Design of a Stand-Alone and Central Solar street-lighting system using MPPT Solar charge controller

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **”Design of a Stand-Alone and Central Solar street-lighting system using MPPT Solar charge controller”** is a bonafide work carried out by **Sayak Halder**, under our supervision and guidance for partial fulfillment of the requirement of **Master of Technology** in **Illumination Technology and Design** in School of Illumination Science, Engineering and Design during the academic session 2021-2022.

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All information in this report has been obtained and presented in accordance with academic rules and ethical conduct.

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Contents

I. Introduction

Light plays an important role in regular human activities which is naturally available from the sun during day time. After sunset artificial lighting is required to carry out human activities. It should be environmentally and functionally suitable for people within the task area. Lighting is the major consumer of electrical energy accounting for 21% of the world's total electricity production. One aspect of using energy efficient lamps is to reduce electrical energy consumption. Also, the power can be generated from renewable energy such as solar, wind and biomass. Power generation from solar offers better energy management.Meeting the energy demand and using the available power in a sensible way is the solution for energy crisis.

The use of LED luminaires help to reduce power consumption. An intelligent LED lighting system automatically adjust the minimum light intensity value to enhance energy efficiency and user satisfaction. As a result there is 21.9% reduction in power consumption [1]. Lighting in educational institution is not only a functional requirement but it also helps in creating an identity and image. Several lighting control algorithms and software techniques are there which pre-visualize the lighting condition. It would help the lighting designers and researchers on the illumination condition for a specified area.

The objective of the thesis is to design a Stand-Alone and Central Solar Street-lighting System for a stretch of road of Jadavpur University Campus. The design should be aesthetically pleasant, visually comfortable and consume less power so that there is a good balance between power generation and power consumption. A stretch of a road is created along with LED lighting system in DIALux and a hardware design is also proposed which is to be implemented with the help of MPPT Solar Charge Controller. LED is used here because the rated lifetime of the lamp ranges from 35000 - 50000 hours. The LED lamp used in this project is obtained from Surya plug in module The rest of the thesis is organized as follows:

1. **Chapter 1:** It describes the basic of Solar Radiation and Sun Tracking.

2. **Chapter 2:** A brief overview on Solar Cell and Solar Panel

3. **Chapter 3:** Lighting Design for a stretch of road at Jadavpur University.

4. **Chapter 4:** It gives information about the selection and estimation of solar panel and battery for Stand-Alone Solar Street-lighting System

5. **Chapter 5:** It gives information about the selection and estimation of solar panel and battery for Central Solar Street-lighting System

6. **Chapter 6:** A brief analysis and scope for future work

II. Literature Review: National and International Research Work

The twenty-first century has became the perfect energy storm. Rising energy prices, reduction in energy availability and security, and increasing environmental concerns gradually changing the global energy perspective. Industrialized societies have become increasingly dependent on fossil fuels for multitude uses. Solar offers least-cost power option in places where access of electrical grid is not possible such as remote rural areas, developing nations. Photo-voltaic provide constructive solutions to power supply problems in both space and remote terrestrial applications. For large power application, portable electronic devices can be charged with the help of solar cell. The major advantage of solar energy over conventional power generators is that the daylight can be converted into solar energy with the help of photo-voltaic solar cells.

According to the paper ”Solar LED street-light using motion sensor and single axis control”[P.P. Desai, V.H. Atodaria, A.P. Parmar] it tells about the concept of energy harnessing and utilizing it in the best possible way. The paper inform about innovative application for optimizing the consumed power using different electronic components such as charge controller and sensors. Passive infrared (PIR) sensor is used for the activation of LED street-light only when an object is approaching the peripheral of street light thereby saving energy during night time as well as absorb energy during day-time, leading to increase the utilization time of street light. Street light use single axis tracker which tracks the path of the sun, for a given elevation angle, absorb maximum energy from the sun through solar panel to the battery. The advantage of the mentioned procedure includes low cost, easy to use, low maintenance, low power consumption. Also the above technique can also be used in home appliances for example to switch on-off the house-lighting system, fans, lights, etc. Implement of solar panel system have an added advantage to the subjected module because of its cost effectiveness and proper return on investment.

According to the paper ”Fossil fuel to Solar Power: A Sustainable Technical Design for Street Lighting in Fugar City, Nigeria”[2] A study was done on replacing fossil fuel energy with solar energy for lighting the dark and gloomy street of Fugar City, Nigeria. There are no street lights installed in Fugar City, every household use fossil energy to illuminate the street. In order to achieve a sustainable solution for lighting up 210 LED Street lights, four proposed solutions were analyzed based on their technical feasibility, environmental parameters like $C0_2$ emission analysis and cost analysis with simple payback periods. On-site solar photo-voltaic is the most proposed solutions in terms of technical and financial feasibility with approximately negligible emissions leading to sustainability.

Diesel generators are technically suitable in any location. These generators provide constant output while working. In Nigeria grid electricity is quite unstable due to huge power outages. It leads to breakdown of the lighting system because of low current and continuous flickering. Solar energy is the most feasible solution in this type of situation. When sun shines, solar energy is harvested more effectively using PV modules and power electronic conversion techniques.

Today world is eyeing for efficient technologies with negligible levels of emissions. In the above study all the proposed result were, analyzed on the basis of CO_2 emissions. CO_2 emission for grid electricity is the product of emission factor for grid electricity to the amount of energy consumed in kWh. The emission factor for grid electricity in Nigeria is 0.43 kg$C0_2$/kWh. Hence the amount of $C0_2$ emission released into the atmosphere for 302.4 kWh of energy per day is around 132.94 kg CO_2 and on annual basis 47858.4 kg$C0_2$/year. In solar energy the amount of $C0_2$ emission released is almost negligible. Therefore, Solar Photo-voltaic system is the most environment friendly solution.

In a similar study K. Karakoulidis et al. (2011), HOMER[3] based hybrid energy utilization concept applied in Kavala town, Greece with combination of PV, Diesel, Battery and Fuel cells and proposed the use of alternative energy system.

III. Problem Identification

This paper is a road-map to guide the decision making process as Jadavpur University transitions to more energy efficient lighting technology. Jadavpur University relies on conventional light sources which has evolved with the built environment overtime. As a result, university campus is illuminated in a way that feels unintentional and ineffective. The university faces challenges in determining how new lighting technology can be implemented to support energy goals as well as making a cost effective smart campus automation system.

IV. Objectives

1. To make Jadavpur University Campus, an energy efficient lighting system
2. By replacing fossil fuel generated energy by Solar energy with SPV based power supply system.

V. Steps of Execution

For making Jadavpur University an energy efficient lighting system with the help of solar panel, charge controller, battery and LED following steps have been executed.

1. Survey on a stretch of road of University campus.
2. Design the stretch of a road of Jadavpur University Campus in DIALux.
3. Design of SPV based power supply system and Single Line Diagram
   (a) Stand-alone

   (b) Central
4. For implementing the design in hardware following steps need to be carried out:
   (a) Selection and estimation of Solar Panel

   (b) Selection and estimation of battery

   (c) Selection of Charge controller

Chapter 1

Solar Radiation and Sun Tracking

1.1 The Sun

The sun which is considered as an average star is a member of spectral type dG2. A gaseous globe with a radius of 7.0*10^5 km and mass of about 2.0*10^{30} kg. It is greater than the earth's mass by a factor of about 330,000. The total rate of energy output from the sun is 3.80*10^{33} ergs/s (3.80*10^{23} kW). At a mean distance of 1.496*10^8 km from the sun, the earth intercepts about 1 part in 2 billion of the above energy.

Most of the energy produced in the fusion furnace of the sun is transmitted radially as electromagnetic radiation, popularly known as Solar energy. The sun radiates at an effective surface temperature of about 5800 K. The electromagnetic spectrum, consist of all the energy radiated by the sun, extends from gamma rays with wavelength of only 10^{-11} cm to radio waves 10^5 cm and longer. The optical spectrum is divided into ultraviolet, visible, and infrared radiation. More than 99% of solar radiation lies within the optical range of 0.276 to 4.96μm. Relatively a small amount of energy reaches earth through the process of conduction. Solar storms in the lower atmosphere of the sun also release streams of energetic particles directly from the photosphere into the atmosphere of the earth. In the vicinity of the Earth, the sun's atmosphere has a density from 100 to 400 protons/cm^3. Although the gas is very thin, it is much denser than the 0.7 hydrogen atoms/cm^3 of interstellar space[4].

The sun emits a plasma of electrically charged particles, consisting of 91.3% protons and 8.7% ionized helium atoms. The plasma reaches the earth and its particles which carry sun's magnetic field interact with the atmosphere and the earth's magnetic field.

1.2 Biosphere

The region of the atmosphere in which the general circulation of the air and local wind cause continuous mixing of the gaseous components is called homosphere. The region extends up to about 100 km. It is made up of the following constituents by volume:

1. Molecular Nitrogen, N_2 = 78.08%
2. Oxygen, O_2 = 20.95%
3. Argon, A = 0.93%

The above percentages are for dry air, since moisture content in the atmosphere varies from 0.1 to 2.8% by volume. Carbon dioxide amounts to 0.0033%, carbon monoxide, sulpher dioxide, nitric oxide, nitrogen dioxide, water vapor, ozone, helium, hydrogen, dust, and a variety of aerosols are the remaining constituents. Solar radiation reaching the earth's outer atmosphere is reflected back into the space with the help of the above constituents. The energy received by the earth reradiates mostly in the infrared, atmospheric constituents absorb much of this energy in the greenhouse effect.

The predominant form of energy in the universe is gravitational. Gravitational energy has no entropy nor has the energy of rotation or orbital motion. Entropy varies as inverse ratio to the temperature associated with an energy form. Sunlight has an entropy of unity. Solar energy can be used in a variety of ways, it is constantly degraded in quality as its entropy increases. For example, chemical reactions proceed with an entropy from 1 to 10, terrestrial waste heat ranges from 10 to 100.

The earth's biosphere receives energy naturally from three sources:

1. intercepted solar radiation
2. thermal energy from the earth's interior produced largely by the decay of radioactive matter in the crust.
3. tidal energy resulting from the interaction between the oceans and the rotation of the earth.

Solar radiation received at the top of the earth's atmosphere is about 170 trillion kW. Heat from inside the earth amounts to about 32 billion kW. Tidal sources contribute only about 3 billion kW.

1. solar radiation = 99.98%
2. Internal Heat = 0.018%
3. Tidal energy = 0.002%

Solar radiation amounts to nearly 5000 times as much as other natural energy inputs combined. The colossal fusion furnace of the sun pours out enormous quantities of electromagnetic radiation, resulting from the fusion of 140 trillion tons of its own mass each year. Each second, 4 million tons of hydrogen is converted to helium, and by product radiation amounting to a continuous $3.8*10^{23}$ kW is emitted. Of the Solar radiation received at the outer atmosphere of the earth, out of which 30% is reflected back into the space as short-wave radiation, additional 47% is absorbed by the atmosphere, the land surface, and oceans. It is converted to heat as the ambient surface temperature of the planet. The remaining 23% drives the evaporation, convection, and precipitation phases of the hydro-logic cycle.

1.3 Use of Solar energy

The sun's radiation at the top of the earth's atmosphere is only about 1.4 kW/m^2. After passing through the atmosphere, solar radiation amounts to about 80 trillion kW globally. A square meter on earth's surface normal to the sun can receive as much as 1 kW of solar radiative power, averaging about half during all the hours of daylight. It has been estimated that 65 hectares of land receives solar energy equivalent to that of an oil producing 2500 bbl of crude oil daily. About 5,000 trillion kWh per year energy is incident over India's land area receiving 4-7 kWh/m^2 per day.

1.4 The Spectral Distribution of Solar Radiation

The power generated by a solar cell is proportional to its area. The irradiance of the sun at equator level is about 1 kW/m^2 at 90°, so a 1 cm^2 solar cell may receive 10 mW. This irradiated power is not distributed equally for the different wavelengths as shown in the figure.

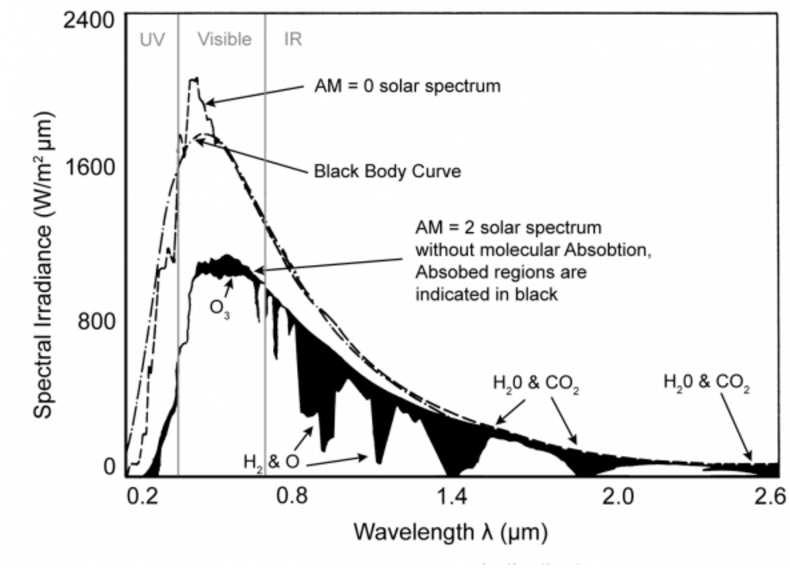

Figure 1.1: Solar spectrum

The solar spectrum shows a maximum intensity at the wavelength λ = 0.5 μm, this intensity falls to half at λ = 1 μm. The absorption spectrum of a semiconductor depends on the band gap. If the band gap is higher than the energy of the incident photon, there will be no transmission of an electron from the valence band to the conduction band. If the energy of the photon is higher than the band gap an electron will be transferred from the valence band to the conduction band, and rest of the energy will be released in the form of heat.

The atmosphere lessened the sun's radiations before it reaches the earth surface, mainly because of the absorption of infrared by water vapor and in the ultraviolet by the ozone layer. The air mass is the level at which the atmosphere affects the sunlight received at the Earth's surface. Lower the air mass, less will be the influence of the atmosphere.

1.5 Tracking Of The Sun

The amount of radiation collected by a solar collector is measured by a tracker which follow the sun throughout the day. The tracking mechanism consist of electric motors, light sensors, gear box, and electronic control for accurate focusing. For small household application a collector is used instead of sun tracking. It is normally mounted at a fixed optimal angle for the whole year. Sun tracking is desirable for relatively large PV systems in order to collect more than 30% extra energy from the same collector.

Two types of tracking are possible:

1. Single-axis tracking

2. Two-axis tracking

In single-axis tracking the collector is rotated on a single-axis only, while in case of two-axis tracking the collector is rotated along two axes. For accurate measurement, two-axis tracking is required as solar azimuth angle as well as solar altitude of the sun varies all the time. In the sun tracking arrangement, minimize sun's incidence angle θ on the collector surface to ensure beam radiation falls perpendicular on the collector surface[5].

1.6 Two-axis Tracking

In two-axis tracking as the collector is rotated at two axes, the sun's incidence angle is always zero ($\theta = 0$). It implies that

$$\cos\theta = 1 \text{ and } \beta = \theta_z$$

1.7 Single-axis Tracking

In single-axis tracking, solar collector is rotated along one of the axes. There are various methods of rotating a collector around single-axis:

1. Rotating around vertical axis with movement along east-west direction.
2. Rotating around horizontal east-west axis with movement along north-south direction.
3. Rotating around horizontal north-south axis with movement along east-west direction.
4. Rotating around the inclined north-south axis with movement along east-west direction

The tracking mechanisms are designed in such a way that maximum beam radiation for a given period can be achieved.

1.8 Vertical Axis or Azimuth Tracking

Solar collector is rotated around the vertical axis or the zenith axis as shown in the figure. The

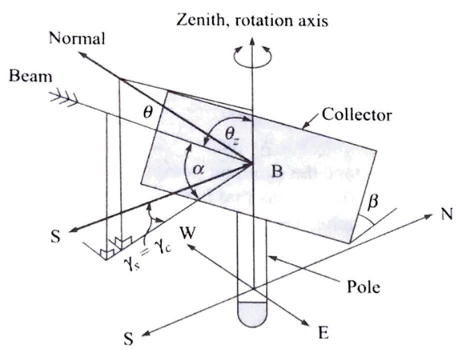

Figure 1.2: Schematic Representation of Vertical Axis Tracking Mechanism

movement of the collector surface is made in the east-west direction. As the movement of the surface and azimuth angle variation is similar, it is also called azimuth tracking. Also the sun's azimuth angle γ_s and the surface azimuth angle γ_c will be equal. The azimuth angle is defined as the angle of a line which represents projection of the sun rays and collector normal with the true south direction in a horizontal plane. Here the collector surface is inclined at an β. Therefore,

$$\cos\theta = \cos(\theta_z - \beta)$$

where θ_z can be derived from the equation given below

$$\cos\theta = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega = \cos\theta$$

The optimal angle β is determined for the maximum daily solar radiation. The collector is installed perpendicularly such that the collector and the sun are in the same line.

$$\beta = \phi - \delta \text{ or } \beta_a = \phi - \delta_a$$

In the above equation 'a' refers to the average value of the parameters over a given time. If average over a year is considered then $\delta_a = 0$. So average collector inclination, $\beta_a = \phi$

Chapter 2

An Overview on Solar Cell and Solar Panel

2.1 Structure of a Solar Cell

A solar cell is made of thin film or semiconductor wafer. Thin film solar cells are made of organic or inorganic materials. Inorganic solar cells are made of p-n junction. Most widely used inorganic solar cells are made of Silicon. The silicon wafer is doped p- on the bottom side and n- on the top layer, the two region formed an interface to develop a p-n junction. In isolation a P-type semiconductor has large number of holes as compared to the electrons and an N-type semiconductor has large number of electrons as compared to holes. As electrons and holes have different carrier concentration, when two material comes in contact with each other electrons will migrate from the N-layer to the P-side and diffusion of holes take place from P-side to N-layer. As holes diffuse from P-side to N-layer, a fixed negative charge in the form of ionized acceptor impurity atom leaves behind after donating a positively charged hole. Similarly, electrons diffuse from N-layer to P-side and a fixed positive charge in the form of ionized donor impurities is left behind.

In this way a layer of positive charges and negative charges appear when P-N junction forms. The charged region in a P-N junction is known as depletion region. Due to the separation of positive and negative charges electric field exist oriented from N-side to P-side. The presence of electric field causes drift current to flow.

The top of the solar cell(n) is of low potential and the bottom(p) of high potential when the cell is exposed to light. The N-layer is made thin to let light penetrate to the junction level. It is absorbed in the form of a photon and energy splits into an electron and a hole. So absorption of a photon leads to transfer of an electron from valence band to conduction band. It occurs when energy of the incident photon is greater than the band gap energy.

Higher the number of photons reaches the p-n junction the more electron-hole pair will be generated leads to higher photo-current. Amplitude of the electric current generated by the absorption of photon in a solar cell of a given size at any given temperature is controlled by the incident light in the following ways:

1. The intensity of the incident light
2. The wavelength of the incident light in correspondence with the semiconductor band gap.

In practical scenario, a solar cell will have the wafer with the p-n junction between front and back ohmic contacts to collect the current and a front anti-reflection coating to limit the losses due to reflection of light. The front contact to collect the current being metallic will be reflective. Thus it is necessary to find a good compromise in the design in order to minimize light reflection. It is made of electrodes designed in fine lines generally called stripes and fingers. The complete structure of a wafer-based solar cell is shown in the figure.

