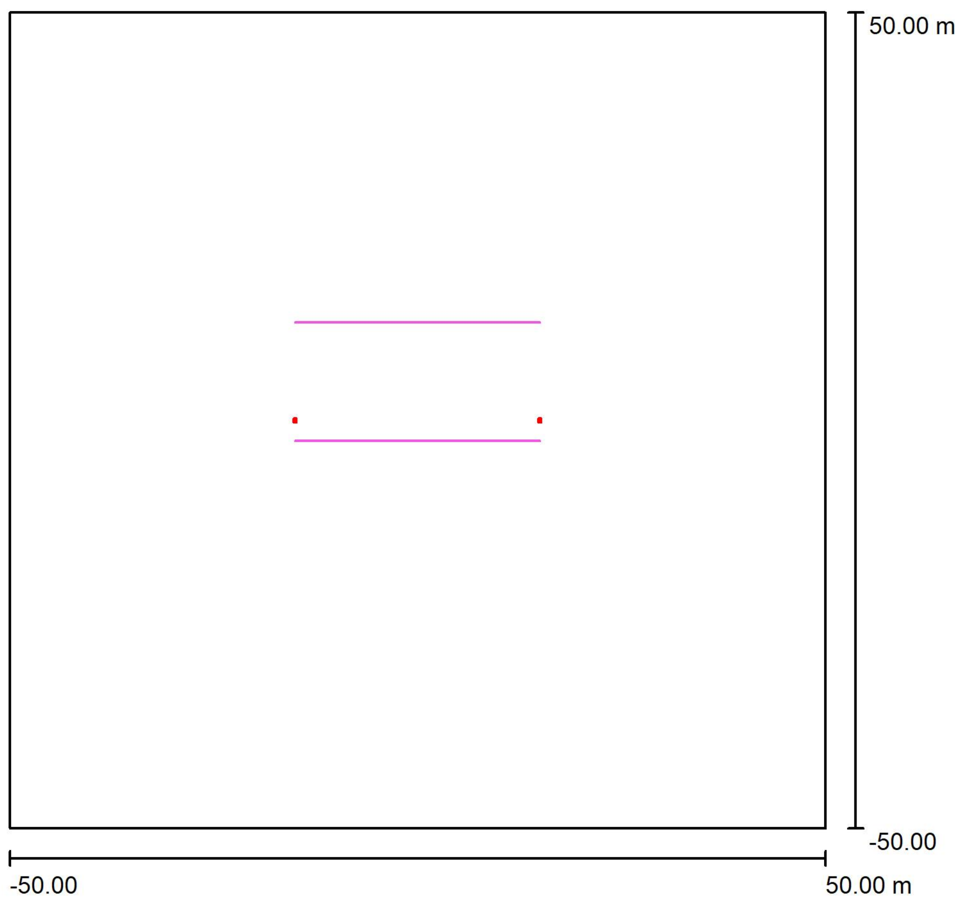


Grid: 128 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.99	0.15	3.89	0.157	0.040

Operator
Telephone
Fax
e-Mail

Light Pollution - M5 / Planning data



Light loss factor: 1.00, ULR (Upward Light Ratio): 0.5%

Scale 1:927

Luminaire Parts List

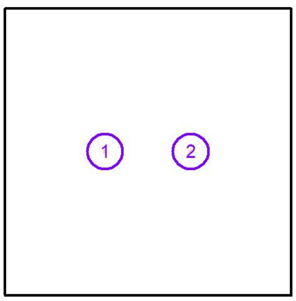
No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	SGS101 MR SON-I CONV (1.000)	3695	5600	80.0
			Total: 7391	Total: 11200	160.0

Operator
Telephone
Fax
e-Mail

Light Pollution - M5 / Luminaires (coordinates list)

