



**CARIBBEAN RENEWABLE ENERGY
DEVELOPMENT PROGRAMME
- CREDP/GIZ -**



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**LED Street Lighting Pilot Project
VINLEC
St. Vincent and the Grenadines

Final Report**

Carried out for:

**VINLEC
St. Vincent and the Grenadines**

On behalf of:

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Program Background

CREDP is a joint Project of CARICOM and the German International Cooperation (GIZ; formerly GTZ). The project is implemented by the Consortium of Projekt-Consult GmbH, Germany and Entec AG, Switzerland on behalf of the GIZ, financed by the Federal German Ministry of Economic Cooperation and Development (BMZ).

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1. BACKGROUND

Among other electric utilities in the Caribbean, the St. Vincent Electricity Services Ltd. (VINLEC) is investigating options to replace the currently used High Pressure Sodium lights (HPS) with energy efficient Light-Emitting Diode Street Lighting (LED SL) to save electricity cost while at the same time maintaining or increasing the street lighting quality.

Therefore, VINLEC set up a pilot project for LED SL in St. Vincent. The goal of the pilot project has not been to find a particular LED luminaire type or manufacturer to supply luminaires to St. Vincent and the Grenadines. It was rather intended to gain experience on technical qualities of LED SL luminaires, their installation requirements, operation and the testing and evaluation of LED SL.

It has been important to identify critical aspects to be addressed in the technical luminaire specification in future tendering processes for street light replacement or installation. This information will assist entities responsible for the installation or replacement, operation and maintenance of street lights to clearly specify the requirements for LED SL and to sample, test and evaluate products offered by suppliers to ensure that good quality luminaires will be supplied and installed.

For the pilot project VINLEC defined the lighting quality requirements for road lighting in St. Vincent and the Grenadines from which a tender document was derived for the procurement of lamps to be tested. The funds for the procurement of the luminaires were provided by the Austrian Development Cooperation through the Caribbean Renewable Energy Development Programme CREDP-GIZ.

A number of 25 suitable lamp manufacturers were identified from internet research and investigation of professional data bases. A tender dossier was sent out to those 25 manufacturers of which six (6) responded. Based on the supplied technical product data and the available budget, 22 LED lamps were procured from each of the six manufacturers to be tested in the pilot.

During the testing phase, three more suppliers of LED SL approached the project team and offered to supply luminaires to be included in the tests free of charge, which was accepted by the project team. Due to smaller numbers of luminaires available from the three additional suppliers, not all tests could be done for those luminaires as was done for the six originally selected luminaire families. Therefore the testing and evaluation of the additional luminaires shows some gaps, that do, however, not jeopardize the overall output of the pilot project.

The results of the pilot project will be shared with other islands and territories with similar climatic conditions.

Each of the six manufacturers that responded to the call for proposals supplied four different luminaires for the replacement of the 50W, 100W, 150W and 250W HPS lamps currently being used in St. Vincent and the Grenadines. The three additional suppliers have sent samples to replace the 100W HPS fixtures only.

In summary the following suppliers / manufacturers were involved in this project:

Company	Manufacturer	Supplier
Suppliers that responded to the Call for Proposals		
Lemnis Lighting	Lemnis Lighting	Lemnis Lighting
LED Roadway Lighting	LED Roadway Lighting	LED Roadway Lighting
Peco International Electric In	GE Lighting	Peco International Electric In
Urbis lighting ltd	Schröder	Urbis lighting ltd
Contemporary Lighting Sales Inc.	American Electric Lighting (AEL)	Contemporary Lighting Sales Inc.
Maxlite Inc	Maxlite Inc	Maxlite Inc
Additional suppliers that offered products for free		
Caribbean LED Lighting Ltd (CLLL)		Caribbean LED Lighting Ltd (CLLL)
LEDenergy	Grah Lighting	LEDenergy
Swarco Austria	Swarco Austria	Swarco Austria

This pilot project is not intended to identify the single best manufacturer of LED street light products but serves to gain experience with the technology in the Caribbean region. Therefore, in the following the company names are substituted with letters A to I that do not correlate to the order of the companies in the list above.