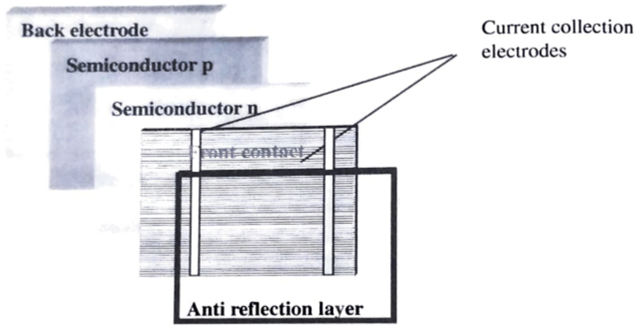

Figure 2.1: Basic Structure of a Photovoltaic solar cell

Monocrystalline and polycrystalline silicon wafer-based solar cells are also shown below

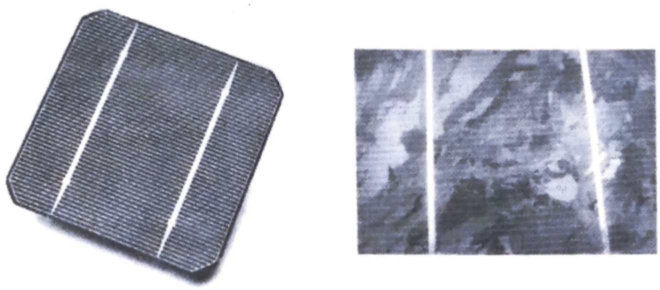

Figure 2.2: Examples of Silicon-based photovoltaic solar cells

Short-circuit current is measured when no load is connected to the cell. It is a characteristic of a solar cell with a perpendicular solar irradiation of 1000 W/m^2 at a temperature of 25°C. Similarly open circuit voltage of a solar cell is measured when no load is connected to the solar cell. Open circuit voltage depends on the material of the solar cell. For Silicon open circuit voltage is 0.55 V.

2.2 Characteristic of Photovoltaic Solar cell

Various Industries around the world are working with the objective of producing lower cost and higher conversion efficiency solar cells. The semiconductor used in the fabrication of solar cells have different band gaps which gives different spectral response to incident light. According to the wavelength of the absorbed photons it display sensitivity. Each semiconductor has threshold energy, band gap energy where absorption of photon leads to transfer of electrons from valence band to the conduction band.

There will be no photovoltaic effect when energy drops below threshold. The photovoltaic effect is related to the wavelength rather than light intensity. The rate of photoelectric emission in the photovoltaic structure proportionally increased with increasing light intensity. The light absorbed by a solar cell is a combination of direct solar radiation and diffused light reflected from the surrounding surfaces. An anti-reflective material is present in solar cell which limit light reflection from the surface and absorb maximum amount of solar radiation.

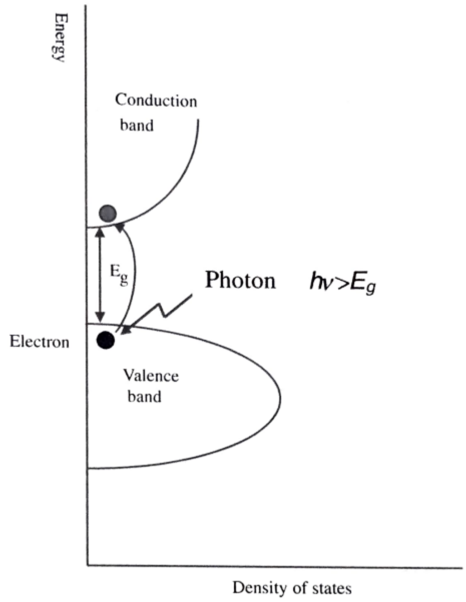

Figure 2.3: Basic Energy Band Diagram of a Semiconductor

Photovoltaic cells can be arranged in a series configuration to form a module. The modules can be connected in parallel or series configurations to form arrays. When cells or modules are connected in series it must have same current rating to produce additive voltage output. Also modules have same voltage rating when cells are connected in parallel to produce large currents.

2.3 Types of Solar Cells

2.3.1 Thin Film Solar Cells

Thin film solar cells are made of organic and inorganic semiconductors with a polycrystalline or amorphous structure and deposited on electrically active or passive substrates such as metal, glass or plastic. Thin film solar cell can be fabricated by techniques such as vapor deposition, plasma deposition and plating or screen printing. Because of lower cost it can also be made on flexible substrates which can cover applications unreachable with wafer based solar cells. The main materials used to make thin film based solar cells are:

1. Amorphous silicon
2. Copper indium selenide (CuInSe_2 or CIS) or with gallium for higher efficiency (CuInGSe_2 or CIGS)
3. Cadmium Telluride (CdTe) and Cadmium Selenide (CdS)

The drawback of the film solar cells is their low efficiency, generally under 10% for inorganic thin films and about 5% for organic solar cells. It also faces problems of long-term instability which effect their efficiency. A rollable solar panel made of thin film on a flexible substrate is shown below.

Figure 2.4: Rollable thin film solar panel

2.3.2 Organic Solar Cells

Organic solar cells are made of thin films of carbon-based materials called organic materials with thickness in the range of 10-100 nm. These materials show a p-type or n-type semiconductor behavior. They are made of polymers or small molecules. Polymer solar cells can be fabricated using technique of spin coating or ink-jet printing from a solution where as small molecule solar cells are generally made by vacuum evaporation. A third type classified organic solar cells based on titanium dioxide called dye-sensitized solar cells. Organic solar cells are fabricated on various substrates including flexible substrates such as plastics which gives them numerous application.

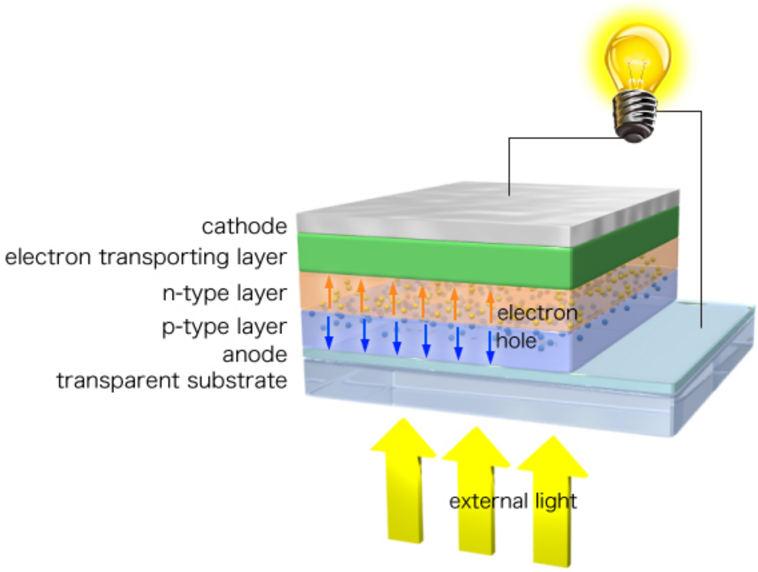

Figure 2.5: Basic Structure Of an Organic Solar Cell

Organic solar cells initially was homo junction, their efficiency is very low. In the mid 1980s hetero junction solar cells were introduced. It is based on small molecules which allow 1% of efficiency. The active part of this solar cells is a bi-layer with an electron donor layer as PPV or CuPc so that light is absorbed and the electrons are generated before being transferred to the acceptor layer.

In the above case the active part of the solar cell, homo or hetero-junction is wedged between two conductive electrodes with different work functions. A transparent front electrode and a metallic electrode as a back contact is used. The efficiency of organic solar cells were improved by adding adjacent materials to the photo-active part such as an electron transport layer and a hole transport layer in order to transmit the photo-generated carriers to the electrodes more efficiently.

The representation of electric conduction in organic materials is different from that of inorganic semiconductors. In organic materials the concept of valence and conduction band is replaced with that of Highest Occupied Molecular Orbital (HOMO) and Lowest Unoccupied Molecular Orbital (LUMO). In the inorganic semiconductors there is an energy gap between HOMO and LUMO. If a photon of sufficient energy is absorbed, an electron will transfer from HOMO to LUMO level leaving a hole in the HOMO.

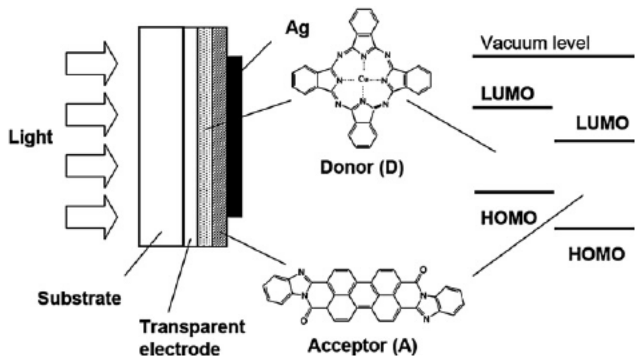

Figure 2.6: Cross-section of bilayer organic solar cells

The fundamental difference in the principles of operation between organic and inorganic solar cells lies in the separation of carriers of the absorption of a photon. In inorganic solar cells such as wafer or thin-film based solar cells there is a p-n junction with built-in electric field which will split the electron and the hole and accelerate them in the opposite direction. In organic solar cells there is no built-in electric field to separate the generated pair of electron and hole. Electron-hole pair needs to diffuse before arriving at the interface in case of hetero-junction solar cells.

2.4 Solar Panel

A photovoltaic solar panel or module is a big solar cell assembled in series or parallel with larger voltage and current output. The connected solar cells are laminated with Ethylene Vinyl Acetate between glass in the front and a tedlar sheet at the back before framed with aluminum. When individual solar cells are chosen and connected in series the resulting solar panel has the same short circuit current as the individual cells and a voltage equal to the sum of their individual voltages. Power generated by a solar cell depends on its efficiency. It is in the range of 10 mW/cm^2 to 25 mW/cm^2 which corresponds to 10% to 25% cell efficiency. The maximum area of a single wafer based solar cell is 225 cm^2. The peak power generated would be 3.37 W_p. For terrestrial applications such as home lighting, water pumping the power generated by a single solar cell is not enough so solar cells are connected together in order to have large power output. In the first level of interconnection, cells are connected in the form of a solar PV module. Solar PV modules are available with a power rating ranging from 3 W_p to 300 W_p. In the second level of interconnection solar PV modules are connected together in the form of an array. Solar PV array has power ranging from few hundred watts to several megawatts.

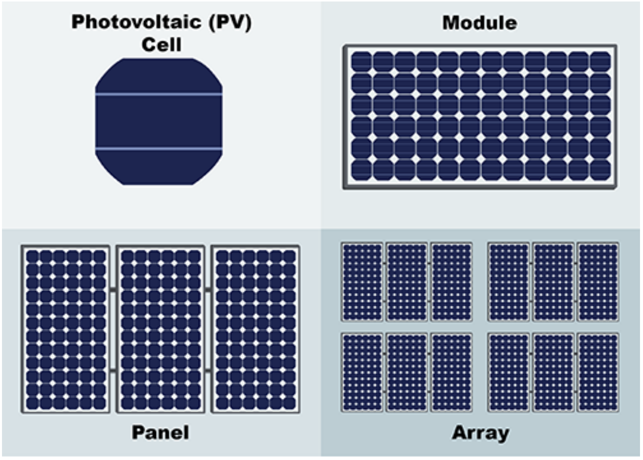

Figure 2.7: Interconnection of Solar cells to Solar PV modules and modules into Solar PV array

2.4.1 Size of the Solar Panel

For Standard solar panels there are two common configuration:

1. 60-cell
2. 72-cell

An individual solar cell has a dimension of 6”*6” square. A 60-cell panel is laid out in a 6*10 grid and 72-cell is laid out in a 6*12 grid.

1. 60-cell panels: 3.25 feet*5.5 feet
2. 72-cell panels: 3.25 feet*6.42 feet

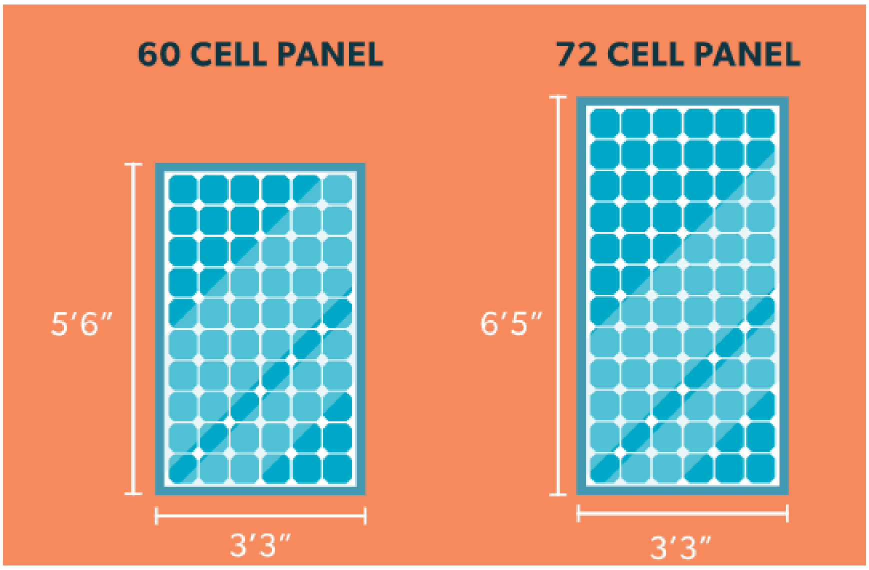

Figure 2.8: Dimension of Solar Panel

2.4.2 Orientation of Solar Panel

In order to produce maximum electricity solar panel needs to be oriented perpendicular to solar rays. At the equator level the sun's radiation strike the ground perpendicularly so solar panel is installed parallel to the ground. At other latitudes, the sun's radiation strike the ground horizontally with an angle equal in average to the latitude of the location. Therefore to receive solar radiation perpendicular to the panel, solar panel should be oriented at an inclination angle which is equal to the latitude of the location towards the north in the southern hemisphere and towards the south in the northern hemisphere.

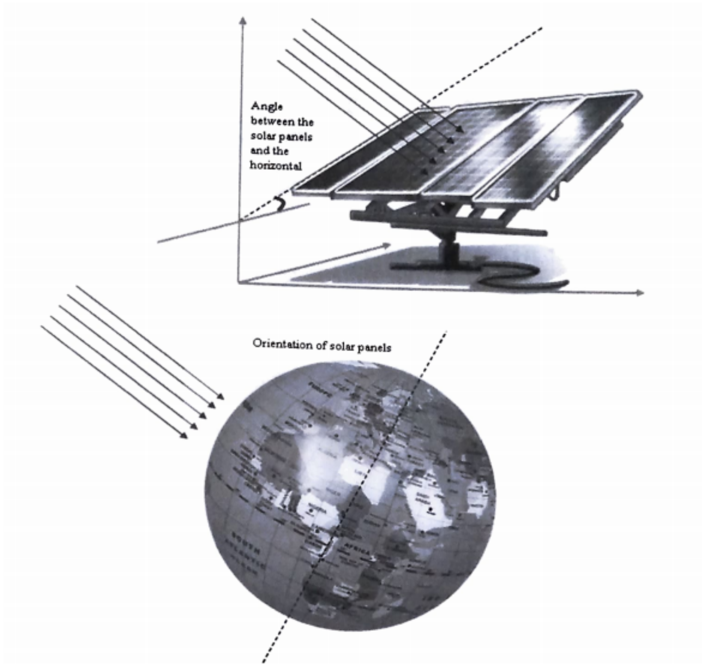

Figure 2.9: Orientation of a Solar Panel

The most optimal tilt angle for installing the PV panel is calculated for all the months in a year by taking the mean monthly solar radiation values for Kolkata located at 22.56° N. The most optimum value of the tilt angle is expressed as

$$\beta_{opt} = \tan^{-1}[\frac{2S_{nh}\cot\alpha}{2S_{nh} + D_{nh} - \rho R_{nh}}] \tag{2.1}$$

where, S_{nh} = Mean direct insolation on a horizontal plane.
R_{nh} = mean global insolation on a horizontal plane.
D_{nh} = mean diffuse insolation on a horizontal plane.
ρ = ground reflectance ratio (≈ 0.2).

The altitude angle is represented as α and expressed as:

$$\alpha = 90° - \phi \pm \delta \tag{2.2}$$

where ϕ is the latitude angle (for Kolkata = 22.56°N) and

$$\delta = 23.45° \sin[\frac{360(n-80)}{365}] \tag{2.3}$$

where n represents the number of days from the beginning of the year (for 3rd April consider n = 93)

A considerable amount of solar energy is received when solar PV panels are tilted at an angle equal to the latitude angle of the location (kolkata). An increase in the tilt angle by 15°in winter months and decrease by 15°in summer months improve the amount of solar energy received on the panel.

2.4.3 Maximum Power Point Tracking

The power delivered by the panel is dependent on the irradiance, temperature, and shadowing conditions thrust upon it, voltage and current depend on these dynamic changes conditions. The maximum power point can be defined using the specific coordinates of the voltage and current value associated with the maximum power output of the PV panel as shown in the PV panel's I-V curve. The point where the product of the load current and the output voltage is highest is designated as the maximum power point (MPP). Three factors are considered when extracting maximum amount of power from PV panel:

- Irradiance: changes PV panel current operating point.
- Temperature: changes PV panel voltage operating point.
- Load: used as a reference for current and voltage.

Maximum power point tracker is a system that optimizes voltage input and voltage output matching between the PV panel and the battery to achieve maximum panel efficiency. Current sensors and voltage sensors are used to detect the operating condition of the PV panel. There are four parameters which are to be measured for performing simple MPPT algorithm:

V_{oc} **:** Open circuit voltage

I_{sc} **:** Short circuit current

V_{MPP} **:** Maximum power point voltage

I_{MPP} **:** Maximum power point current

The parameters V_{oc}, I_{sc}, V_{MPP}, I_{MPP} with the help of irradiance determines the type of MPPT algorithm required to compute maximum power output of the PV panel. Perturb and Observe method is the most commonly implemented MPPT algorithm. Perturb and Observe maintains maximum power by changing panel's output voltage and observing whether output power increases or decreases in response. The algorithm provides appropriate modifications to the duty cycle of the DC-DC converter for modifying the panel voltage.

From the figure it can be concluded that if the change in power is positive on the left side of MPP, $\frac{dP}{dV} > 0$, then the output will move closer to MPP and the controller will continue to perturb the PV panel in the same direction. If the change in power is negative and on the right side of MPP, $\frac{dP}{dV} < 0$ then the output will move further from MPP and the controller switches to perturb the voltage in the opposite direction. Therefore, Perturb and Observe method uses a specified step to increase or decrease the voltage in an attempt to match MPP.

- Decreasing the voltage on right hand side of MPP, power increases towards MPP
- Increasing the voltage on left hand side of MPP, power increases towards MPP

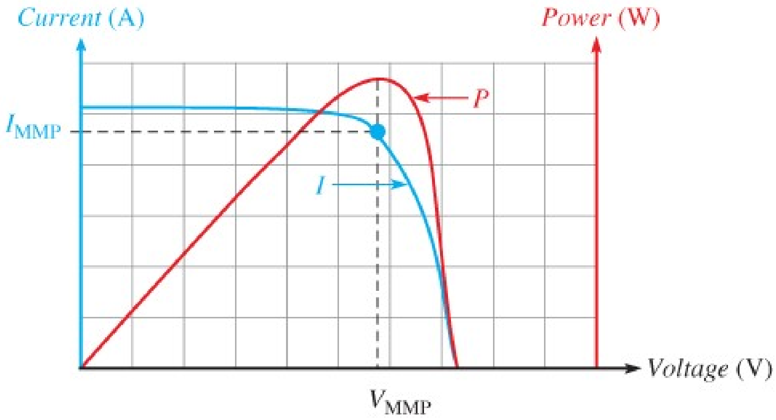

Figure 2.10: Maximum Power Point Tracking

2.4.4 MPPT Algorithm

The maximum power tracking mechanism make use of an algorithm and an electronic circuitry. The mechanism is based on the principle of impedance matching between load and PV module. This impedance matching is done by using a DC to DC converter. Using a DC to DC converter, the impedance is matched by changing the duty cycle (d) of the switch.