SGS101 MR SON-I CONV

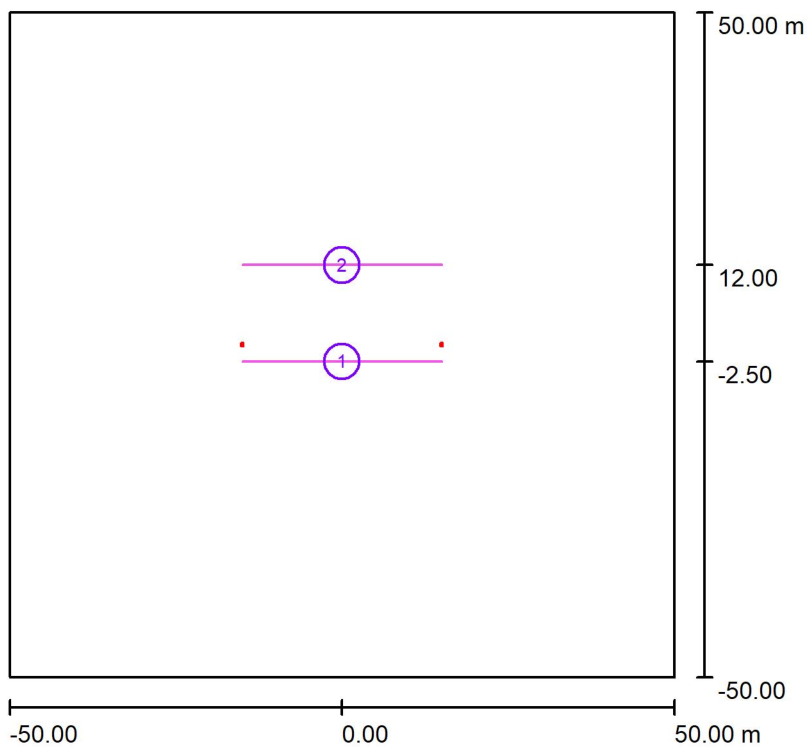
3695 lm, 80.0 W, 1 x 1 x SON-I-70W-CO (Correction Factor 1.000).



No.	Position [m]			Rotation [°]		
	X	Y	Z	X	Y	Z
1	-15.000	0.000	6.103	10.0	0.0	0.0
2	15.000	0.000	6.103	10.0	0.0	0.0

Operator
Telephone
Fax
e-Mail

Light Pollution - M5 / Calculation surfaces (results overview)



Scale 1 : 1138

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Facade behind the light pole	perpendicular	128 x 64	1.21	0.00	13	0.000	0.000
2	Facade in front of the light pole	perpendicular	128 x 64	0.74	0.06	3.25	0.076	0.017

Summary of Results

Type	Quantity	Average [lx]	Min [lx]	Max [lx]	u0	E_{min} / E_{max}
perpendicular	2	0.97	0.00	13	0.00	0.00

Operator
Telephone
Fax
e-Mail

Light Pollution - M5 / Facade behind the light pole / Value Chart (E, Perpendicular)

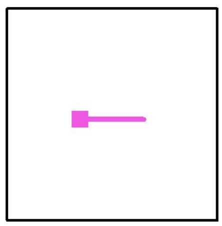
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.55	0.23	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.02	0.03	0.05	0.30	0.66
4.40	3.08	1.20	0.47	0.29	0.10	0.06	0.04	0.04	0.04	0.04	0.07	0.13	0.31	0.60	1.54	3.86	2.93
8.24	5.89	2.36	1.06	0.55	0.33	0.19	0.12	0.10	0.10	0.16	0.24	0.42	0.81	1.57	4.02	7.87	11
10	7.69	3.84	1.75	0.85	0.48	0.28	0.21	0.18	0.19	0.25	0.36	0.64	1.26	2.74	6.04	8.86	13

6.00 m
0.00
0.00
30.00 m

Values in Lux, Scale 1 : 215

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-15.000 m, -2.500 m, 8.000 m)



Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1.21	0.00	13	0.000	0.000

Operator
Telephone
Fax
e-Mail

Light Pollution - M5 / Facade in front of the light pole / Value Chart (E, Perpendicular)