For the pilot project a concept was developed which comprises the following steps:

- Step 1: Specifying the lighting requirements for several SL situations, such as roads in town, mayor rural roads, minor rural roads, squares. Define key parameters that lighting equipment has to fulfill in terms of lighting strength, glare level, light distribution, light color, influence area of lights, etc.
- Step 2: From the established requirements Terms of Reference were established that were sent out to manufacturers of LED SL systems in order to request their suggestions for suitable products including all required technical data and a cost quotation.
- Step 3: From the submitted proposals from LED SL manufacturers a number of suitable manufacturers were identified and samples procured and installed at designated test sites.
- Step 4: During a period of one week on average the installations were operated and tested for their different parameters as specified below. Key parameters were energy consumption, quality of light distribution, absolute light strength and the optical acceptability by the public. To facilitate easy comparison, the same light poles were used for the tests and the different fixtures were exchanged for each round of tests. For the acceptability of the selected lighting appliances surveys were made among people in the neighborhood of the test road section in the community.
- Step 5: The different lamp models were then ranked according their performance indicators. After completion of the tests the luminaires were installed spread in the country accompanied by a public awareness campaign to make people aware of the new lighting fixtures. Subsequently the public will be asked to give their opinion about the replacement fixtures in order to measure the public acceptance

- for the new technology.
- Step 6: After compiling all results of the various tests, the applied approach and procedures and their results were summarized in this report that can be used for dissemination of the information in other countries.
- Step 7: Roll-out of the LED-SL replacement on the whole island. This can be done either by VINLEC or through an Energy Service Company (ESCO) or other means of financing and implementation. The economics will define if the complete roll-out will be done in stages according to replacement needs or completely at once for the entire island.

This report describes the results obtained from Steps 1 through 6 of the above concept and shall serve as preparation for Step 7.

2. RECOMMENDATIONS FOR FUTURE LED SL PROJECTS

For future procurement of street lighting fixtures there is a number of criteria that should help to select the most appropriate luminaire. It is important to recognize that the technology of LED street lighting fixtures keeps on developing.

For future tendering for the replacement of street lighting fixtures it's important to define critical parameters that the LED luminaires should comply with in any case:

Energy consumption is a crucial factor. It is important to evaluate the system-wattages to proof that the luminaires comply with the projected energy-saving. The permissible maximum wattage and power factor have to be clearly specified in the tendering documents in order to insure that the projected savings are met.

Lighting characteristics should be specified.

It could be seen from the subjective evaluation with questionnaires handed to passers-by, brightness combined with a good uniformity has the most influence on the good-feeling factor. Therefore a requested illuminance level should be defined to get the right balance between energy-saving and a good acceptance by the public. Based on the test results an average illuminance level of about 10 lx can be reached for the 100 W HPS replacement by maintaining the requested 40 % energy saving. Individual luminaires would even allow higher levels, which is however not recommended to make a requirement. As a reference: According to the European norm 10 lx are representing the level of a 4 lane main street. For the 50 W HPS replacement an average illuminance level of 5 lx seems reasonable. Also the uniformity of the lighting should be defined in the technical specifications. The means to define the uniformity can be either as done in this project (AM = minimum illuminance / average illuminance of the test field) or by a similar means.

Geometry of the street and poles

Usually the supplier/manufacturer should be able to do a lighting-simulation using a specific software to calculate the level of illuminance that can be reached. To do the calculation, the geometry of the street and poles (width of the road, pole distance, mounting heights, tilt and overhang) have to be specified, either for individual luminaires or as general definition of lighting situations (major road, minor road, square, etc.).

The **color temperature** should be defined in the tendering documents with a range of 4.000 K to 5.500 K.

Request free samples

In the tendering process it's important to get a minimum of 3, better 5 LED fixtures as samples, if possible at no cost. It is recommended to open one luminaire and check, whether it complies with the specified parameters regarding its mechanical structure.

Test samples individually...

The samples should be installed for tests on a defined test field, where the horizontal illuminance, energy consumption (system wattage), current, voltage and power factor should be measured and evaluated isolated from other light sources as much as possible. With this data the average illuminance E_{av} and the uniformity AM have to be calculated.

...and in interaction

Installation of sample luminaires on a test road is also recommended. Here, the horizontal illuminance of more than one luminaire interacting can be measured while placed at a realistic situation regarding road geometry, characteristics of the optics, as well as the influence of other light sources. For the test it is recommended to have the supplier or manufacturer on site to give advice how to install and align their luminaire on the pole.

Use of the luminaire

The tendering documents should include a clear statement regarding the use of the luminaire, e.g. for main streets, minor streets, squares and so on, to help the manufacturer to provide the right optics.

Limitation of current

In Europe currents through the LED luminaire higher than 0.75 A are generally considered as being critical due to resulting increased temperatures and thus decreased LED lifetime. This limit should be specified in the tendering documents.