The power from the solar module is calculated by measuring the voltage and current. This power is an input to the algorithm which adjust the duty cycle of the switch, resulting in the adjustment of the reflected load impedance according to the power output of the PV module. For instance, the relation between the input voltage (V_i) and the output voltage (V_o) and the impedance of the load (R_L) reflected at the input side (R_i) of a buck type DC to DC converter is given as:

$$\begin{aligned} V_o &= (V_i) * d \\ R_i &= \frac{R_L}{d^2} \end{aligned} \tag{2.4}$$

where d is the duty cycle. By adjusting the duty cycle, R_i is varied which is same as the impedance of solar PV module (R_{PV}) in a given operating condition for maximum power transfer. A simplified Perturb and Observe algorithm is shown below

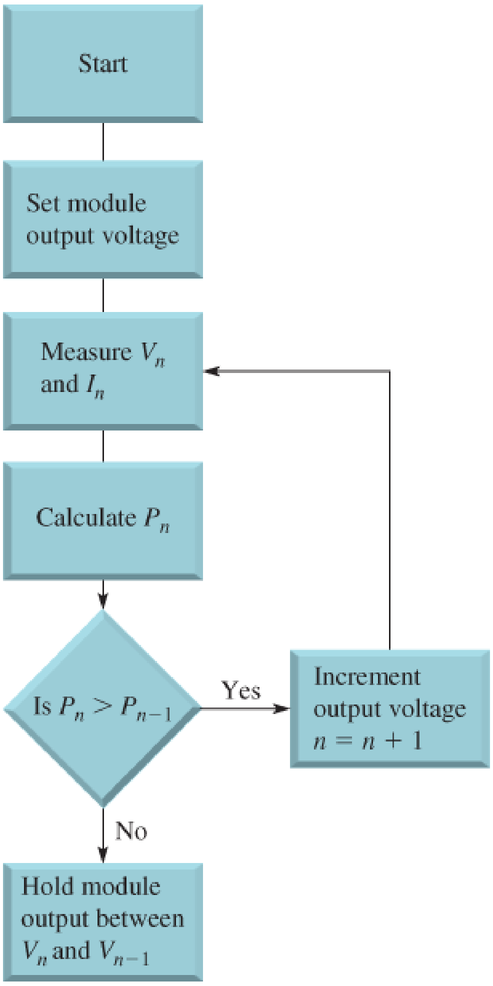

Figure 2.11: Perturb and Observe MPPT algorithm flowchart

Chapter 3

Design of Stand-Alone Solar Street-Lighting System

3.1 DIALux Simulation Of Street-Lighting

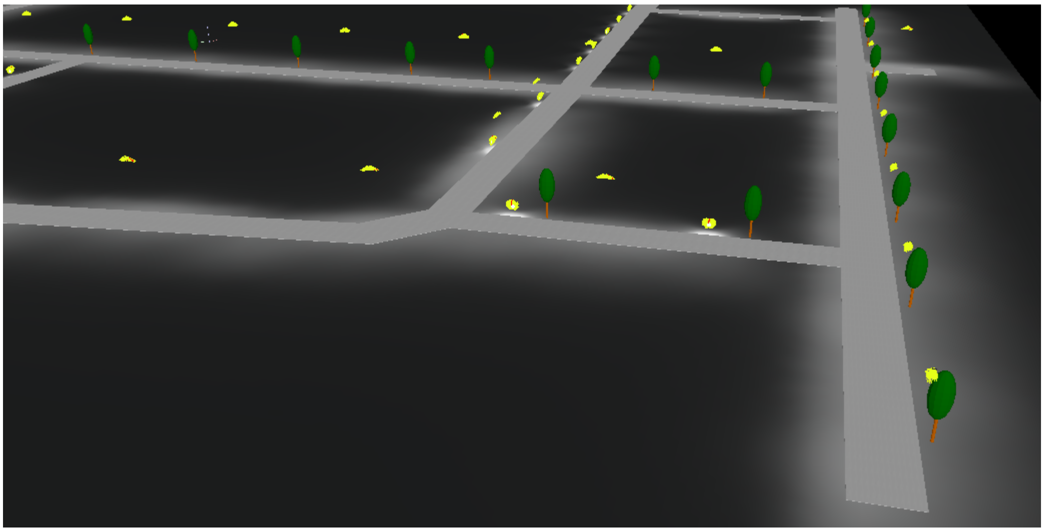

Figure 3.1: Design of a sretch of road of Jadavpur University campus

Lighting Design plan of a stretch of road of Jadavpur University campus is shown in the figure.From Gate Number-1 to Gate Number-3 the design was performed in DIALux. There are 7 stretches which has been highlighted as shown in the table.

Name of the Stretch	Dimension	Average Illuminance(lx)	Overall Uniformity(u0)
Road towards Aurobindo Bhavan	Length = 133.35 m, Width = 3.50 m	8.02	0.67
Road towards VLSI Building	Length = 27.60 m, Width = 3.50 m	8.36	0.54
Road towards Library	Length = 131.56 m, Width = 3.50 m	6.38	0.45
Road towards Mechanical Building	Length = 28.19 m, Width = 3.50 m	7.35	0.58
Road towards laser building	Length = 61.59 m, Width = 3.50 m	6.86	0.53
Way to Gate Number 3	Length = 47.04 m, Width = 3.50 m	6.54	0.50
Road beside SISED Building	Length = 31.18 m, Width = 3.50 m	6.72	0.52

Table 3.1: Seven Stretches of Jadavpur University Campus

A survey was initiated for performing the design of a stretch of road of Jadavpur University Campus in DIALux. During the survey the length and breadth of the given stretches shown in the table was calculated. With the help of the dimensions the model was first drawn in AUTO-CAD and then it was implemented in DIALux. A 3D Model from gate number 1 to gate number 3 was created with the help of extrusion volume.

3.1.1 Design Analysis of a Stretch of Road towards Aurobindo Bhavan

For **Road towards Aurobindo Bhavan** the length and width of the road are 133.35 m and 3.50 m respectively. During survey it was noticed 9 pole with equal spacing, 30 m are installed in a single-sided arrangement. The height of the pole is 11 m. 45 W LED Luminaire is mounted on each pole. During night 8 luminaires are working properly. The given stretch of a road is designed in DIALux where 9 pole with equal spacing, 30 m are installed in a single-sided arrangement. 45 W LED luminaire is mounted on each pole. The average illuminance and overall uniformity is 8.02 lx and 0.67 respectively. The given value interprets that all spots on the road are clearly visible and the pedestrians have a good facial recognition.Lighting class for pedestrian and low speed traffic are shown below.

Lighting class	Lighting Criteria		
	$E_{hor,av}$(lx)	$E_{hor,min}$(lx)	$E_{hor,av,max}$(lx)
P1	15	3.0	22.5
P2	7.5	1.5	11.2
P3	2.0	0.4	3.0

Table 3.2: Lighting class for pedestrian and low speed traffic according to CIE2010

Specification of the Luminaire used in the DIALux:

Model Number	NGN SLE UL 45W IP66 K
Wattage	$45 \pm 10\%$
Current	≤ 0.21 A
pf	≥ 0.95
Ithd	$\leq 10\%$
Efficacy	$\geq$ 100lm/W
CCT	5700 K
CRI	≥ 70
Main housing,frame	power coated,pressure die-cast aluminum housing
Ingress Protection	IP66
Gear	Integral, Electronic, constant current driver
Rated voltage, Frequency	240 V, 50 Hz AC

Table 3.3: Technical Specification of LED Street-light Luminaire

For calculating average lighting level of **Road towards Aurobindo Bhavan** 9-point method is the most acceptable. The layout of a 9-point measuring grid is shown below

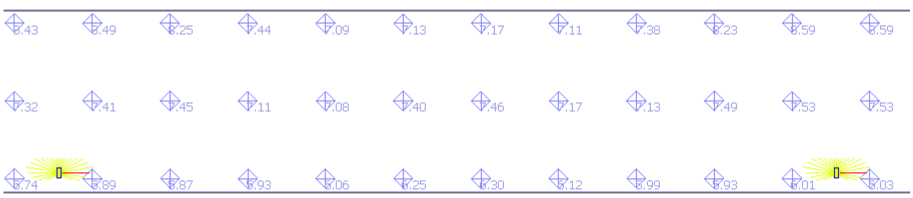

Figure 3.2: Measuring Grid of a stretch of road towards aurobindo bhavan

Average Illuminance of a stretch of road using 9-point method:

$$
\begin{aligned}
E_{av} &= \frac{P1+P3+P7+P9}{16} + \frac{P2+P4+P6+P8}{8} + \frac{P5}{4} \\
E_{av} &= \frac{5.89+8.49+6.01+8.59}{16} + \frac{7.41+6.30+7.17+7.53}{8} + \frac{7.46}{4} \\
E_{av} &= 1.81+3.55+1.87 = 7.23lx
\end{aligned}
\tag{3.1}
$$

3.1.2 Design Analysis of a Stretch of Road towards VLSI Building

For **Road towards VLSI Building** the length and width of the road are 27.60 m and 3.50 m respectively. During survey it was noticed a single pole is installed in a single-sided arrangement. The height of the pole is 11 m. 45 W LED **Philips** luminaire is mounted on the given pole. During night it was observed that the illuminance level for the given stretch of road is quite low. The given stretch of a road is designed in DIALux where two poles are installed in staggered arrangement. 45 W **Surya** LED Luminaire is mounted on each pole. The average illuminance and overall uniformity is 8.36 lx and 0.54 respectively. The given value interprets that all spots on the road are clearly visible and the pedestrians have a good facial recognition.

9-point method is applied on a stretch of road towards VLSI Building. The layout of the measuring grid is shown below

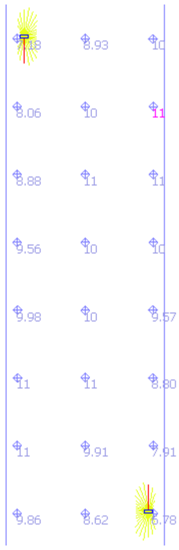

Figure 3.3: Measuring Grid of Road towards VLSI Building

Average Illuminance of a stretch of road towards VLSI Building:

$$\begin{aligned}
E_{av} &= \frac{P1 + P3 + P7 + P9}{16} + \frac{P2 + P4 + P6 + P8}{8} + \frac{P5}{4} \\
E_{av} &= \frac{10 + 7.18 + 6.78 + 9.86}{16} + \frac{8.93 + 9.57 + 9.98 + 8.62}{8} + \frac{10}{4} \\
E_{av} &= 2.11 + 4.64 + 2.5 = 9.25lx
\end{aligned} \tag{3.2}$$

3.1.3 Design Analysis of a Stretch of Road towards Library

For **Road towards Library** the length and width of the road are 131.56 m and 3.50 m respectively. During survey it was noticed six pole is installed in a single-sided arrangement. The height of the pole is 11 m. 45 W **Philips** LED Luminaire is mounted on each pole. During night it was observed that 5 luminaires are working properly but a part of the road is in dark as one luminaire is not functioning properly. The given stretch of a road is designed in DIALux where 6 pole are installed in single-sided arrangement. 45 W **Surya** LED Luminaire is mounted on each pole. The average illuminance and overall uniformity is 6.38 lx and 0.45 respectively.

The given value interprets that all spots on the road are clearly visible and the pedestrians have a good facial recognition.

9-point method is applied on a stretch of road towards library. The layout of the measuring grid is shown below

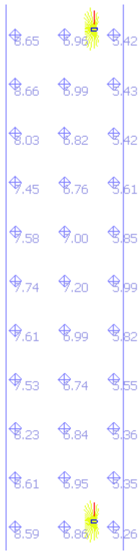

Figure 3.4: Measuring Grid of a stretch of road towards library

Average Illuminance of a stretch of road towards library:

$$
\begin{aligned}
E_{av} &= \frac{P1 + P3 + P7 + P9}{16} + \frac{P2 + P4 + P6 + P8}{8} + \frac{P5}{4} \\
E_{av} &= \frac{5.42 + 8.65 + 5.26 + 8.59}{16} + \frac{6.96 + 5.99 + 7.74 + 6.86}{8} + \frac{7.20}{4} \\
E_{av} &= 1.75 + 3.44 + 1.80 = 6.99 lx
\end{aligned} \tag{3.3}
$$

3.1.4 Design Analysis of a Stretch of Road towards Mechanical Building

For **Road towards Mechanical Building** the length and width of the road are 28.19 m and 3.50 m respectively. During survey it was noticed no pole was installed in the given stretch of a road. As a result the given space remains dark during night. The given stretch of a road is designed in DIALux where 2 poles are installed in a single-sided arrangement. 45 W LED Luminaire is mounted on each pole. The average illuminance and overall uniformity is 7.35 lx and 0.58 respectively. The given value interprets that all spots on the road are clearly visible and the pedestrians have a good facial recognition.

9-point method is applied on a stretch of road towards mechanical building. The layout of the measuring grid is shown below

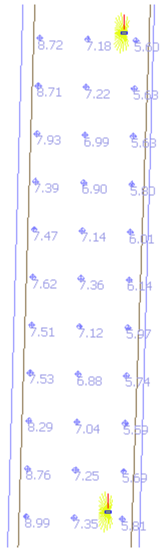

Figure 3.5: Measuring grid of a stretch of road towards mechanical building

Average illuminance of a stretch of road towards mechanical building:

$$
\begin{aligned}
E_{av} &= \frac{P1+P3+P7+P9}{16} + \frac{P2+P4+P6+P8}{8} + \frac{P5}{4} \\
E_{av} &= \frac{5.60+8.72+5.81+8.99}{16} + \frac{7.18+6.14+7.62+7.35}{8} + \frac{7.36}{4} \\
E_{av} &= 1.82+3.54+1.84 = 7.2lx
\end{aligned} \tag{3.4}
$$

3.1.5 Design Analysis of a Stretch of Road towards Laser Building

For **Road towards Laser Building** the length and width of the road are 61.59 m and 3.50 m respectively. During survey it was noticed 4 pole was installed in the given stretch of a road where each pole mounted with a 45 W LED Luminaire. Now the given stretch of a road is designed in DIALux where 4 pole are installed in a single-sided arrangement. 45 W LED Luminaire (ies file) is mounted on each pole. The average illuminance and overall uniformity is 6.86 lx and 0.53 respectively. The given value interprets that all spots on the road are clearly visible and the pedestrians have a good facial recognition.

9-point method is applied on a stretch of road towards laser building. The layout of the measuring grid is shown below

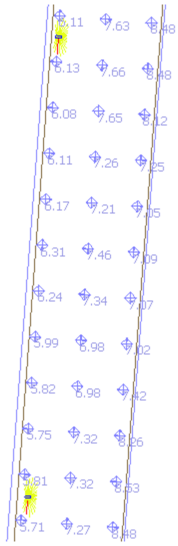

Figure 3.6: Measuring Grid of a stretch of road towards laser building

Average illuminance of a stretch of road towards laser building:

$$
\begin{aligned}
E_{av} &= \frac{P1+P3+P7+P9}{16} + \frac{P2+P4+P6+P8}{8} + \frac{P5}{4} \\
E_{av} &= \frac{5.81+8.53+6.13+8.48}{16} + \frac{7.32+6.31+7.09+7.66}{8} + \frac{7.46}{4} \\
E_{av} &= 1.81+3.55+1.87 = 7.23lx
\end{aligned}
\tag{3.5}
$$

3.1.6 Design Analysis of a stretch of road beside SISED Building

For **Road beside SISED Building** the length and width of the road are 31.18 m and 3.50 m respectively. During survey it was noticed only one pole is installed in the given stretch of a road mounted with a 45 W LED Luminaire. Now the given stretch of a road is designed in DIALux where 2 poles are installed in a single-sided arrangement. 45 W LED Luminaire (ies file) is mounted on each pole. The average illuminance and overall uniformity is 6.72 lx and 0.52 respectively. Detailed Output of the Design is to be attached in the annexure.

9-point method is applied on a stretch of road beside SISED building. The layout of the measuring grid is shown below

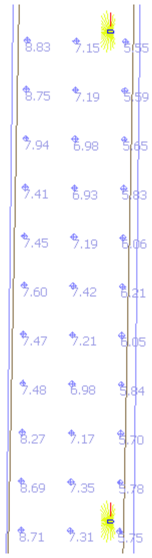

Figure 3.7: Measurement Grid of a stretch of road beside SISED Building

Average illuminance of a stretch of road beside SISED building:

$$
\begin{aligned}
E_{av} &= \frac{P1+P3+P7+P9}{16} + \frac{P2+P4+P6+P8}{8} + \frac{P5}{4} \\
E_{av} &= \frac{8.69+5.78+8.83+5.55}{16} + \frac{7.35+7.45+6.06+7.15}{8} + \frac{7.19}{4} \\
E_{av} &= 1.80+3.50+1.79 = 7.09lx
\end{aligned} \tag{3.6}
$$

3.1.7 Design Analysis of a Stretch of Road towards Gate No. 3

For **Road towards Gate No. 3** the length and width of the road are 47.04 m and 3.50 m respectively. During survey two poles are installed in the given stretch of a road mounted with a 45 W LED Luminaire. Now the given stretch of a road is designed in DIALux where 3 poles are installed in a single-sided arrangement. 45 W LED Luminaire (ies file) is mounted on each pole. The average illuminance and overall uniformity is 6.54 lx and 0.50 respectively.