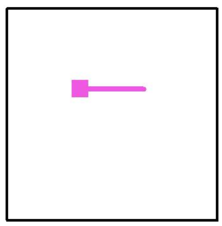
0.37	0.21	0.15	0.14	0.12	0.08	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.11	0.14	0.15	0.17	0.33
0.55	0.39	0.31	0.26	0.20	0.12	0.10	0.11	0.10	0.09	0.11	0.10	0.10	0.18	0.24	0.30	0.35	0.51
0.76	0.62	0.48	0.42	0.36	0.27	0.24	0.22	0.22	0.23	0.22	0.23	0.26	0.35	0.41	0.47	0.52	0.72
1.40	1.17	0.89	0.67	0.54	0.45	0.42	0.39	0.39	0.39	0.39	0.40	0.45	0.52	0.60	0.81	1.09	1.35
2.54	2.23	1.80	1.36	1.01	0.76	0.65	0.60	0.56	0.56	0.58	0.60	0.72	0.94	1.24	1.67	2.12	2.47
3.11	2.86	2.46	2.00	1.54	1.17	0.92	0.74	0.71	0.70	0.72	0.86	1.08	1.43	1.85	2.33	2.75	3.06

6.00 m
0.00
0.00
30.00 m

Values in Lux, Scale 1 : 215

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-15.000 m, 12.000 m, 2.000 m)

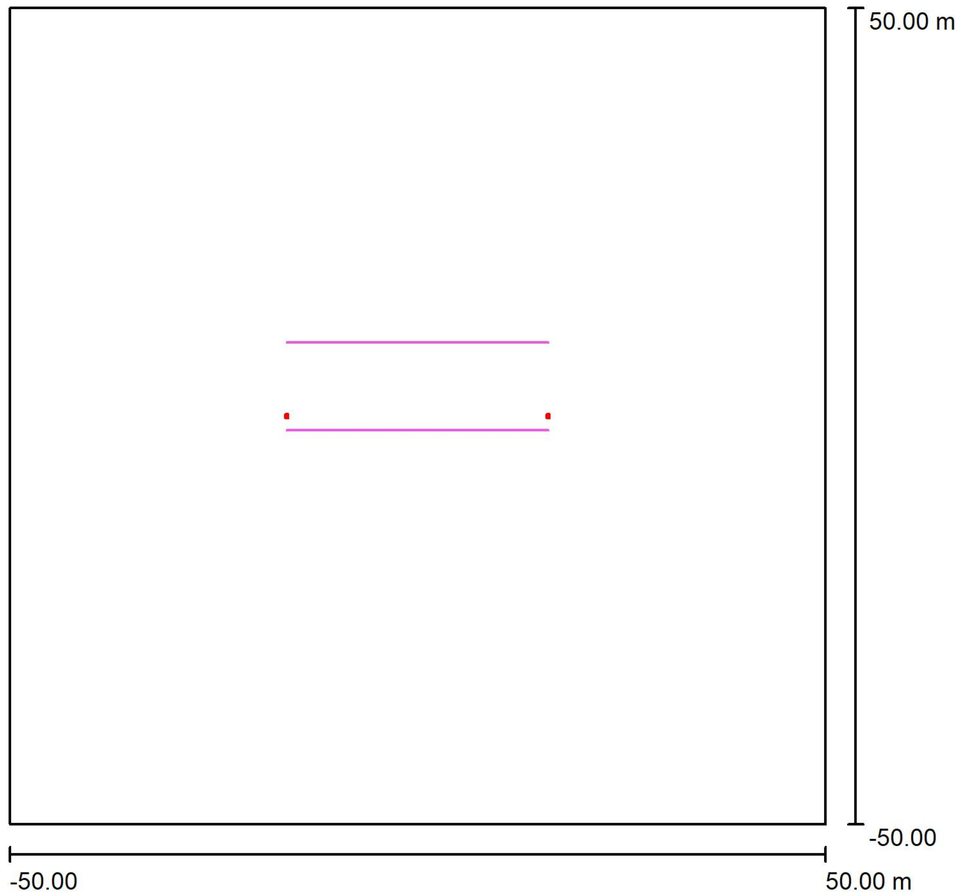


Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.74	0.06	3.25	0.076	0.017

Operator
Telephone
Fax
e-Mail

Light Pollution - M6 / Planning data



Light loss factor: 1.00, ULR (Upward Light Ratio): 0.0%

Scale 1:927

Luminaire Parts List

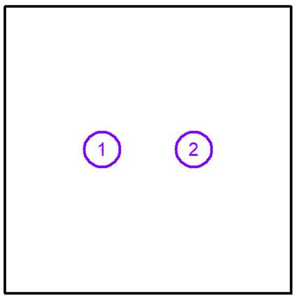
No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	2	SGS101 MR SON-I CONV (1.000)	3695	5600	80.0
			Total: 7391	Total: 11200	160.0