Considerations to photo cells

Most street lights are switched individually by photo cells, and the street light operator usually has already experience with a photo cell manufacturer and the cell reliability. Provided the quality of the currently used photo cell is satisfactory, the new lamp fixtures shall be equipped with a socket that can hold the existing photo cells. Thereby the cost for photocells can be saved as the existing cells can be used on the new lights.

When replacing faulty photo cells in a future stage, considerations should be given to use photo cells that switch the lights on at a lower light level, for example at 60 lx instead of 100 lx. The LED lights do not need a warm up phase and develop their light output more or less instantaneously. Therefore the lights can be switched on a bit later. By changing from 100 lx to 60 lx cells the lights will operate about 5 minutes less every day.

Dimmable lights

Some LED SL manufacturers offer fixtures that allow dimming of the light for a certain time period. For example, between midnight and 5 am the light output could be reduced from 100 % to 60 %, which leads to electricity savings in about the same amount. If desired by the tendering authority, dimmable fixtures should be specified in the tender documents. A high end solution for dimmable LED SL are motion sensors that increase the light output when motion is recognized and lowers the light output afterwards.

Request manufacturer data sheet

The supplier should be asked to provide the main data on the luminaire to be tested (system wattage, current of the LEDs, optical equipment,...). This written information will help to compare the measured values with the data in the data sheet. As LED luminaires' technology is revised and further developed in short cycles, the offered products do not necessarily represent the latest status of research and development.

Luminaire robustness

For the Caribbean it is mandatory to evaluate the build-up of the luminaires. The luminaires must not provide holes allowing salty air entering in the fixture's interior and should be equipped with a sealing ring to protect the inner parts from rain, dust and humidity and prevent corrosion at the electrical components. Furthermore stainless steel screws instead of brackets provide better tightness of the luminaire. Within the lifespan of a LED luminaire no light bulbs have to be replaced and hence maintenance is reduced significantly. Therefore the tightness of the luminaire is much more critical for a longer lifetime than for conventional fixtures like HPS. The tightness of a luminaire is usually rated in IP classes. The minimum for the Caribbean should be IP 65. It is not recommended to specify components inside the luminaire. The housing of the luminaire should be defined as (die-cast) aluminium.

Luminaire handling

The various tested fixtures have shown many different design concepts. It should be checked that the fixtures allow easy handling during installation and maintenance of the fixtures. For example, lamp covers that open downwards and that are not secured by a chain, wire or other means from falling down when opening the screws pose a security risk and should be avoided.

Warranty

The supplier has to provide a reasonable warranty, which should be at least 5 years. The warranty will be one of the main economical evaluation criteria during the selection process for suitable LED SL suppliers.

Sample evaluation

A checklist and some photos of the inner and outer parts of the luminaire should be used to compare different products. The use of an evaluation matrix to evaluate luminaires as shown in this report is strongly recommended.

Ask the users

Because street lighting is everyone's concern, it is important to include the opinion of passers-by in the evaluation of the luminaires. The use of a questionnaire similar to the one used in the pilot project can be useful.

3. CHARACTERISTICS OF AN LED STREET LIGHT

Though HPS lights are considered an efficient street lighting option, LED street lights can save up to 50% of electricity consumption compared with a HPS light. Also, the color rendering is comparatively low with an average value of CRI=22. The Color Rendering Index CRI is a quantitative measure of the ability of a light source to reproduce the colors of various objects faithfully in comparison with an ideal or natural light source. This means that the identification of contrasts, people and objects is worse with HPS light than with LED light.

The LED is a point light source, so optical elements like lenses or reflectors help to direct the light so that the LED SL can illuminate a specific area. Moreover, the optical elements can form various types of light intensity distributions. Especially in curves the light intensity distribution is relevant to provide a good uniformity on the street. These optics look differently for various purposes like small roads, wide roads, squares, parking lots, etc. The specification of the space to be lit, like road dimensions, should be specified in the technical specification. Furthermore, illuminance and uniformity are depending on mounting heights and the distance between poles (see 'Photometric Distance Law' or 'Inverse Square Law').

The LED produces light on the basis of electroluminescence, where different semiconductor crystals are put under a specific voltage to emit light with a part of their received energy. The other part of the received energy produces heat that has to be led off.

The current is generated by an electronic driver. Typical currents to operate a LED SL are 350 mA, 500 mA and 750mA. The light output increases more or less linear with higher currents. Usually the electronic driver can be programmed with specific 'dimming' levels at chosen time slots. To achieve dimming, the driver reduces the current. By turning the current down the wattage and light output are decreasing proportionally.