9-point method is applied on a stretch of road towards Gate No. 3. The layout of the measuring grid is shown below

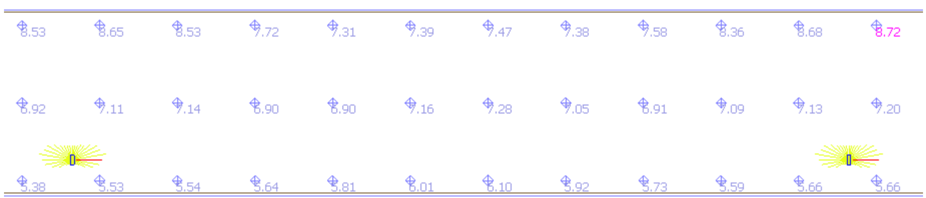

Figure 3.8: Measuring Grid of a stretch of road towards Gate No. 3

Average illuminance of a stretch of road towards gate no. 3:

$$
\begin{aligned}
E_{av} &= \frac{P1+P3+P7+P9}{16} + \frac{P2+P4+P6+P8}{8} + \frac{P5}{4} \\
E_{av} &= \frac{5.53+8.65+5.66+8.68}{16} + \frac{7.11+6.10+7.47+7.13}{8} + \frac{7.28}{4} \\
E_{av} &= 1.78+3.48+1.82 = 7.08lx
\end{aligned}
\tag{3.7}
$$

3.2 Selection and Estimation of Solar Panel

For 12 V battery system:
Consider a 45 W lighting system powered by a standalone photovoltaic system. Active hours LED luminaire remains ON per day : 10 hours
Energy Usage per day : 45*10 = 450 Wh
Consider energy loss during the period = 1.3
Total energy required to draw from the PV panel per day:

$$Energy_T = 450 * 1.3 = 585Wh \tag{3.8}$$

Consider **panel generation factor** in India = 4 [5]
Total Watt-peak required to draw from the PV modules to operate street-light = $\frac{585}{4}$ = 147 W_p
Number of PV modules required = $\frac{147}{150}$ = 1

3.3 Selection and estimation of battery

Deep Cycle battery should be chosen for the hardware design.
Consider battery loss = 0.85
Depth of discharge = 0.5
Nominal battery voltage = 12 V
Consider days of autonomy = 3 days

$$
\begin{aligned}
BatteryCapacity &= \frac{totalWatt - hrperday * Daysofautonomy}{0.85 * 0.5 * Nominalbatteryvoltage} \\
BatteryCapacity &= \frac{585 * 3}{0.85 * 0.5 * 12} \\
BatteryCapacity &= \frac{1755}{5.1} = 344.12Ah \approx 350Ah
\end{aligned}
\tag{3.9}
$$

Therefore, Number of batteries required for designing **stand-alone solar street-lighting system** = 1

3.4 Single line Diagram of Stand-Alone system

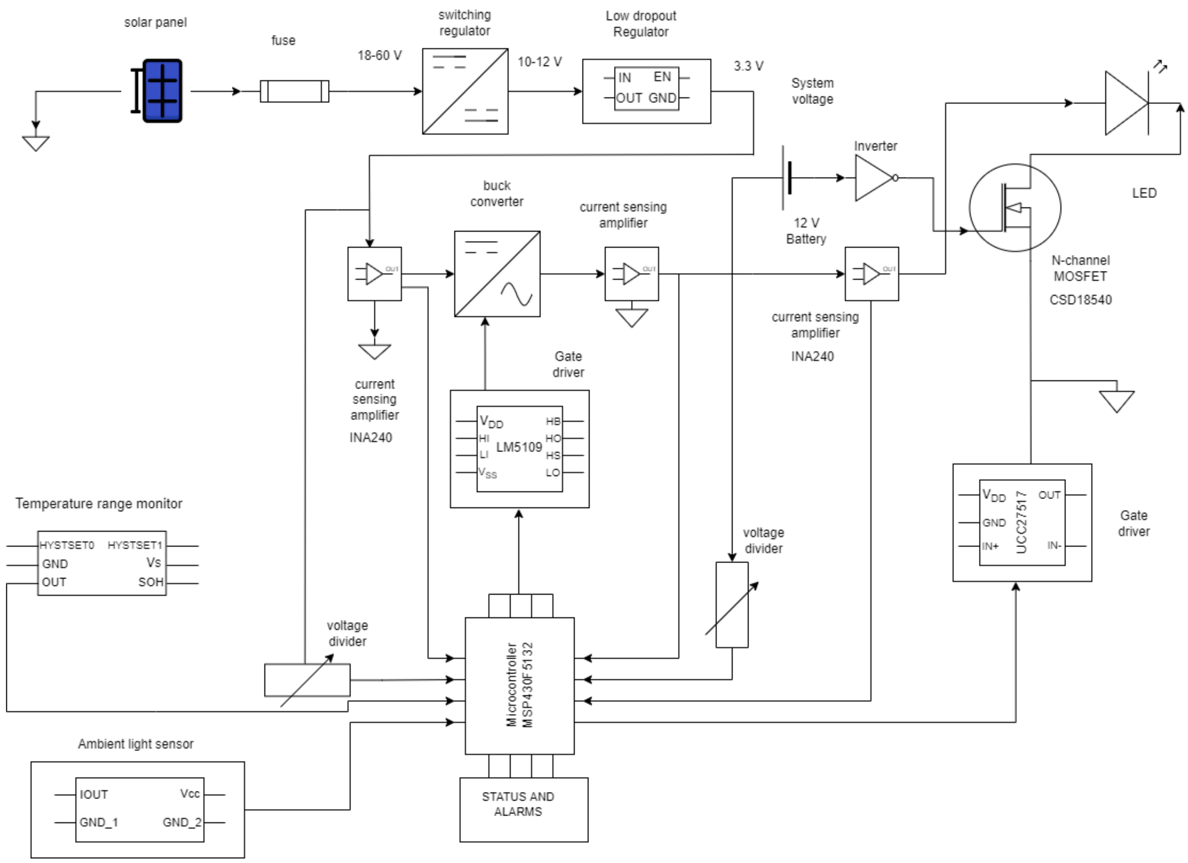

Figure 3.9: Single Line Diagram of Stand-Alone Solar Street-lighting System

From the single line diagram it is observed that only one solar panel is required to charge the battery for Stand-Alone street-lighting system. Microcontroller gathers data from the panel and battery voltage lines and panel, battery and current sense amplifiers. Microcontroller calculates and tracks the maximum power point of the solar panel. It generates PWM signals which drive the gate drivers (LM5109B) of the interleaved buck converter. The interleaved buck converter control the output battery charging current to maximize power conversion efficiency and to prevent battery over-charge to increase the lifetime of the battery. A switching regulator is used to step-down either the panel or battery voltage to 10 V. From 10 V a low-dropout regulator (LDO) is used to regulate a 3.3 V line for the system components.

During battery charging mode microcontroller generates pulse-width modulated signals to the interleaved buck converter, where duty cycle is proportional to the output current or battery charging current of the buck stage. Microcontroller is also responsible for managing the battery voltage by preventing over charging of the battery. It is done by disabling the buck converter once a threshold voltage is reached and protect from over-discharging by disconnecting the load once a threshold load current is reached.

A reference design of solar charge controller is given below

Figure 3.10: Reference Design of Solar Charge Controller

Chapter 4

Design of Central Solar Street-lighting System

4.1 Selection and Estimation of Solar Panel

Number of LED street-lights connected to Central SPV panel = 20
Active hours Luminaires remain ON per day = 10 hours
Energy required per day = 20 * 45 * 10 = 9000 Wh
Consider energy loss during the period = 1.3
Total energy required to draw from the PV panel per day:

$$Energy_T = 9000 * 1.3 = 11700Wh \tag{4.1}$$

Consider **panel generation factor** in India = 4[6]
Total Watt-peak required to draw from the PV modules to operate street-light = $\frac{11700}{4}$ = 2925 W_p
Number of PV modules required = $\frac{2925}{350}$ = 8.35 $\approx$ 8

4.2 Selection and estimation of battery

Consider battery loss = 0.85
Depth of discharge = 0.5
Nominal battery voltage = 12 V
Consider days of autonomy = 3 days

$$\begin{aligned} BatteryCapacity &= \frac{totalWatt - hrperday * Daysofautonomy}{0.85 * 0.5 * Nominalbatteryvoltage} \\ BatteryCapacity &= \frac{11700 * 3}{0.85 * 0.5 * 12} \\ BatteryCapacity &= \frac{35100}{5.1} = 6882.35Ah \approx 7000Ah \end{aligned} \tag{4.2}$$

Battery Selection: 12 V 350 Ah XH-03-350
Number of batteries in parallel = $\frac{BatteryCapacity}{IndividualBatteryCapacity}$
Number of Batteries in parallel = $\frac{7000}{350}$ = 20

4.3 Single Line Diagram Central Street-lighting System

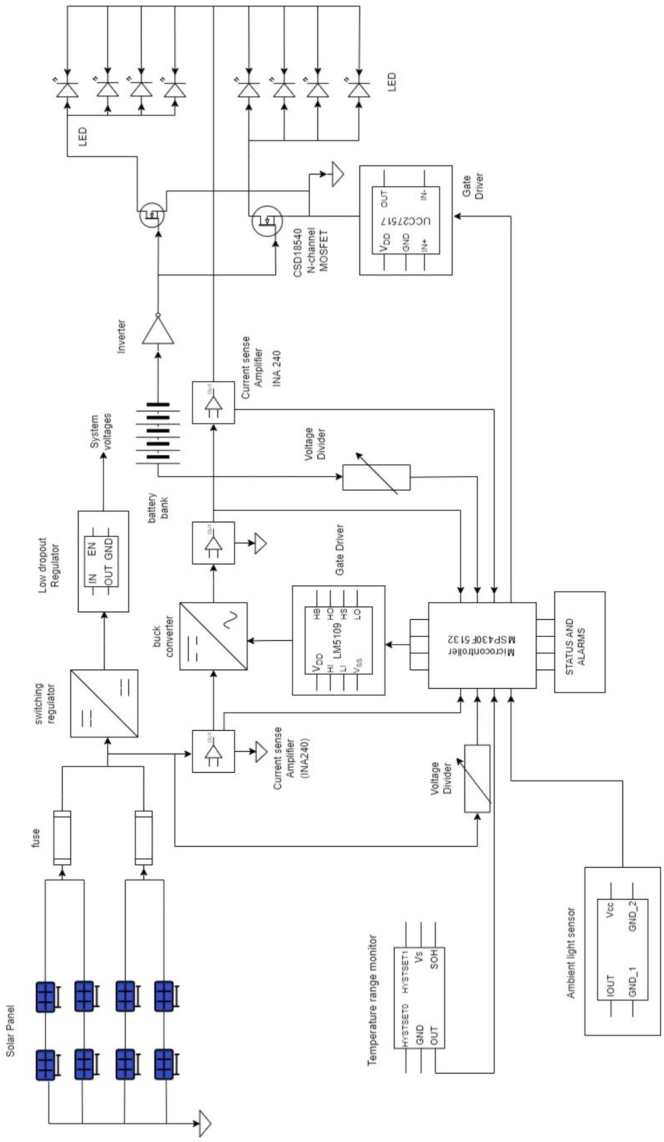

Figure 4.1: Single Line Diagram of Central Solar Street-lighting System

From the single line diagram, it is observed that 8 solar panels are connected in parallel to charge the battery bank for Central Solar street-lighting system. 8 LED luminaire is connected to two N-channel MOSFET and 20 number of batteries required to be charged are connected in parallel. Microcontroller calculates and tracks the maximum power point of the solar panel. It generates PWM signals which drive the gate drivers (LM5109B) of the interleaved buck converter. The interleaved buck converter control the output battery charging current to maximize power conversion efficiency and to prevent battery over-charge to increase the lifetime of the battery. A switching regulator is used to step-down either the panel or battery voltage to 10 V. From 10 V a low-dropout regulator (LDO) is used to regulate a 3.3 V line for the rest of the system components.

Chapter 5

Analysis and Conclusion

5.1 Analysis

In order to do design analysis Bill of Quantity, equipment specifications for solar panel and battery are shown in the table.

For Stand-Alone street-lighting system:

Installed rated capacity of battery = 12 V, 350 Ah
Watt-hour of battery (W_B) = Rated voltage * Ampere-hour of battery
W_B = 12 * 350 = 4200 Wh
Load Capacity = 45 W
Back up time is given by:

$$\begin{aligned} Backuptime(B_T) &= \frac{W_B}{Load} \\ B_T &= \frac{4200Wh}{45W} \\ B_T &= 93.33hour \approx 94hour \end{aligned} \tag{5.1}$$

The charging current (I_c) should be 1/10^{th} of the battery ampere hour.
I_c = $\frac{350}{10}$ = 35 A
Charging time required by the battery (T) is given by:

$$\begin{aligned} T &= \frac{Ah}{I_c} \\ T &= \frac{350}{10} \\ T &= 35A \end{aligned} \tag{5.2}$$

The above value is considered for ideal cases. But in practical condition during battery charging 40% loss is considered. The value of charging time should be taken between 10 to 12 hours.
The charging time for 12 V, 350 Ah battery should be:
Battery Rating = 350 Ah + losses
Battery Rating = 350 Ah + 350 * $\frac{40}{100}$
Battery Rating = 490 Ah

Therefore, battery charging time (T) = $\frac{490Ah}{40A}$ = 12.25 hours.

Solar panel, battery specifications and bill of materials required for the project is given below:

Quantity	Symbol	Specification
Peak power	W_p	150 W
Current max power	I_{MPP}	8.41 A
Voltage max power	V_{MPP}	17.85 V
short-circuit current	I_{sc}	8.7 A
open-circuit voltage	V_{oc}	22.58 V
Max System voltage		1000 V
Cell Technology	MONO	
Module Dimension		1012 mm * 982 mm * 36 mm

Table 5.1: Solar Panel Specifications

Quantity	Specification
Model No.	12 V 350 Ah XH-03-350
Nominal Voltage	12.8 V
Nominal Capacity	350 Ah
Dimension	520 * 320 * 160
Standard Charging current	$\leq$ 80 A
Discharge current	$\leq$ 200 A
Product Name	12 V Lifepo4 lithium battery
Cycle life	4000 Cycles

Table 5.2: Battery Specification

SL No.	Components	Quantity
1	Solar Panel	8
2	Battery	20
3	Lamp	20
4	Pole(one arm)	20
5	Charge controller	1

Table 5.3: Bill of Materials

5.2 Future Scope

Designing a Stand-Alone and Central Solar Street-lighting system of a stretch of road is developed in this research work. It is developed using MPPT solar charge controller. Perturb and Observe method is implemented to get maximum power output from solar panel. The process involves slightly increasing or decreasing the operating voltage of the panel. By performing the perturbations and observing the power output, the system begins to operate close to MPP of the panel with slight oscillation around MPP.

The above design can be implemented in Indoor Lighting using Incremental Conductance Algorithm. It calculates the relation of the power curve derivative and the voltage at zero which gives MPP. Any value on left side of MPP is a positive slope and anything on the right side of MPP is a negative slope. Thus, the comparison is actually the positive incremental conductance versus the negative instantaneous conductance.

5.3 Conclusion

A stretch of road of Jadavpur University campus illuminated with LED lighting system powered by solar PV module with the help of MPPT solar charge controller has presented in this thesis. Measured photometric parameter from the LED lighting system has proved that Uniformity, visual comfortability are within the specified level as mentioned in the National Lighting Code. The power generation from Solar PV module and power consumption by LED lighting system results leads to better energy management when compared to conventional power generation and lighting system. Hence the solar PV powered LED lighting system is the best suited energy saving technique.

Reference

1. Wong F.T.K. (2014). A Cost Effective Solar Powered Led Street Light. A project report submitted to the Faculty of Electrical and Electronic Engineering UniversitiTun Hussein Onn Malaysia.

2. Fathi M. and Chikouche A. (2010). LEDs Application to the Photovoltaic Street Lighting. International Conference on Renewable Energies, 101-104.

3. O.S. Sastry a,n, V.KamalaDevi b, P.C.Pant a, G.Prasad a, RajeshKumar a, BibekBandyopadhyay a, " Development of white LED based PV lighting systems", Solar Energy Materials and Solar Cells, Vol.94 (2010) pp.1430–1433.

4. Oke A.O., Adigun A.A. and Fenwa O.D. (2013). Design and Construction of Solar Power-Based Lighting System. International Journal of Engineering Sciences and Research Technology, 2(9), ISSN: 2277-9655.

5. Guo L. (2010). AC 2010-355: Design and implementation of a solar battery charger. age, 15, 1.

6. Jessica A. Onwuzuruike, Maruf A. Aminu, "Experimental Determination of Panel Generation Factor for Apo Area of Federal Capital Territory in Nigeria", 24(3): 1-5, 2019, ISSN: 2320-0227

Annexure

DIALux Simulation Result

Lighting Design Plan of a Stretch of Road of Jadavpur University Campus

Road towards Aurobindo Bhavan(Length = 133.35 m, Width = 3.50 m)

Road towards VLSI Building
(Length = 27.60 m, Width = 3.50 m)

Road towards Library (Length = 131.56 m, Width = 3.50 m)

Road towards Mechanical Building (Length = 28.19 m, Width = 3.50 m)

Road towards laser building (Length = 61.59 m, Width = 3.50 m)

Way to Gate Number 3 (Length = 47.04 m, Width = 3.50 m)

Road beside SISED Building (Length = 31.18 m, Width = 3.50 m)

We have to achieve:

E_{av} = 2-15 lx, $u_0 \geq 0.40$ according to National Lighting Code for the given stretches.

Partner for Contact:
Order No.:
Company:
Customer No.:

Date: 14.08.2022
Operator:

Operator
Telephone
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e-Mail

Table of contents

Operator
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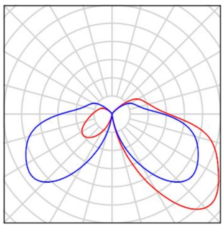
Lighting Design Plan of a Stretch of Road of Jadavpur University Campus / Luminaire parts list

14 Pieces

National Lighting Solutions LLC RDN-X-T3-16L-7-50K LED BOLLARD
Article No.: RDN-X-T3-16L-7-50K LED BOLLARD
Luminous flux (Luminaire): 3256 lm
Luminous flux (Lamps): 3256 lm
Luminaire Wattage: 35.0 W
Luminaire classification according to CIE: 80
CIE flux code: 17 49 79 80 100
Fitting: 1 x User defined (Correction Factor 1.000).

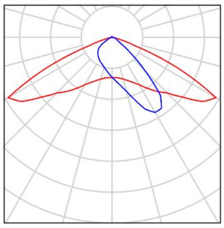
See our luminaire catalog for an image of the luminaire.



45 Pieces

Surya SLE UL 45W IP66 LXN
Article No.: SLE UL 45W IP66 LXN
Luminous flux (Luminaire): 4504 lm
Luminous flux (Lamps): 4500 lm
Luminaire Wattage: 45.0 W
Luminaire classification according to CIE: 100
CIE flux code: 41 84 99 100 100
Fitting: 1 x User defined (Correction Factor 1.000).

See our luminaire catalog for an image of the luminaire.



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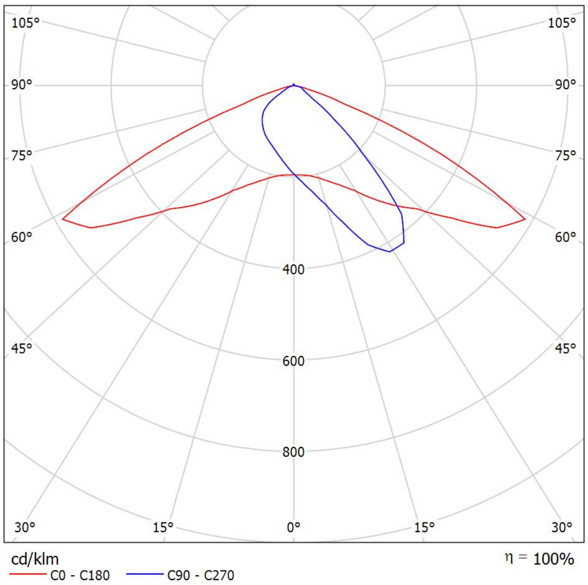
Surya SLE UL 45W IP66 LXN / Luminaire Data Sheet

Luminous emittance 1:

See our luminaire catalog for an image of the luminaire.



Luminaire classification according to CIE: 100
CIE flux code: 41 84 99 100 100

Due to missing symmetry properties, no UGR table can be displayed for this luminaire.