Operator
Telephone
Fax
e-Mail

Light Pollution - M6 / Luminaires (coordinates list)

SGS101 MR SON-I CONV

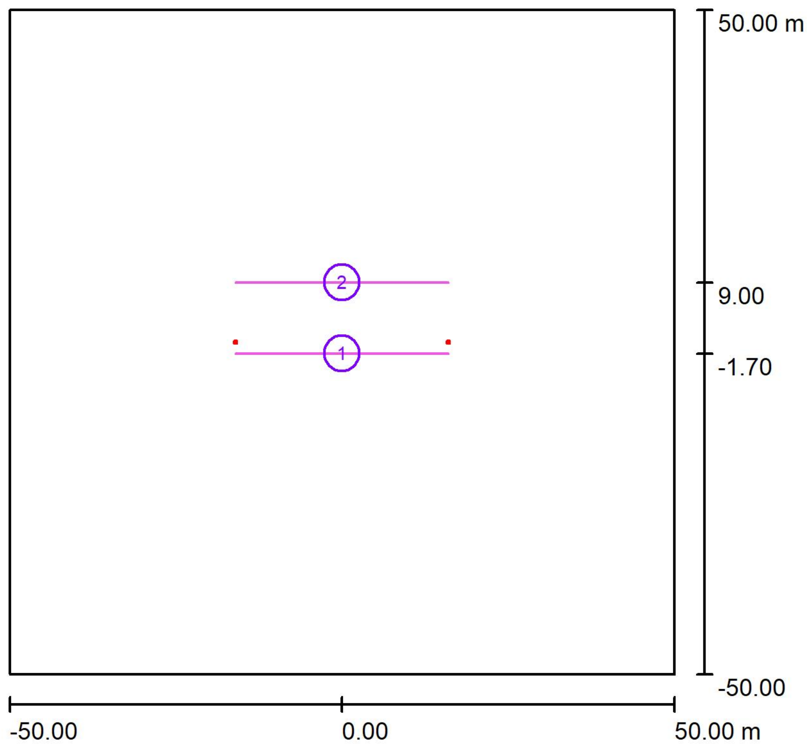
3695 lm, 80.0 W, 1 x 1 x SON-I-70W-CO (Correction Factor 1.000).



No.	Position [m]			Rotation [°]		
	X	Y	Z	X	Y	Z
1	-16.000	0.000	5.603	0.0	0.0	0.0
2	16.000	0.000	5.603	0.0	0.0	0.0

Operator
Telephone
Fax
e-Mail

Light Pollution - M6 / Calculation surfaces (results overview)



Scale 1 : 1138

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Facade behind the light pole	perpendicular	128 x 16	6.11	0.06	48	0.010	0.001
2	Facade in front of the light pole	perpendicular	128 x 64	0.98	0.17	4.08	0.174	0.042

Summary of Results

Type	Quantity	Average [lx]	Min [lx]	Max [lx]	u0	E_{min} / E_{max}
perpendicular	2	3.55	0.06	48	0.02	0.00

Operator
Telephone
Fax
e-Mail

Light Pollution - M6 / Facade behind the light pole / Value Chart (E, Perpendicular)

28	12	3.46	1.20	0.51	0.25	0.13	0.08	0.07	0.06	0.10	0.18	0.37	0.82	2.10	6.84	21	39
19	11	5.35	2.12	0.95	0.48	0.27	0.19	0.16	0.16	0.24	0.37	0.69	1.48	3.58	7.98	15	22

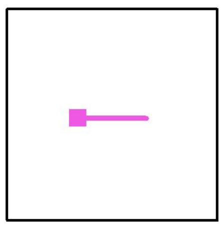
2.00 m
0.00

0.00 — 32.00 m

Values in Lux, Scale 1 : 229

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-16.000 m, -1.700 m, 3.500 m)



Grid: 128 x 16 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.11	0.06	48	0.010	0.001