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Exterior Scene 1 / Planning data

Light loss factor: 0.80, ULR (Upward Light Ratio): 12.5%

Scale 1:3926

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	14	National Lighting Solutions LLC RDN-X-T3-16L-7-50K LED BOLLARD (1.000)	3256	3256	35.0
2	45	Surya SLE UL 45W IP66 LXN (1.000)	4504	4500	45.0
			Total: 248285	Total: 248083	2515.0

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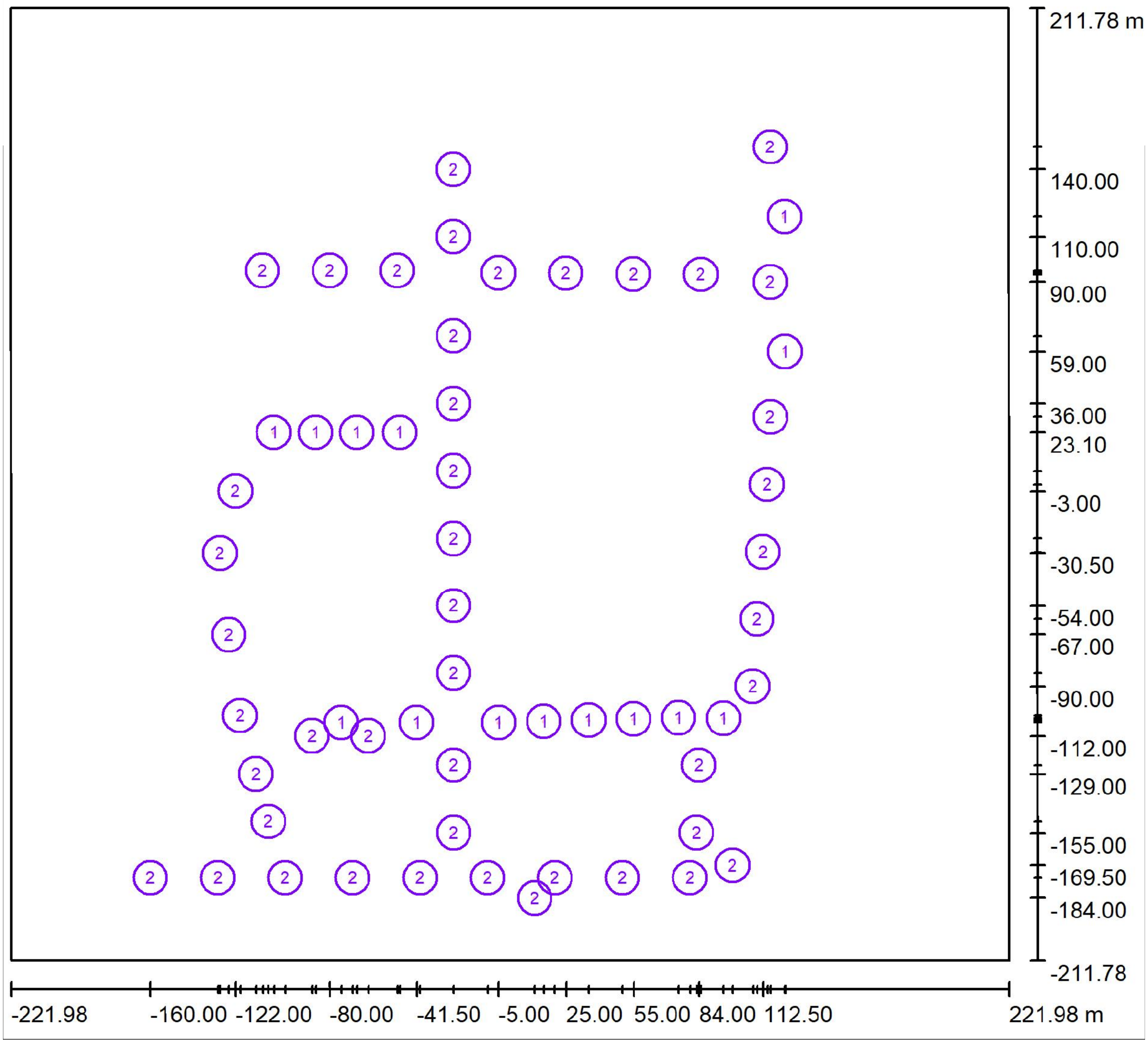
Exterior Scene 1 / Luminaires (layout plan)



Scale 1 : 3174

Luminaire Parts List

No.	Pieces	Designation
1	14	National Lighting Solutions LLC RDN-X-T3-16L-7-50K LED BOLLARD
2	45	Surya SLE UL 45W IP66 LXN

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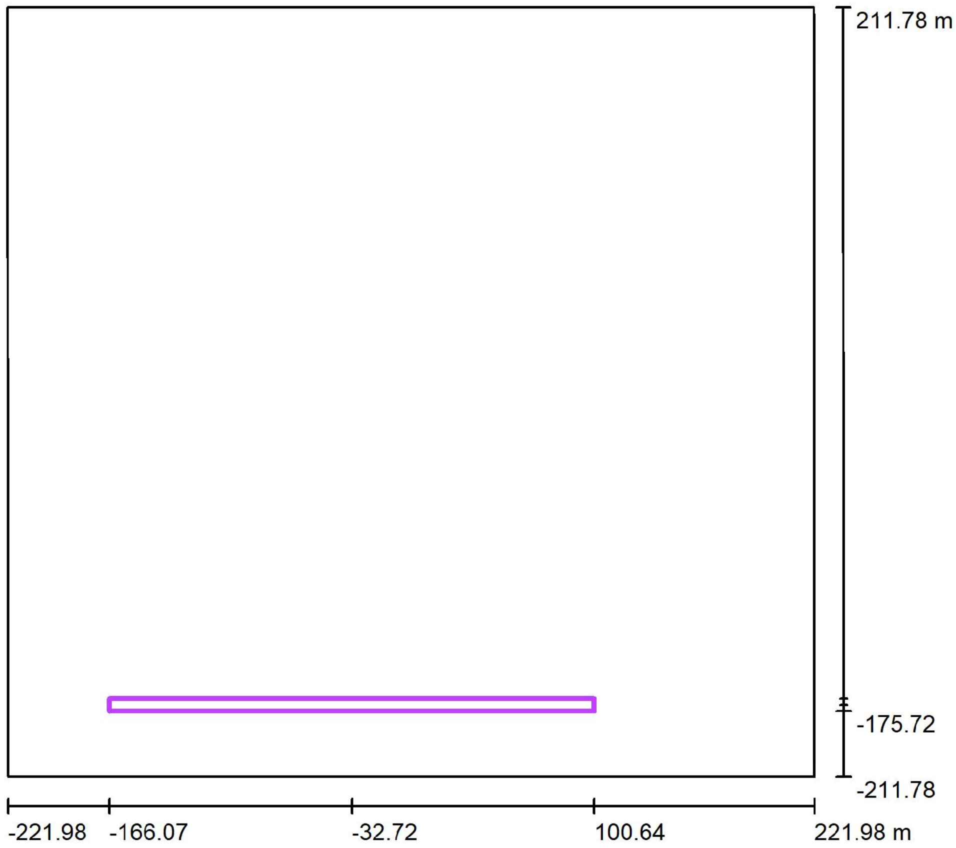
Exterior Scene 1 / Road towards Aurobindo Bhavan / Summary



Scale 1 : 4039

Position: (-32.720 m, -172.220 m, 0.052 m)
Size: (266.710 m, 7.006 m)
Rotation: (0.0°, 0.0°, 0.0°)
Type: Normal, Grid: 89 x 3 Points

Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\ m}/E_m$	H [m]	Camera
1	horizontal	8.02	5.38	15	0.67	0.37	/	0.000	/

$E_{h\ m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

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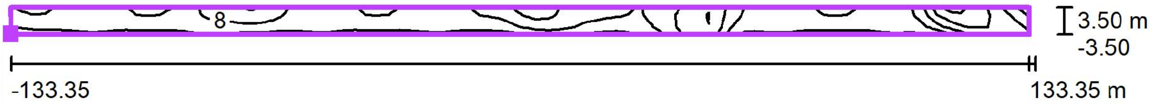
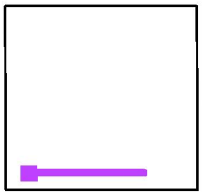
Exterior Scene 1 / Road towards Aurobindo Bhavan / Isolines (E, Horizontal)



Values in Lux, Scale 1 : 1907

Position of surface in external scene:
Marked point: (-166.075 m, -175.723 m, 0.052 m)



Grid: 89 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.02	5.38	15	0.67	0.37

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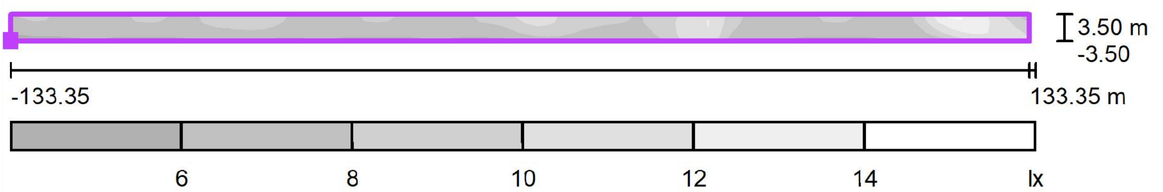
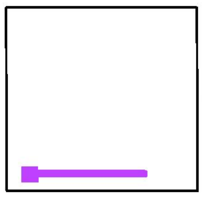
Exterior Scene 1 / Road towards Aurobindo Bhavan / Greyscale (E, Horizontal)



Scale 1 : 1907

Position of surface in external scene:
Marked point: (-166.075 m, -175.723 m, 0.052 m)



Grid: 89 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.02	5.38	15	0.67	0.37

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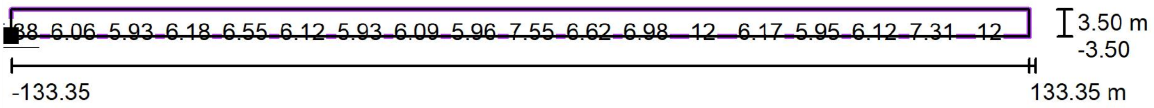
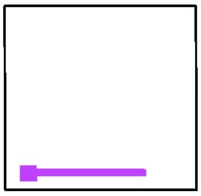
Exterior Scene 1 / Road towards Aurobindo Bhavan / Value Chart (E, Horizontal)



Values in Lux, Scale 1 : 1907

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point: (-166.075 m, -175.723 m, 0.052 m)



Grid: 89 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.02	5.38	15	0.67	0.37

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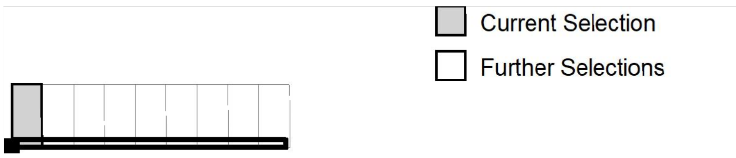
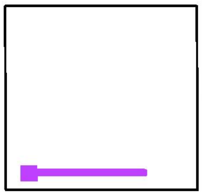
Exterior Scene 1 / Road towards Aurobindo Bhavan / Table (E, Horizontal)



Position of surface in external scene:
Marked point: (-166.075 m, -175.723 m, 0.052 m)



7.500	7.89	8.43	8.49	8.25	7.44	7.09	7.13	7.17	7.11	7.38
4.500	7.05	7.32	7.41	7.46	7.11	7.08	7.40	7.46	7.17	7.13
1.500	5.38	5.74	5.89	5.87	5.93	6.06	6.25	6.30	6.12	5.99
m	**1.500**	**4.500**	**7.500**	**10.500**	**13.500**	**16.500**	**19.500**	**22.500**	**25.500**	**28.500**

Attention: The coordinates refer to the image above. Values in Lux.

Grid: 89 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.02	5.38	15	0.67	0.37

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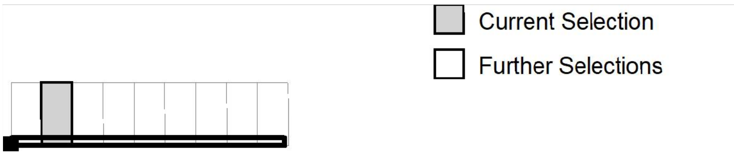
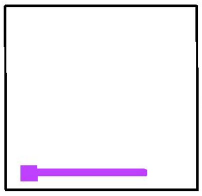
Exterior Scene 1 / Road towards Aurobindo Bhavan / Table (E, Horizontal)



Position of surface in external scene:
Marked point: (-166.075 m, -175.723 m, 0.052 m)



7.500	8.23	8.59	8.59	8.35	7.57	7.35	7.96	8.79	9.25	9.47
4.500	7.49	7.53	7.52	7.55	7.22	7.24	7.76	8.13	8.09	8.21
1.500	5.93	6.01	6.03	5.97	6.02	6.18	6.46	6.62	6.54	6.53
m	**31.500**	**34.500**	**37.500**	**40.500**	**43.500**	**46.500**	**49.500**	**52.500**	**55.500**	**58.500**

Attention: The coordinates refer to the image above. Values in Lux.

Grid: 89 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.02	5.38	15	0.67	0.37

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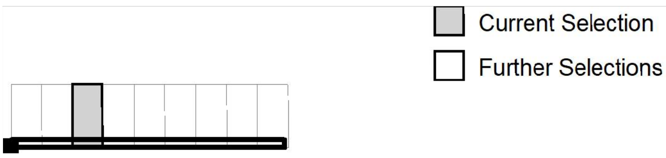
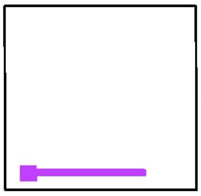
Exterior Scene 1 / Road towards Aurobindo Bhavan / Table (E, Horizontal)



Position of surface in external scene:
Marked point: (-166.075 m, -175.723 m, 0.052 m)



7.500	10	10	9.51	8.78	7.65	7.18	7.18	7.20	7.12	7.38
4.500	8.63	8.54	8.21	7.87	7.28	7.15	7.43	7.48	7.18	7.14
1.500	6.55	6.57	6.42	6.14	6.05	6.12	6.28	6.32	6.13	6.00
m	**61.500**	**64.500**	**67.500**	**70.500**	**73.500**	**76.500**	**79.500**	**82.500**	**85.500**	**88.500**

Attention: The coordinates refer to the image above. Values in Lux.

Grid: 89 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.02	5.38	15	0.67	0.37

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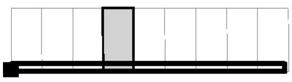
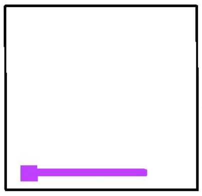
Exterior Scene 1 / Road towards Aurobindo Bhavan / Table (E, Horizontal)



Current Selection
Further Selections

Position of surface in external scene:
Marked point: (-166.075 m, -175.723 m, 0.052 m)



7.500	8.22	8.57	8.56	8.30	7.48	7.12	7.16	7.20	7.13	7.41
4.500	7.49	7.52	7.50	7.52	7.15	7.11	7.42	7.48	7.19	7.16
1.500	5.93	6.00	6.02	5.95	5.98	6.09	6.27	6.32	6.14	6.02
m	**91.500**	**94.500**	**97.500**	**100.500**	**103.500**	**106.500**	**109.500**	**112.500**	**115.500**	**118.500**

Attention: The coordinates refer to the image above. Values in Lux.

Grid: 89 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.02	5.38	15	0.67	0.37

Operator
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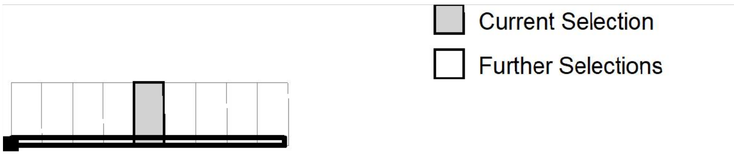
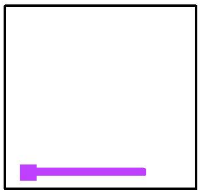
Exterior Scene 1 / Road towards Aurobindo Bhavan / Table (E, Horizontal)



Position of surface in external scene:
Marked point: (-166.075 m, -175.723 m, 0.052 m)



7.500	8.27	8.66	8.78	9.39	11	11	11	10	9.51	8.97
4.500	7.53	7.59	7.69	8.24	9.10	9.92	10	9.96	9.23	8.61
1.500	5.96	6.06	6.12	6.27	6.90	7.55	7.95	7.97	7.61	7.11
m	**121.500**	**124.500**	**127.500**	**130.500**	**133.500**	**136.500**	**139.500**	**142.500**	**145.500**	**148.500**

Attention: The coordinates refer to the image above. Values in Lux.

Grid: 89 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.02	5.38	15	0.67	0.37

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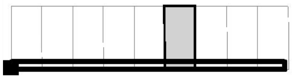
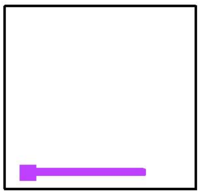
Exterior Scene 1 / Road towards Aurobindo Bhavan / Table (E, Horizontal)



Current Selection
Further Selections

Position of surface in external scene:
Marked point: (-166.075 m, -175.723 m, 0.052 m)



7.500	9.14	9.04	8.78	8.49	7.86	7.94	8.61	9.41	10	11
4.500	8.32	7.90	7.69	7.75	7.60	7.97	8.93	9.87	11	11
1.500	6.62	6.33	6.20	6.19	6.47	6.98	7.81	8.88	10	11
m	**151.500**	**154.500**	**157.500**	**160.500**	**163.500**	**166.500**	**169.500**	**172.500**	**175.500**	**178.500**

Attention: The coordinates refer to the image above. Values in Lux.

Grid: 89 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.02	5.38	15	0.67	0.37

Operator
Telephone
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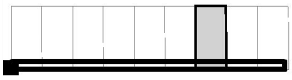
e-Mail

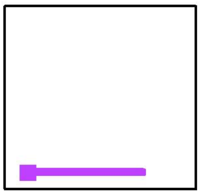
Exterior Scene 1 / Road towards Aurobindo Bhavan / Table (E, Horizontal)



Current Selection

Further Selections

Position of surface in external scene:
Marked point: (-166.075 m, -175.723 m, 0.052 m)



7.500	12	12	9.76	8.54	7.57	7.16	7.19	7.21	7.13	7.39
4.500	13	12	9.45	7.90	7.27	7.17	7.46	7.50	7.20	7.15
1.500	12	11	8.28	6.37	6.12	6.17	6.31	6.34	6.15	6.01
m	**181.500**	**184.500**	**187.500**	**190.500**	**193.500**	**196.500**	**199.500**	**202.500**	**205.500**	**208.500**

Attention: The coordinates refer to the image above. Values in Lux.

Grid: 89 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.02	5.38	15	0.67	0.37

Operator
Telephone
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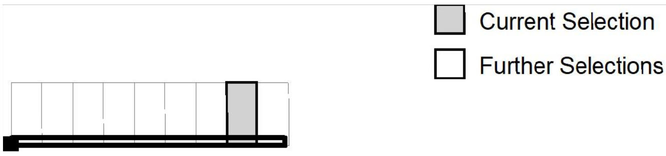
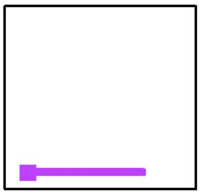
Exterior Scene 1 / Road towards Aurobindo Bhavan / Table (E, Horizontal)



Position of surface in external scene:
Marked point: (-166.075 m, -175.723 m, 0.052 m)



7.500	8.24	8.59	8.58	8.33	7.51	7.17	7.25	7.36	7.50	8.96
4.500	7.50	7.54	7.52	7.54	7.18	7.15	7.49	7.60	7.48	8.22
1.500	5.95	6.02	6.03	5.97	6.00	6.12	6.32	6.40	6.30	6.54
m	**211.500**	**214.500**	**217.500**	**220.500**	**223.500**	**226.500**	**229.500**	**232.500**	**235.500**	**238.500**

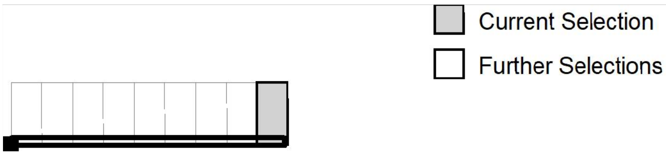
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 89 x 3 Points

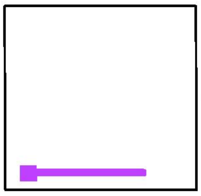
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.02	5.38	15	0.67	0.37

Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards Aurobindo Bhavan / Table (E, Horizontal)



Position of surface in external scene:
Marked point: (-166.075 m, -175.723 m, 0.052 m)



7.500	12	14	15	14	13	12	10	8.90	7.50
4.500	10	12	13	13	13	12	12	11	9.44
1.500	7.31	8.50	9.87	11	11	12	12	11	11
m	**241.500**	**244.500**	**247.500**	**250.500**	**253.500**	**256.500**	**259.500**	**262.500**	**265.500**

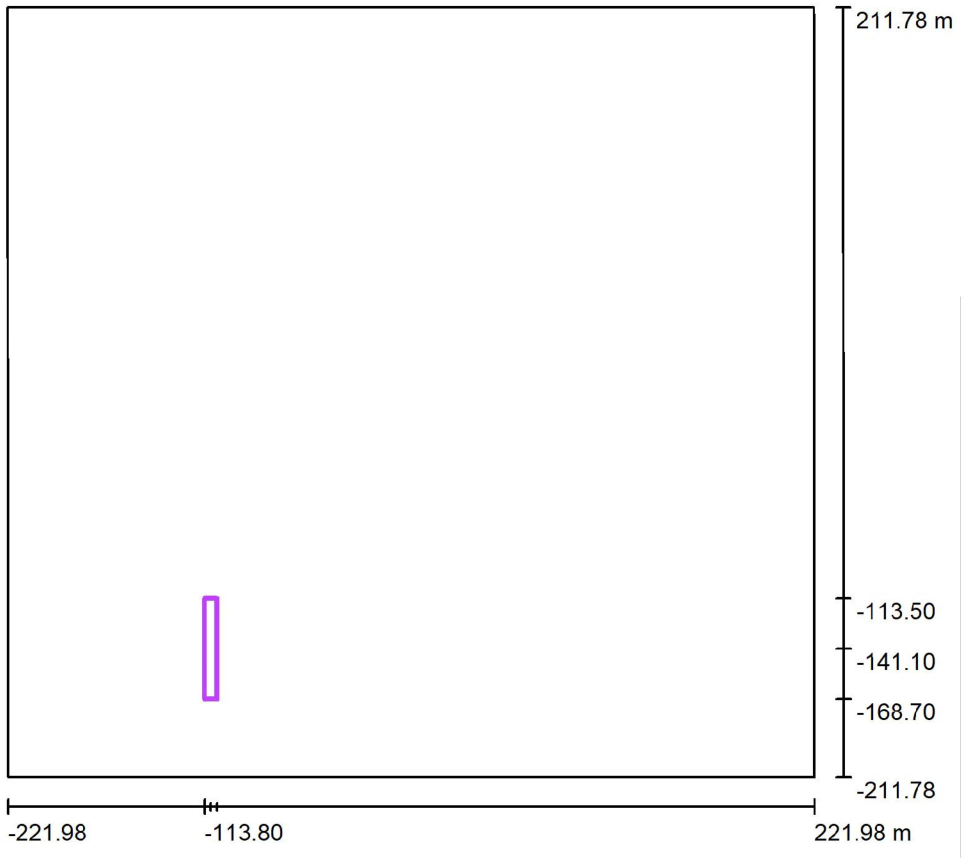
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 89 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.02	5.38	15	0.67	0.37

Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards VLSI Building / Summary



Scale 1 : 4039

Position: (-110.300 m, -141.100 m, 0.052 m)
Size: (7.000 m, 55.200 m)
Rotation: (0.0°, 0.0°, 0.0°)
Type: Normal, Grid: 3 x 19 Points

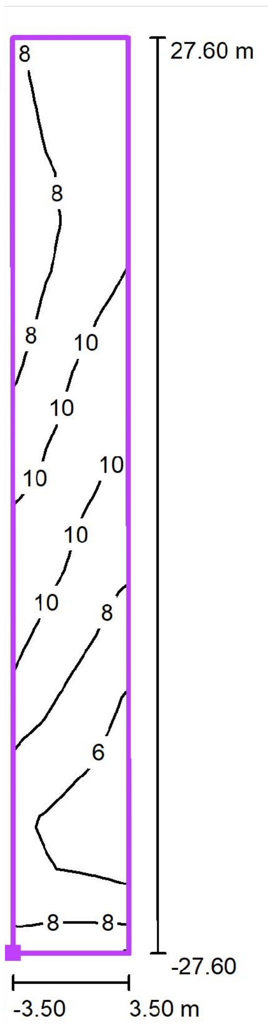
Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\ m}/E_m$	H [m]	Camera
1	horizontal	8.36	4.55	11	0.54	0.42	/	0.000	/

$E_{h\ m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

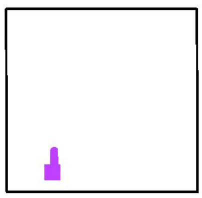
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards VLSI Building / Isolines (E, Horizontal)



Values in Lux, Scale 1 : 443

Position of surface in external scene:
Marked point: (-113.800 m, -168.700 m, 0.052 m)

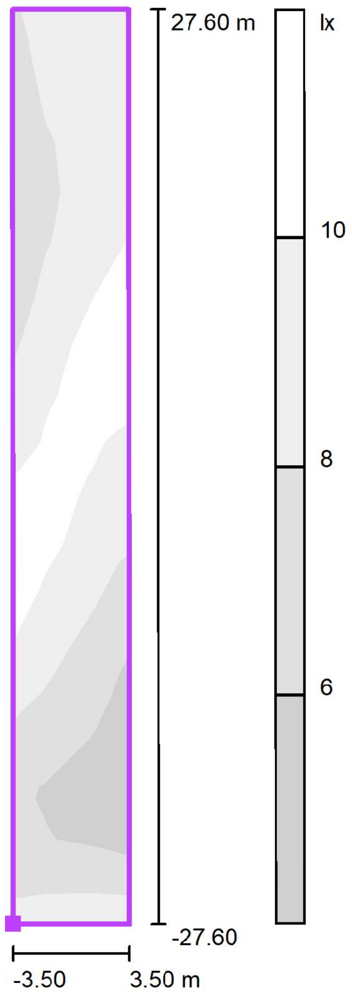


Grid: 3 x 19 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.36	4.55	11	0.54	0.42

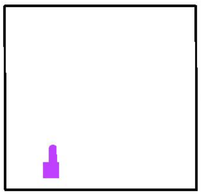
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards VLSI Building / Greyscale (E, Horizontal)



Scale 1 : 443

Position of surface in external scene:
Marked point: (-113.800 m, -168.700 m, 0.052 m)

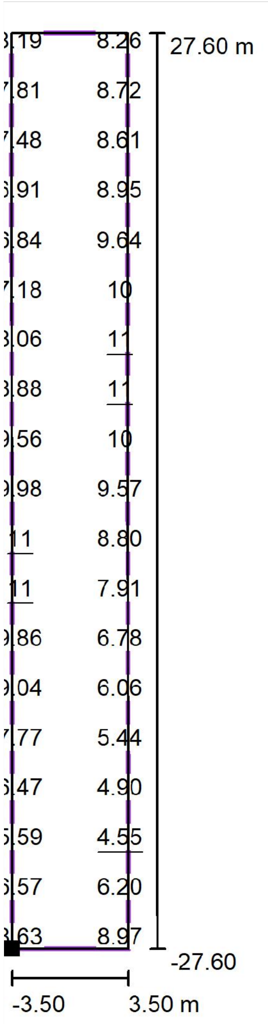


Grid: 3 x 19 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.36	4.55	11	0.54	0.42

Operator
Telephone
Fax
e-Mail

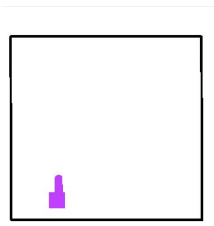
Exterior Scene 1 / Road towards VLSI Building / Value Chart (E, Horizontal)



Values in Lux, Scale 1 : 443

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point: (-113.800 m, -168.700 m, 0.052 m)



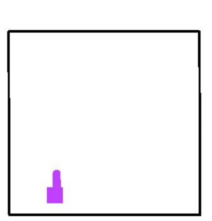
Grid: 3 x 19 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.36	4.55	11	0.54	0.42

Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards VLSI Building / Table (E, Horizontal)

Position of surface in external scene:
Marked point: (-113.800 m, -168.700 m, 0.052 m)



55.500	8.19	9.29	8.26
52.500	7.81	8.95	8.72
49.500	7.48	8.67	8.61
46.500	6.91	8.33	8.95
43.500	6.84	8.46	9.64
40.500	7.18	8.93	10
37.500	8.06	10	11
34.500	8.88	11	11
31.500	9.56	10	10
28.500	9.98	10	9.57
25.500	11	11	8.80
22.500	11	9.91	7.91
19.500	9.86	8.62	6.78
16.500	9.04	7.91	6.06
13.500	7.77	7.06	5.44
10.500	6.47	6.01	4.90
7.500	5.59	5.37	4.55
4.500	6.57	6.76	6.20
1.500	8.63	8.99	8.97
m	**1.500**	**4.500**	**7.500**

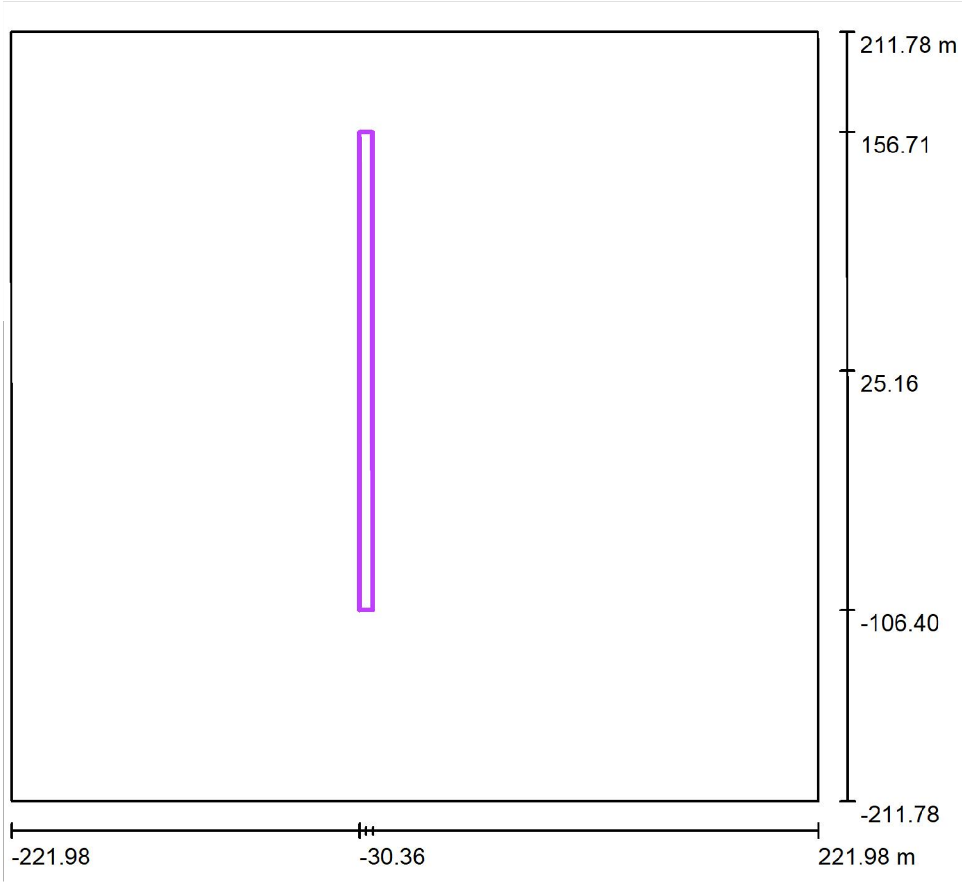
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 3 x 19 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
8.36	4.55	11	0.54	0.42

Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / road towards library / Summary



Scale 1 : 4039

Position: (-26.792 m, 25.157 m, 0.052 m)
Size: (7.145 m, 263.114 m)
Rotation: (0.0°, 0.0°, 0.0°)
Type: Normal, Grid: 3 x 88 Points

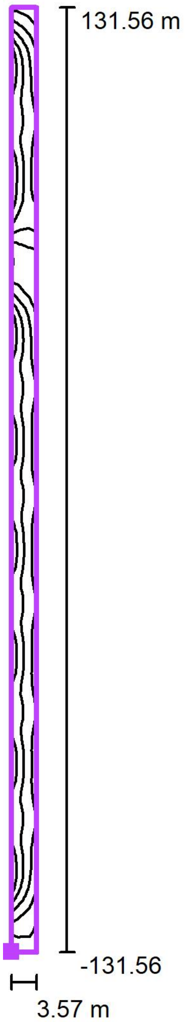
Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	6.38	2.87	8.72	0.45	0.33	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

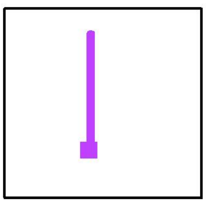
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / road towards library / Isolines (E, Horizontal)



Values in Lux, Scale 1 : 2110

Position of surface in external scene:
Marked point: (-30.365 m, -106.400 m, 0.052 m)

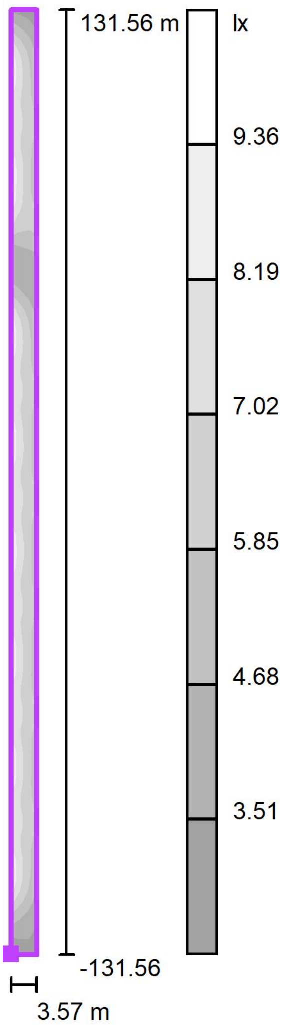


Grid: 3 x 88 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.38	2.87	8.72	0.45	0.33

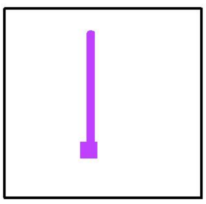
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / road towards library / Greyscale (E, Horizontal)



Scale 1 : 2110

Position of surface in external scene:
Marked point: (-30.365 m, -106.400 m, 0.052 m)

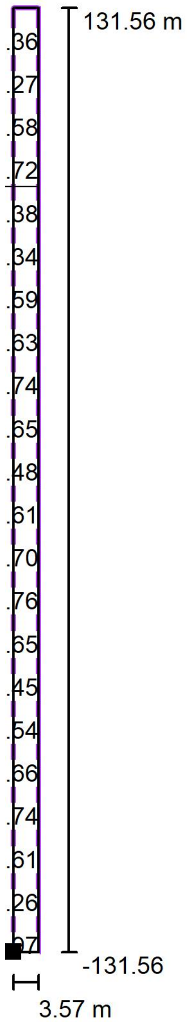


Grid: 3 x 88 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.38	2.87	8.72	0.45	0.33

Operator
Telephone
Fax
e-Mail

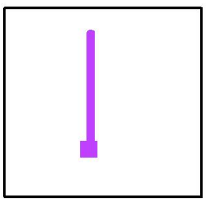
Exterior Scene 1 / road towards library / Value Chart (E, Horizontal)



Values in Lux, Scale 1 : 2110

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point: (-30.365 m, -106.400 m, 0.052 m)

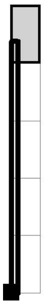


Grid: 3 x 88 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.38	2.87	8.72	0.45	0.33

Operator
Telephone
Fax
e-Mail

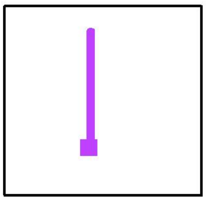
Exterior Scene 1 / road towards library / Table (E, Horizontal)



Current Selection

Further Selections

Position of surface in external scene:
Marked point: (-30.365 m, -106.400 m, 0.052 m)



262.500	3.51	3.41	<u>2.87</u>
259.500	4.81	4.20	3.39
256.500	6.03	5.14	4.01
253.500	7.36	6.07	4.55
250.500	8.39	6.63	4.96
247.500	8.57	6.84	5.21
244.500	8.61	6.90	5.33
241.500	8.27	6.85	5.34
m	**1.500**	**4.500**	**7.500**

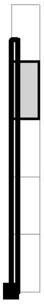
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 3 x 88 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.38	2.87	8.72	0.45	0.33

Operator
Telephone
Fax
e-Mail

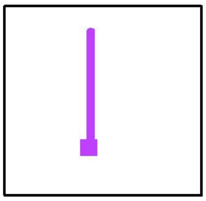
Exterior Scene 1 / road towards library / Table (E, Horizontal)



Current Selection

Further Selections

Position of surface in external scene:
Marked point: (-30.365 m, -106.400 m, 0.052 m)



238.500	7.60	6.74	5.54
235.500	7.54	6.99	5.81
232.500	7.67	7.18	5.99
229.500	7.58	7.01	5.87
226.500	7.45	6.78	5.64
223.500	7.95	6.82	5.46
220.500	8.68	6.99	5.40
217.500	8.72	6.99	5.38
214.500	8.70	6.94	5.33
211.500	8.57	6.86	5.42
208.500	8.12	6.70	5.95
205.500	7.38	6.22	6.21
202.500	6.46	5.87	6.10
199.500	5.28	5.33	5.53
196.500	3.98	4.40	4.74
193.500	3.34	3.82	4.05
190.500	3.76	3.96	3.76
187.500	4.49	4.22	3.64
184.500	5.39	4.71	3.84
181.500	6.59	5.61	4.37
m	**1.500**	**4.500**	**7.500**

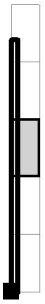
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 3 x 88 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.38	2.87	8.72	0.45	0.33

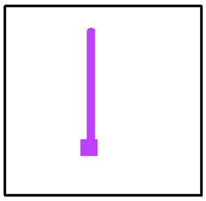
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / road towards library / Table (E, Horizontal)



Current Selection
Further Selections

Position of surface in external scene:
Marked point: (-30.365 m, -106.400 m, 0.052 m)



178.500	7.87	6.35	4.75
175.500	8.49	6.78	5.13
172.500	8.60	6.88	5.29
169.500	8.63	6.95	5.36
166.500	8.01	6.80	5.38
163.500	7.44	6.75	5.60
160.500	7.58	7.00	5.85
157.500	7.74	7.20	6.00
154.500	7.62	7.00	5.83
151.500	7.54	6.76	5.58
148.500	8.26	6.87	5.40
145.500	8.65	7.01	5.44
142.500	8.66	6.97	5.42
139.500	8.68	7.00	5.44
136.500	8.05	6.84	5.43
133.500	7.48	6.78	5.62
130.500	7.63	7.03	5.87
127.500	7.81	7.25	6.03
124.500	7.69	7.05	5.87
121.500	7.61	6.81	5.61
m	**1.500**	**4.500**	**7.500**

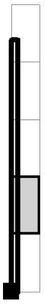
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 3 x 88 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.38	2.87	8.72	0.45	0.33

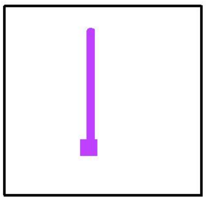
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / road towards library / Table (E, Horizontal)



Current Selection
Further Selections

Position of surface in external scene:
Marked point: (-30.365 m, -106.400 m, 0.052 m)



118.500	8.32	6.91	5.43
115.500	8.70	7.04	5.46
112.500	8.69	7.00	5.44
109.500	8.70	7.02	5.45
106.500	8.05	6.84	5.44
103.500	7.47	6.78	5.63
100.500	7.60	7.02	5.87
97.500	7.76	7.22	6.01
94.500	7.63	7.01	5.84
91.500	7.55	6.77	5.58
88.500	8.26	6.87	5.41
85.500	8.65	7.01	5.44
82.500	8.65	6.97	5.42
79.500	8.66	7.00	5.43
76.500	8.03	6.82	5.42
73.500	7.45	6.77	5.61
70.500	7.59	7.01	5.86
67.500	7.74	7.20	6.00
64.500	7.62	7.00	5.83
61.500	7.54	6.76	5.58
m	**1.500**	**4.500**	**7.500**

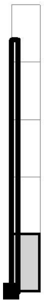
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 3 x 88 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.38	2.87	8.72	0.45	0.33

Operator
Telephone
Fax
e-Mail

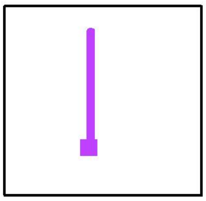
Exterior Scene 1 / road towards library / Table (E, Horizontal)



Current Selection

Further Selections

Position of surface in external scene:
Marked point: (-30.365 m, -106.400 m, 0.052 m)



58.500	8.25	6.87	5.40
55.500	8.65	7.00	5.43
52.500	8.65	6.96	5.42
49.500	8.66	6.99	5.43
46.500	8.03	6.82	5.42
43.500	7.45	6.76	5.61
40.500	7.58	7.00	5.85
37.500	7.74	7.20	5.99
34.500	7.61	6.99	5.82
31.500	7.53	6.74	5.55
28.500	8.23	6.84	5.36
25.500	8.61	6.95	5.35
22.500	8.59	6.86	5.26
19.500	8.46	6.71	5.06
16.500	7.56	6.21	4.66
13.500	6.26	5.38	4.24
10.500	5.13	4.53	3.75
7.500	4.11	4.01	3.53
4.500	3.25	3.51	3.37
1.500	2.97	3.36	3.31
m	**1.500**	**4.500**	**7.500**