Operator
Telephone
Fax
e-Mail

Light Pollution - M6 / Facade in front of the light pole / Value Chart (E, Perpendicular)

1.90	1.34	0.94	0.70	0.51	0.41	0.35	0.27	0.24	0.24	0.26	0.33	0.39	0.47	0.64	0.85	1.21	1.76
3.63	2.86	1.95	1.24	0.80	0.62	0.52	0.45	0.42	0.42	0.44	0.49	0.59	0.74	1.08	1.71	2.60	3.45

2.00 m

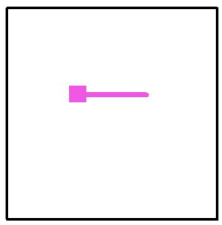
0.00

0.00 32.00 m

Values in Lux, Scale 1 : 229

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-16.000 m, 9.000 m, 1.500 m)

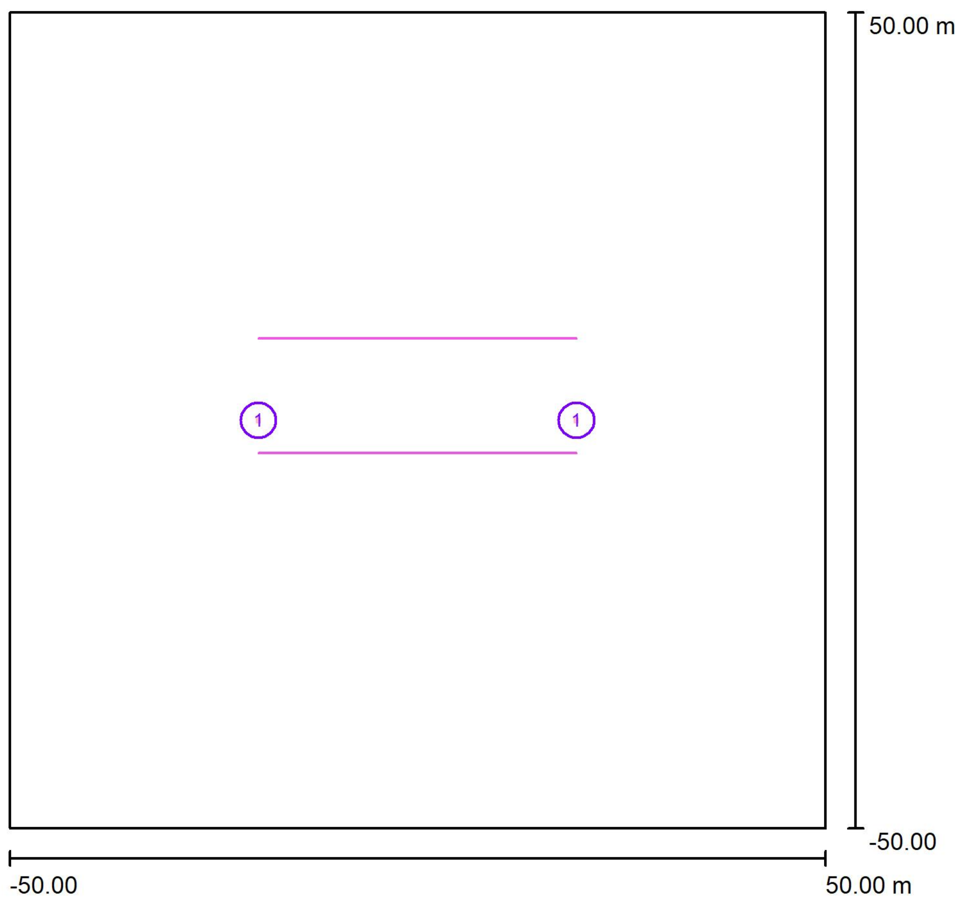


Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.98	0.17	4.08	0.174	0.042

Operator
Telephone
Fax
e-Mail

Light Pollution - P4 / Planning data



Light loss factor: 1.00, ULR (Upward Light Ratio): 0.0%

Scale 1:927

Luminaire Parts List

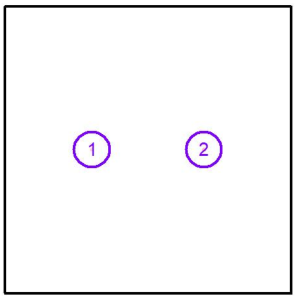
No.	Pieces	Designation (Correction Factor)		Φ (Luminaire) [lm]		Φ (Lamps) [lm]	P [W]
1	2	SGS101 MR SON-I CONV (1.000)		2244		3400	61.0
			Total:	4487	Total:	6800	122.0