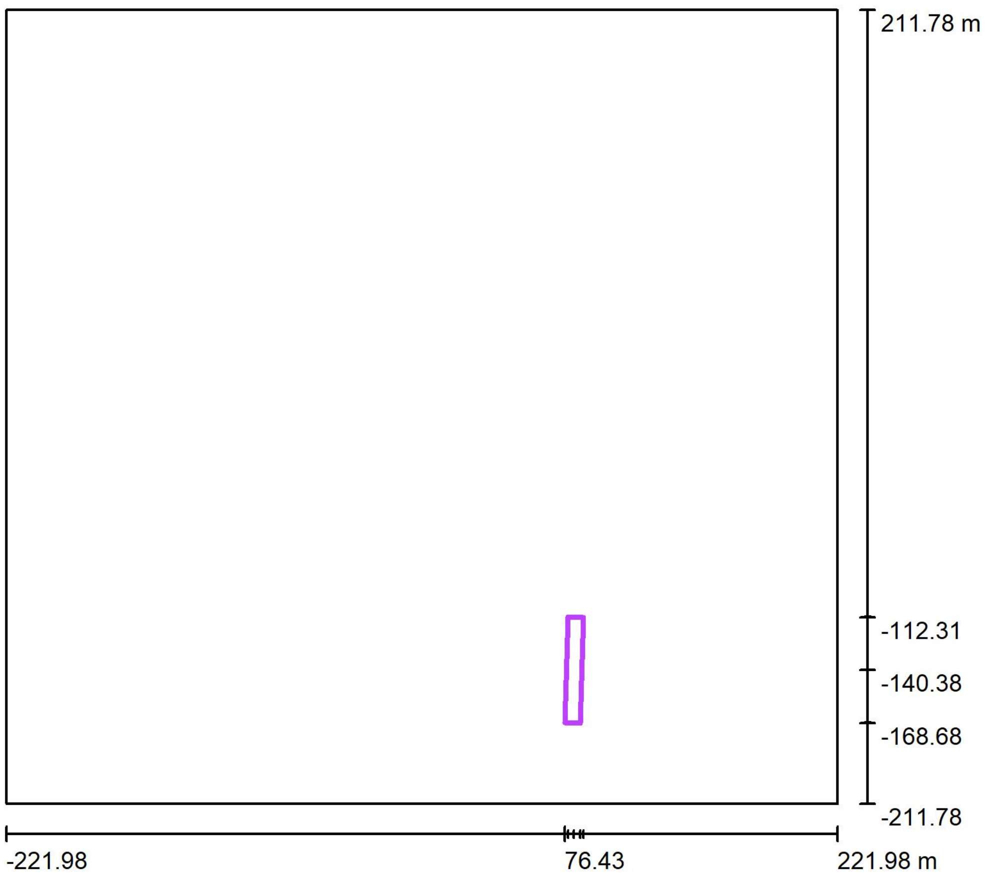
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 3 x 88 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.38	2.87	8.72	0.45	0.33

Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards mechanical building / Summary



Scale 1 : 4039

Position: (81.318 m, -140.384 m, 0.052 m)
Size: (8.200 m, 56.389 m)
Rotation: (0.0°, 0.0°, -1.6°)
Type: Normal, Grid: 3 x 19 Points

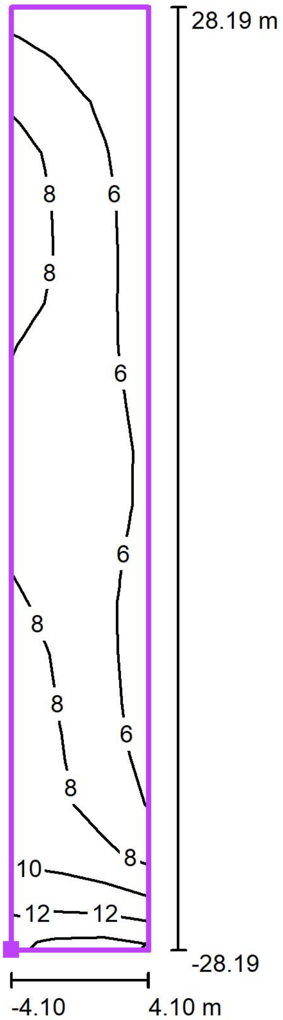
Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	7.35	4.24	14	0.58	0.31	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

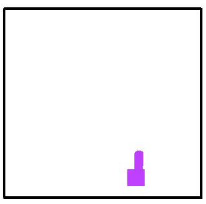
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards mechanical building / Isolines (E, Horizontal)



Values in Lux, Scale 1 : 452

Position of surface in external scene:
Marked point: (76.433 m, -168.452 m, 0.052 m)

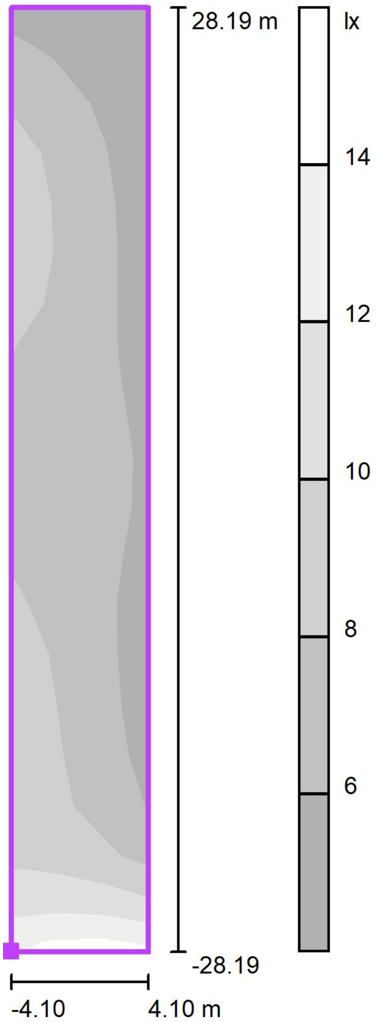


Grid: 3 x 19 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
7.35	4.24	14	0.58	0.31

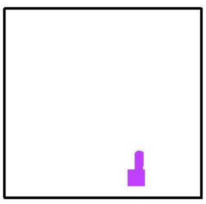
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards mechanical building / Greyscale (E, Horizontal)



Scale 1 : 452

Position of surface in external scene:
Marked point: (76.433 m, -168.452 m, 0.052 m)

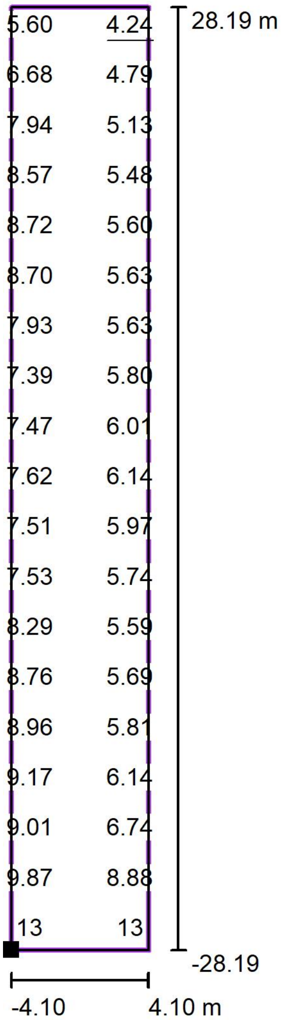


Grid: 3 x 19 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
7.35	4.24	14	0.58	0.31

Operator
Telephone
Fax
e-Mail

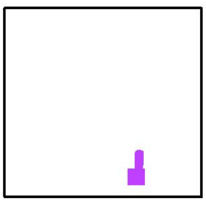
Exterior Scene 1 / Road towards mechanical building / Value Chart (E, Horizontal)



Values in Lux, Scale 1 : 452

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point: (76.433 m, -168.452 m, 0.052 m)

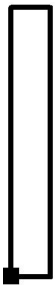


Grid: 3 x 19 Points

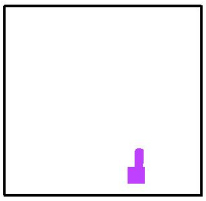
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
7.35	4.24	14	0.58	0.31

Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards mechanical building / Table (E, Horizontal)



Position of surface in external scene:
Marked point: (76.433 m, -168.452 m, 0.052 m)



55.500	5.60	5.14	4.24
52.500	6.68	5.99	4.79
49.500	7.94	6.71	5.13
46.500	8.57	7.11	5.48
43.500	8.72	7.18	5.60
40.500	8.70	7.22	5.63
37.500	7.93	6.99	5.63
34.500	7.39	6.90	5.80
31.500	7.47	7.14	6.01
28.500	7.62	7.36	6.14
25.500	7.51	7.12	5.97
22.500	7.53	6.88	5.74
19.500	8.29	7.04	5.59
16.500	8.76	7.25	5.69
13.500	8.96	7.35	5.81
10.500	9.17	7.67	6.14
7.500	9.01	8.18	6.74
4.500	9.87	9.86	8.88
1.500	13	14	13
m	**1.500**	**4.500**	**7.500**

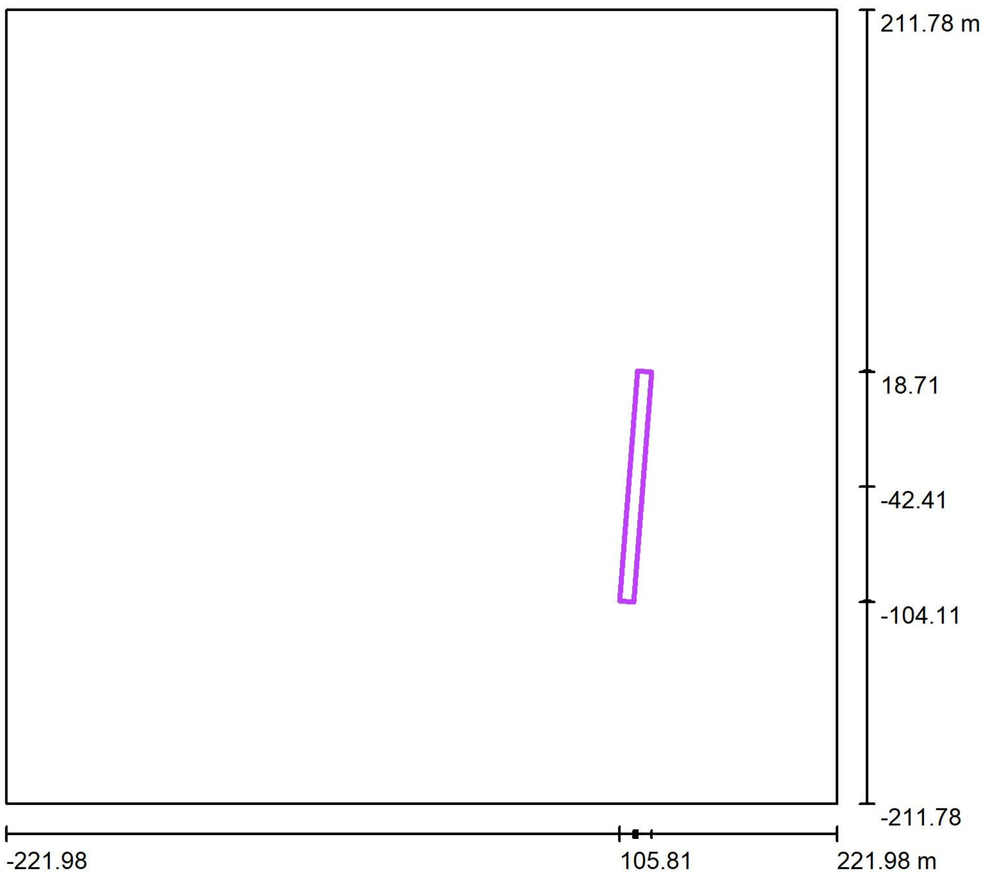
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 3 x 19 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
7.35	4.24	14	0.58	0.31

Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards laser building / Summary



Scale 1 : 4039

Position: (114.338 m, -42.408 m, 0.052 m)
Size: (7.624 m, 123.184 m)
Rotation: (0.0°, 0.0°, -4.4°)
Type: Normal, Grid: 3 x 42 Points

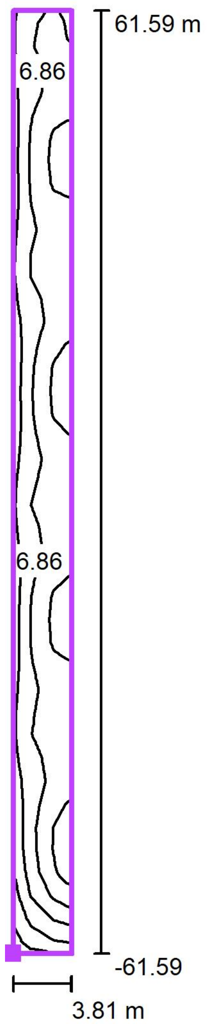
Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	6.86	3.65	8.54	0.53	0.43	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

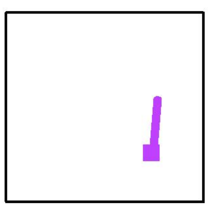
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards laser building / Isolines (E, Horizontal)



Values in Lux, Scale 1 : 987

Position of surface in external scene:
Marked point: (105.812 m, -103.526 m, 0.052 m)

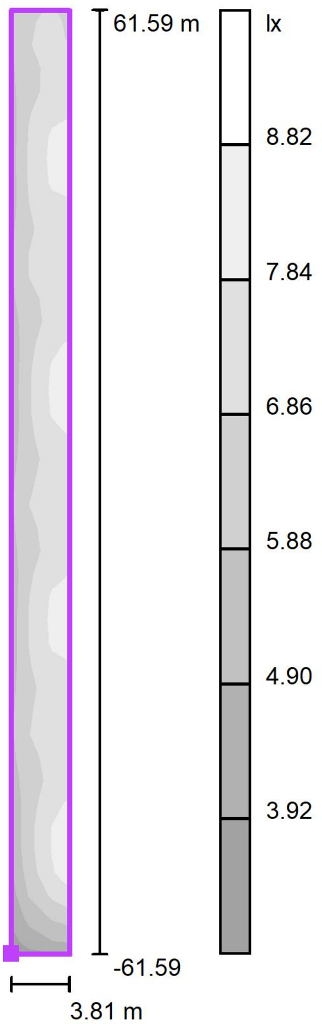


Grid: 3 x 42 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.86	3.65	8.54	0.53	0.43

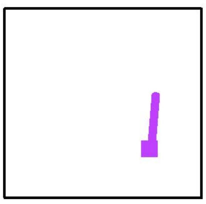
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards laser building / Greyscale (E, Horizontal)



Scale 1 : 987

Position of surface in external scene:
Marked point: (105.812 m, -103.526 m, 0.052 m)

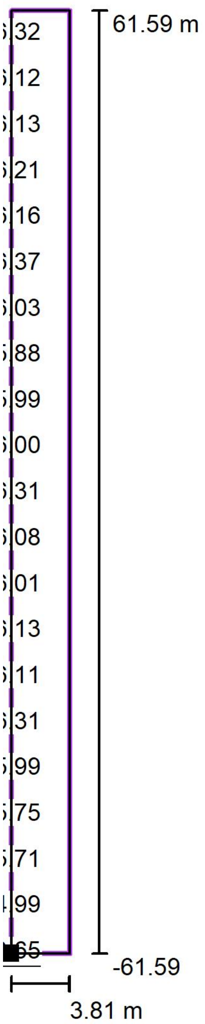


Grid: 3 x 42 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.86	3.65	8.54	0.53	0.43

Operator
Telephone
Fax
e-Mail

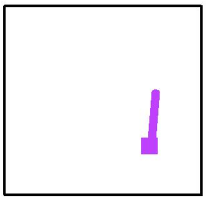
Exterior Scene 1 / Road towards laser building / Value Chart (E, Horizontal)



Values in Lux, Scale 1 : 987

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point: (105.812 m, -103.526 m, 0.052 m)

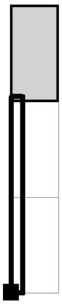


Grid: 3 x 42 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.86	3.65	8.54	0.53	0.43

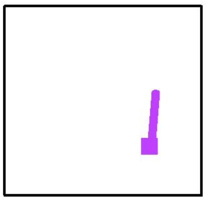
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards laser building / Table (E, Horizontal)



Current Selection
Further Selections

Position of surface in external scene:
Marked point: (105.812 m, -103.526 m, 0.052 m)



124.500	6.19	7.17	6.76
121.500	6.32	7.39	6.92
m	**1.500**	**4.500**	**7.500**

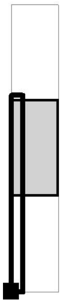
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 3 x 42 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.86	3.65	8.54	0.53	0.43

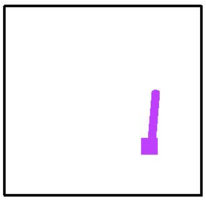
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road towards laser building / Table (E, Horizontal)



Current Selection
Further Selections

Position of surface in external scene:
Marked point: (105.812 m, -103.526 m, 0.052 m)



118.500	6.25	7.31	6.91
115.500	6.12	7.03	6.89
112.500	6.10	7.23	7.30
109.500	6.13	7.70	8.14
106.500	6.23	7.72	8.43
103.500	6.21	7.74	8.43
100.500	6.15	7.72	8.00
97.500	6.16	7.31	7.15
94.500	6.23	7.30	6.99
91.500	6.37	7.52	7.05
88.500	6.27	7.36	7.01
85.500	6.03	7.00	6.99
82.500	5.89	7.05	7.43
79.500	5.88	7.45	8.27
76.500	5.98	7.47	8.54
73.500	5.99	7.51	8.54
70.500	5.94	7.50	8.18
67.500	6.00	7.14	7.30
64.500	6.11	7.14	7.02
61.500	6.31	7.45	7.07
m	**1.500**	**4.500**	**7.500**

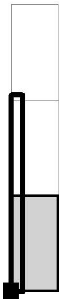
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 3 x 42 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.86	3.65	8.54	0.53	0.43

Operator
Telephone
Fax
e-Mail

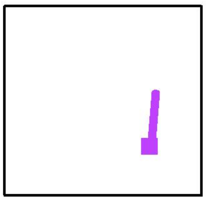
Exterior Scene 1 / Road towards laser building / Table (E, Horizontal)



Current Selection

Further Selections

Position of surface in external scene:
Marked point: (105.812 m, -103.526 m, 0.052 m)



58.500	6.27	7.40	7.04
55.500	6.08	7.07	6.98
52.500	6.00	7.16	7.31
49.500	6.01	7.59	8.17
46.500	6.11	7.63	8.48
43.500	6.13	7.66	8.48
40.500	6.08	7.65	8.12
37.500	6.11	7.26	7.25
34.500	6.17	7.21	7.05
31.500	6.31	7.46	7.09
28.500	6.24	7.34	7.07
25.500	5.99	6.98	7.02
22.500	5.82	6.98	7.42
19.500	5.75	7.32	8.26
16.500	5.81	7.32	8.53
13.500	5.71	7.27	8.48
10.500	5.40	7.07	8.00
7.500	4.99	6.28	6.81
4.500	4.23	5.16	5.56
1.500	3.65	4.34	4.34
m	**1.500**	**4.500**	**7.500**