Operator
Telephone
Fax
e-Mail

Light Pollution - P4 / Luminaires (coordinates list)

SGS101 MR SON-I CONV

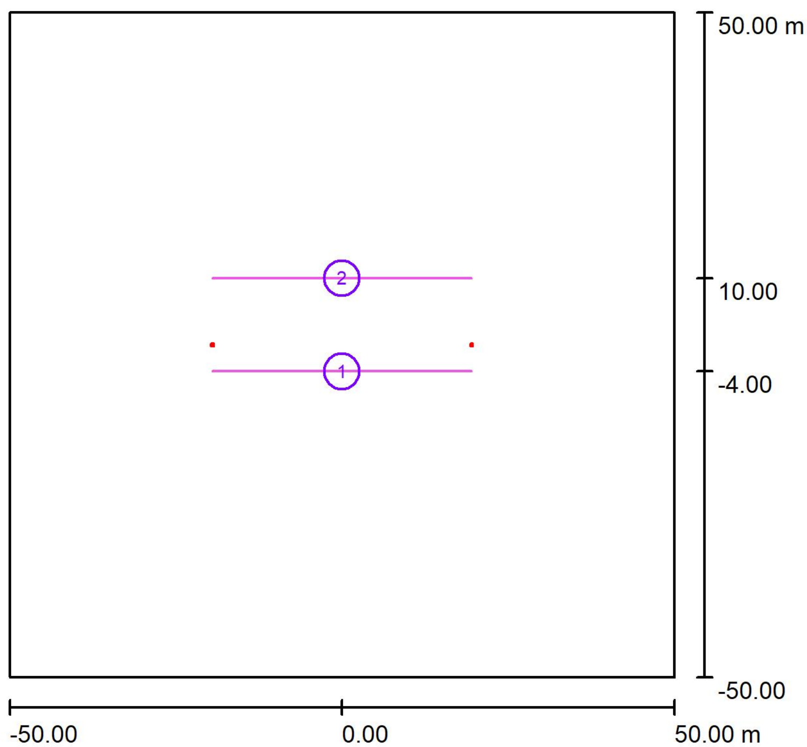
2244 lm, 61.0 W, 1 x 1 x SON-I-50W-CO (Correction Factor 1.000).



No.	Position [m]			Rotation [°]		
	X	Y	Z	X	Y	Z
1	-19.500	0.000	5.103	0.0	0.0	0.0
2	19.500	0.000	5.103	0.0	0.0	0.0

Operator
Telephone
Fax
e-Mail

Light Pollution - P4 / Calculation surfaces (results overview)



Scale 1 : 1138

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Facade behind the light pole	perpendicular	128 x 16	0.69	0.01	5.67	0.013	0.002
2	Facade in front of the light pole	perpendicular	128 x 64	0.17	0.00	1.43	0.006	0.001

Summary of Results

Type	Quantity	Average [lx]	Min [lx]	Max [lx]	u0	E_{min} / E_{max}
perpendicular	2	0.43	0.00	5.67	0.00	0.00

Operator
Telephone
Fax
e-Mail

Light Pollution - P4 / Facade behind the light pole / Value Chart (E, Perpendicular)

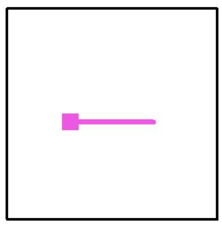
0.45	0.49	0.12	0.08	0.06	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.07	0.09	0.18	0.52	0.26
2.34	1.65	0.71	0.36	0.19	0.10	0.05	0.03	0.03	0.03	0.03	0.07	0.13	0.23	0.43	0.89	1.94	2.40

Height: 0.00 – 4.00 m; Length: 0.00 – 39.00 m

Values in Lux, Scale 1 : 279

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-19.500 m, -4.000 m, 5.000 m)



Grid: 128 x 16 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.69	0.01	5.67	0.013	0.002

Operator
Telephone
Fax
e-Mail

Light Pollution - P4 / Facade in front of the light pole / Value Chart (E, Perpendicular)

0.21	0.10	0.07	0.04	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.04	0.07	0.10	0.17
0.47	0.30	0.24	0.14	0.10	0.09	0.06	0.05	0.05	0.05	0.05	0.05	0.08	0.10	0.11	0.21	0.29	0.41
0.90	0.61	0.42	0.31	0.21	0.16	0.12	0.09	0.07	0.07	0.08	0.11	0.15	0.20	0.28	0.37	0.55	0.82

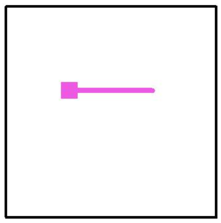
4.00 m
0.00

0.00
39.00 m

Values in Lux, Scale 1 : 279

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-19.500 m, 10.000 m, 1.500 m)

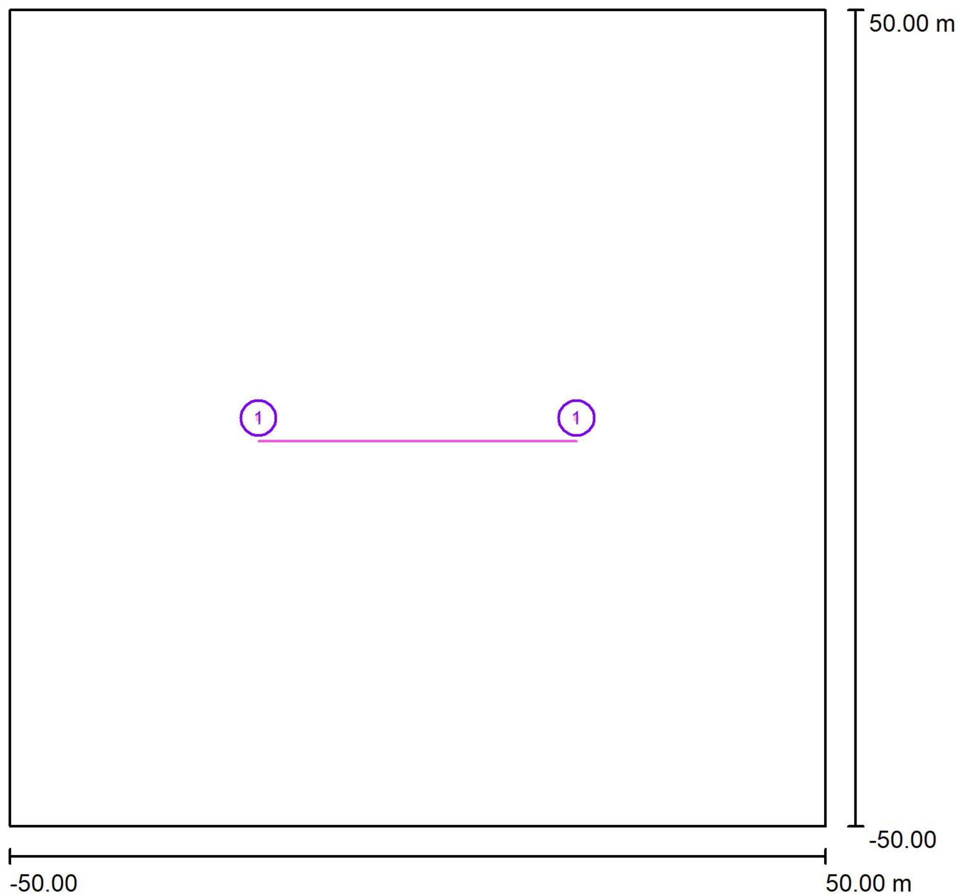


Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
0.17	0.00	1.43	0.006	0.001

Operator
Telephone
Fax
e-Mail

Light Pollution - Sidewalk / Planning data



Light loss factor: 1.00, ULR (Upward Light Ratio): 0.0%

Scale 1:927

Luminaire Parts List

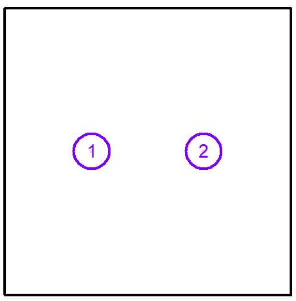
No.	Pieces	Designation (Correction Factor)		Φ (Luminaire) [lm]		Φ (Lamps) [lm]	P [W]
1	2	SGS101 MR SON-I CONV (1.000)		3695		5600	80.0
			Total:	7391	Total:	11200	160.0