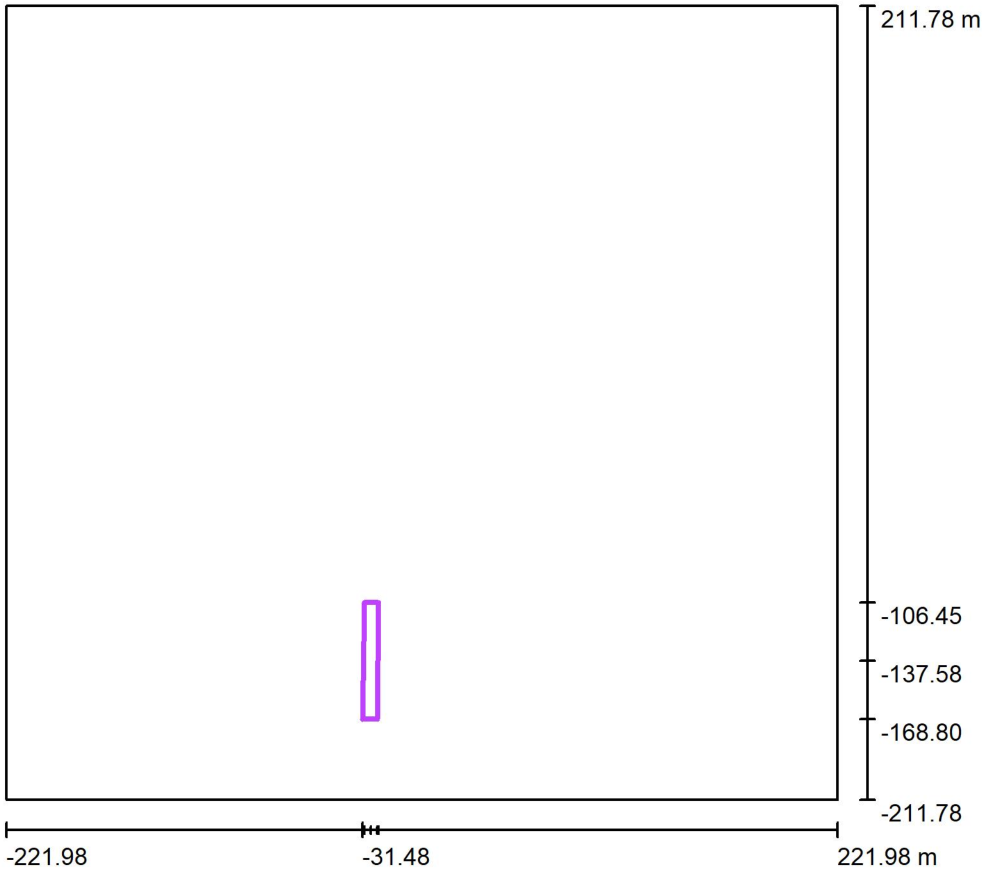
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 3 x 42 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.86	3.65	8.54	0.53	0.43

Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road beside SISED Building / Summary



Scale 1 : 4039

Position: (-27.225 m, -137.578 m, 0.052 m)
Size: (7.742 m, 62.363 m)
Rotation: (0.0°, 0.0°, -0.7°)
Type: Normal, Grid: 3 x 21 Points

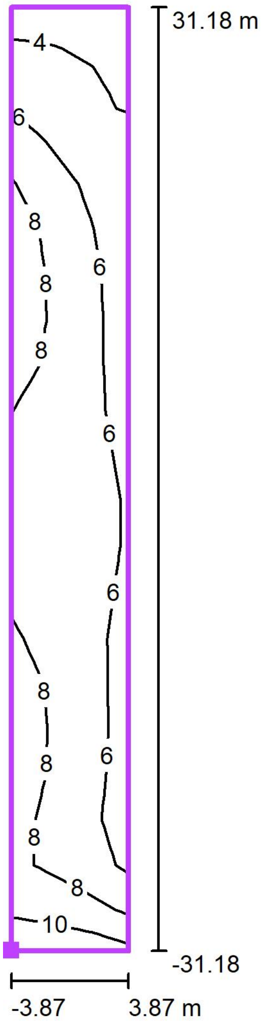
Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\,m}/E_m$	H [m]	Camera
1	horizontal	6.72	3.48	11	0.52	0.33	/	0.000	/

$E_{h\,m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

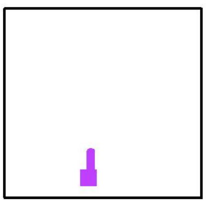
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road beside SISED Building / Isolines (E, Horizontal)



Values in Lux, Scale 1 : 500

Position of surface in external scene:
Marked point: (-31.477 m, -168.710 m, 0.052 m)

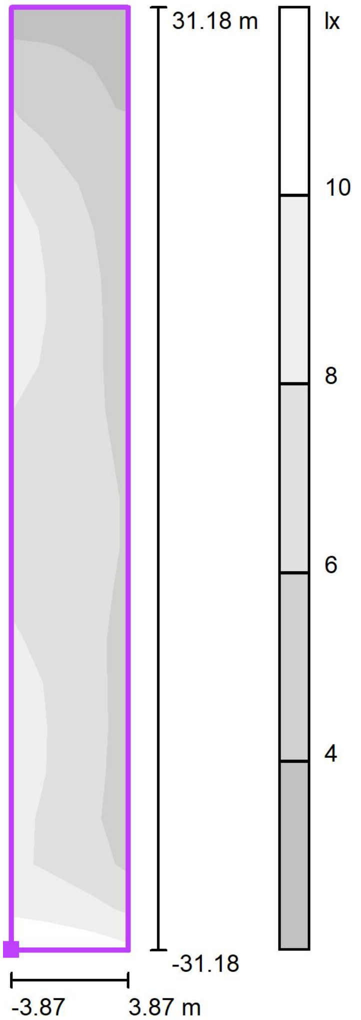


Grid: 3 x 21 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.72	3.48	11	0.52	0.33

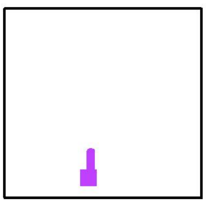
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road beside SISED Building / Greyscale (E, Horizontal)



Scale 1 : 500

Position of surface in external scene:
Marked point: (-31.477 m, -168.710 m, 0.052 m)

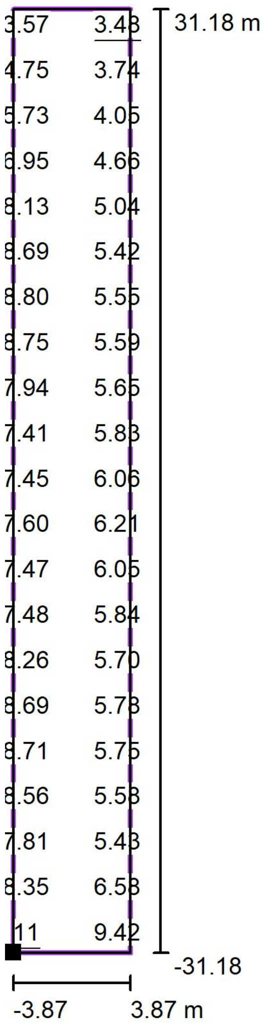


Grid: 3 x 21 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.72	3.48	11	0.52	0.33

Operator
Telephone
Fax
e-Mail

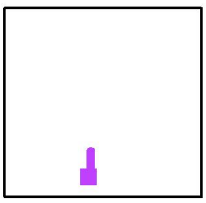
Exterior Scene 1 / Road beside SISED Building / Value Chart (E, Horizontal)



Values in Lux, Scale 1 : 500

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point: (-31.477 m, -168.710 m, 0.052 m)

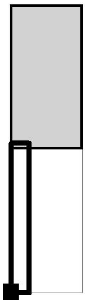


Grid: 3 x 21 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.72	3.48	11	0.52	0.33

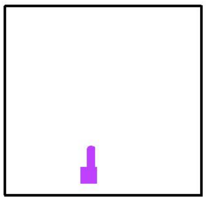
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road beside SISED Building / Table (E, Horizontal)



Current Selection
Further Selections

Position of surface in external scene:
Marked point: (-31.477 m, -168.710 m, 0.052 m)



61.500	3.57	3.69	3.48
m	**1.500**	**4.500**	**7.500**

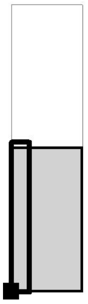
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 3 x 21 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.72	3.48	11	0.52	0.33

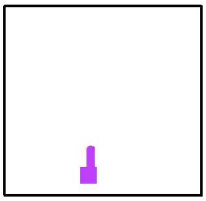
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Road beside SISED Building / Table (E, Horizontal)



Current Selection
Further Selections

Position of surface in external scene:
Marked point: (-31.477 m, -168.710 m, 0.052 m)



58.500	4.75	4.35	3.74
55.500	5.73	4.96	4.05
52.500	6.95	5.94	4.66
49.500	8.13	6.66	5.04
46.500	8.69	7.05	5.42
43.500	8.80	7.15	5.55
40.500	8.75	7.19	5.59
37.500	7.94	6.98	5.65
34.500	7.41	6.93	5.83
31.500	7.45	7.19	6.06
28.500	7.60	7.42	6.21
25.500	7.47	7.21	6.05
22.500	7.48	6.98	5.84
19.500	8.26	7.17	5.70
16.500	8.69	7.35	5.78
13.500	8.71	7.31	5.75
10.500	8.56	7.29	5.58
7.500	7.81	6.96	5.43
4.500	8.35	7.92	6.58
1.500	11	10	9.42
m	**1.500**	**4.500**	**7.500**

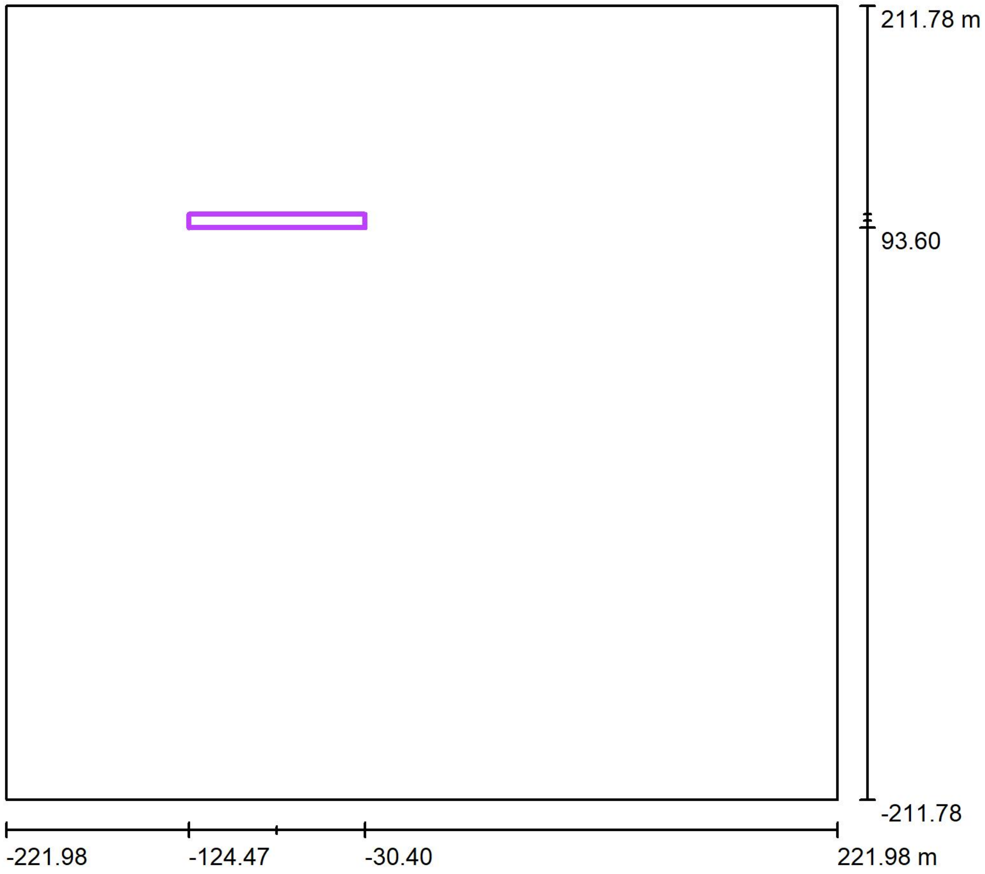
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 3 x 21 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.72	3.48	11	0.52	0.33

Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Way to Gate No. 3 / Summary



Scale 1 : 4039

Position: (-77.437 m, 97.200 m, 0.052 m)
Size: (94.074 m, 7.200 m)
Rotation: (0.0°, 0.0°, 0.0°)
Type: Normal, Grid: 32 x 3 Points

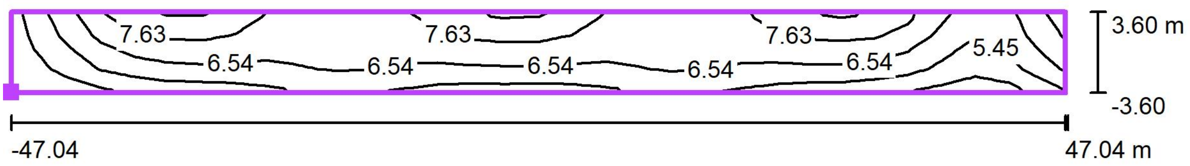
Results overview

No.	Type	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}	$E_{h\ m}/E_m$	H [m]	Camera
1	horizontal	6.54	3.27	8.72	0.50	0.38	/	0.000	/

$E_{h\ m}/E_m$ = Relationship between middle horizontal and vertical illuminance, H = Measuring Height

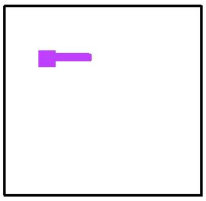
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Way to Gate No. 3 / Isolines (E, Horizontal)



Values in Lux, Scale 1 : 673

Position of surface in external scene:
Marked point: (-124.474 m, 93.600 m, 0.052 m)

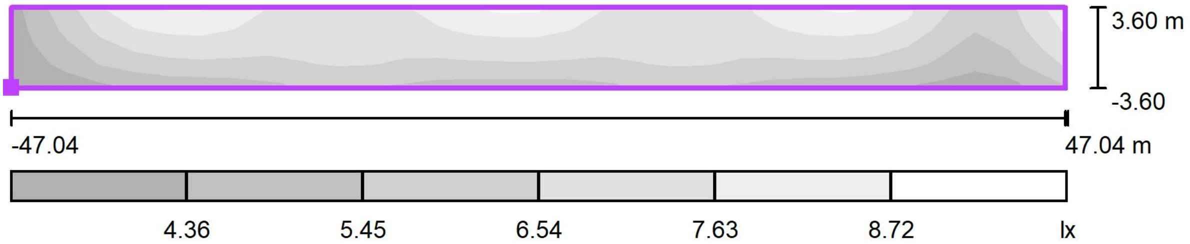


Grid: 32 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.54	3.27	8.72	0.50	0.38

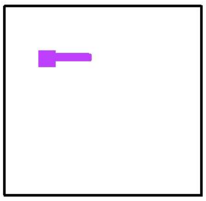
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Way to Gate No. 3 / Greyscale (E, Horizontal)



Scale 1 : 673

Position of surface in external scene:
Marked point: (-124.474 m, 93.600 m, 0.052 m)

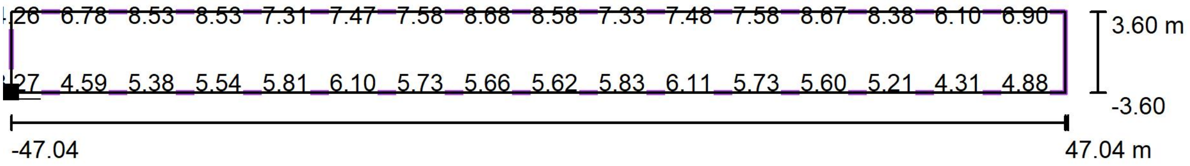


Grid: 32 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.54	3.27	8.72	0.50	0.38

Operator
Telephone
Fax
e-Mail

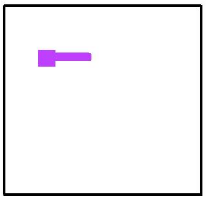
Exterior Scene 1 / Way to Gate No. 3 / Value Chart (E, Horizontal)



Values in Lux, Scale 1 : 673

Not all calculated values could be displayed.

Position of surface in external scene:
Marked point: (-124.474 m, 93.600 m, 0.052 m)

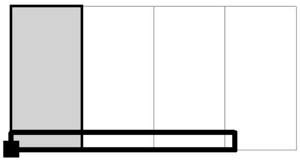


Grid: 32 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.54	3.27	8.72	0.50	0.38

Operator
Telephone
Fax
e-Mail

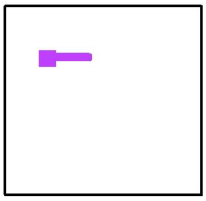
Exterior Scene 1 / Way to Gate No. 3 / Table (E, Horizontal)



Current Selection

Further Selections

Position of surface in external scene:
Marked point: (-124.474 m,
93.600 m, 0.052 m)



7.500	4.26	5.47	6.78	8.00	8.53	8.65	8.53	7.72	7.31	7.39
4.500	3.98	4.79	5.89	6.63	6.93	7.11	7.14	6.90	6.90	7.16
1.500	<u>3.27</u>	3.82	4.59	5.00	5.38	5.53	5.54	5.64	5.81	6.01
m	**1.500**	**4.500**	**7.500**	**10.500**	**13.500**	**16.500**	**19.500**	**22.500**	**25.500**	**28.500**

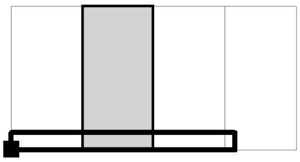
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 32 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.54	3.27	8.72	0.50	0.38

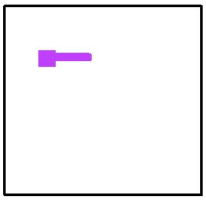
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Way to Gate No. 3 / Table (E, Horizontal)



Current Selection
Further Selections

Position of surface in external scene:
Marked point: (-124.474 m,
93.600 m, 0.052 m)



7.500	7.47	7.38	7.58	8.36	8.68	8.72	8.58	7.75	7.33	7.40
4.500	7.28	7.05	6.91	7.09	7.14	7.20	7.19	6.94	6.92	7.18
1.500	6.10	5.92	5.73	5.59	5.66	5.66	5.62	5.69	5.83	6.03
m	**31.500**	**34.500**	**37.500**	**40.500**	**43.500**	**46.500**	**49.500**	**52.500**	**55.500**	**58.500**

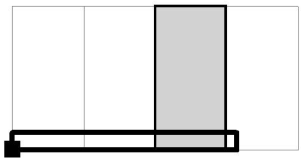
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 32 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.54	3.27	8.72	0.50	0.38

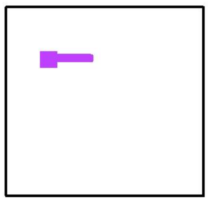
Operator
Telephone
Fax
e-Mail

Exterior Scene 1 / Way to Gate No. 3 / Table (E, Horizontal)



Current Selection
Further Selections

Position of surface in external scene:
Marked point: (-124.474 m,
93.600 m, 0.052 m)



7.500	7.48	7.40	7.58	8.36	8.67	8.67	8.38	7.29	6.10	5.49
4.500	7.29	7.06	6.91	7.08	7.11	7.10	6.90	6.27	5.35	5.04
1.500	6.11	5.93	5.73	5.56	5.60	5.49	5.21	4.85	4.31	4.03
m	**61.500**	**64.500**	**67.500**	**70.500**	**73.500**	**76.500**	**79.500**	**82.500**	**85.500**	**88.500**

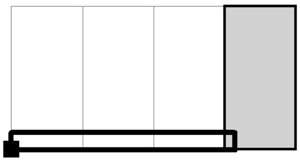
Attention: The coordinates refer to the image above. Values in Lux.

Grid: 32 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.54	3.27	8.72	0.50	0.38

Operator
Telephone
Fax
e-Mail

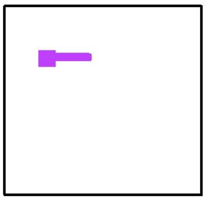
Exterior Scene 1 / Way to Gate No. 3 / Table (E, Horizontal)



Current Selection

Further Selections

Position of surface in external scene:
Marked point: (-124.474 m,
93.600 m, 0.052 m)



7.500	6.90	7.96
4.500	6.35	7.19
1.500	4.88	5.84
m	**91.500**	**94.500**

Attention: The coordinates refer to the image above. Values in Lux.

Grid: 32 x 3 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
6.54	3.27	8.72	0.50	0.38