Operator
Telephone
Fax
e-Mail

Light Pollution - Sidewalk / Luminaires (coordinates list)

SGS101 MR SON-I CONV

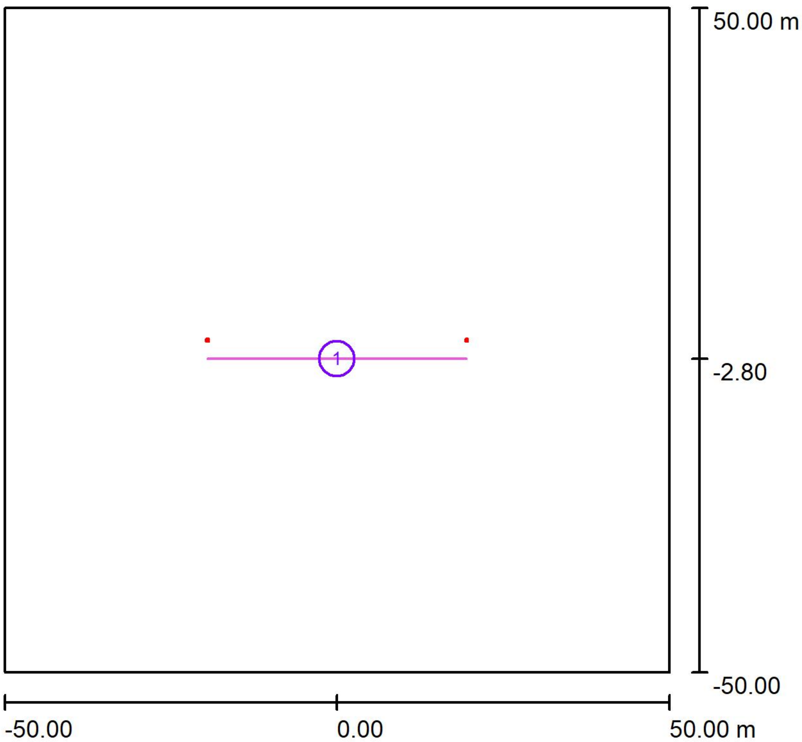
3695 lm, 80.0 W, 1 x 1 x SON-I-70W-CO (Correction Factor 1.000).



No.	Position [m]			Rotation [°]		
	X	Y	Z	X	Y	Z
1	-19.500	0.000	5.603	0.0	0.0	0.0
2	19.500	0.000	5.603	0.0	0.0	0.0

Operator
Telephone
Fax
e-Mail

Light Pollution - Sidewalk / Calculation surfaces (results overview)



Scale 1 : 1138

Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Facade behind the light pole	perpendicular	128 x 16	2.63	0.02	19	0.007	0.001

Operator
Telephone
Fax
e-Mail

Light Pollution - Sidewalk / Facade behind the light pole / Value Chart (E, Perpendicular)

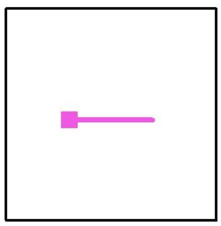
5.78	2.39	0.72	0.27	0.10	0.04	0.03	0.02	0.02	0.02	0.02	0.03	0.05	0.11	0.37	1.05	2.86	5.07
13	5.66	1.77	0.75	0.33	0.20	0.11	0.07	0.06	0.05	0.09	0.14	0.28	0.52	1.13	3.46	10	18

4.00 m
0.00
0.00
39.00 m

Values in Lux, Scale 1 : 279

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point:
(-19.500 m, -2.800 m, 5.000 m)



Grid: 128 x 16 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
2.63	0.02	19	0.007	0.001