A typical LED SL consists of electrical components (driver, cable, ...), a board with a defined number of LED's according to the desired illumination level, optics to direct the light (lenses, reflectors, ...), a cooling element to lead off the heat that is produced by the generation of light, a sealing ring to protect the components from humidity, and a corpus, usually die-cast aluminum, that is closed by a bracket or screws.

Within the lifespan of the LED luminaire no maintenance is necessary, except for cleaning the body and the cooling device from the outside. To obtain a long-life product the corpus of the luminaire should be as tight as possible to keep humidity and dirt out of the inner parts of the luminaire. Beside the locking device, the sealing ring is a crucial factor for the tightness of the luminaire.

To avoid corrosion the screws should be made of stainless steel (e.g. SAE grade 316 or higher). The lamp compartment should have a minimal protection of IP 65 (protected against splash water).

The opening of a luminaire is more comfortable with a bracket instead of screws, although the estimated low-maintenance-period of an LED SL is about 10 years. In other words one can expect that there is no need to open the housing within the first 10 years. A disadvantage of brackets can be that they cause a decrease of tightness.

The lifetime of an LED SL is often falsely understood as being equal to the lifetime of the LED cell itself. Furthermore, the indicated lifetime is a calculated value, based on testing results in a laboratory. Currently, no long time results of operating LED SL for more than 10 years are published. The lifetime of an individual LED package is considered to be the time at which the light output has fallen to 70 per cent of its original value ("L70") combined with the value for the conventional electric failure lifetime (e.g. F10 or F50 = percentage of LEDs with no output). In contrast to the lumen maintenance lifetime that causes a reduced light level, the electric failure lifetime means that part of the LED's do not emit any light. In addition

to that it's important to have equally long-life electrical components, or, to the extent they are not, they will limit the system lifetime. The typical lifetime of the LED board in Europe is calculated to be 80.000 h - 100.000 h, while the lifetime for the electrical components, especially the driver, is calculated to be 60.000 h - 70.000 h.

Another important point of a long-life LED SL is the thermal management. Though the LED is no heat radiator itself, the generation of light produces heat that has to be led off through a cooling device.

The produced heat of the LED's is conducted through the corpus of the luminaire towards the cooling fin. The picture below shows a well-done thermal management, resulting in a low constant temperature of 99.14 °F (37.3 °C) around the entire body.

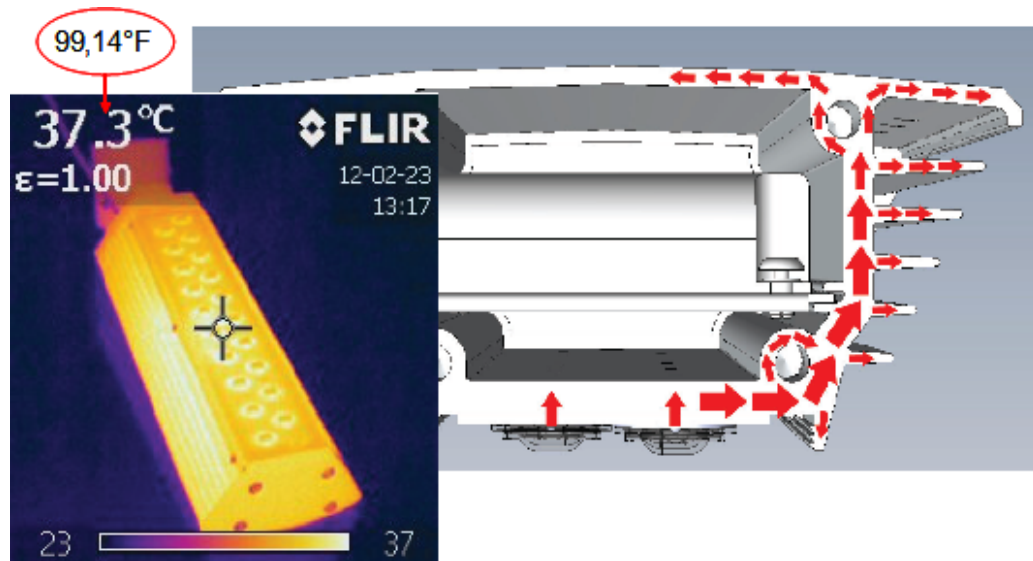


Figure 1: Heat Conduction

The lifetime and also the luminous flux of the LED drops proportionally to the increase of temperature, as the diagram below illustrates. Therefore the temperature should be kept as low as possible.

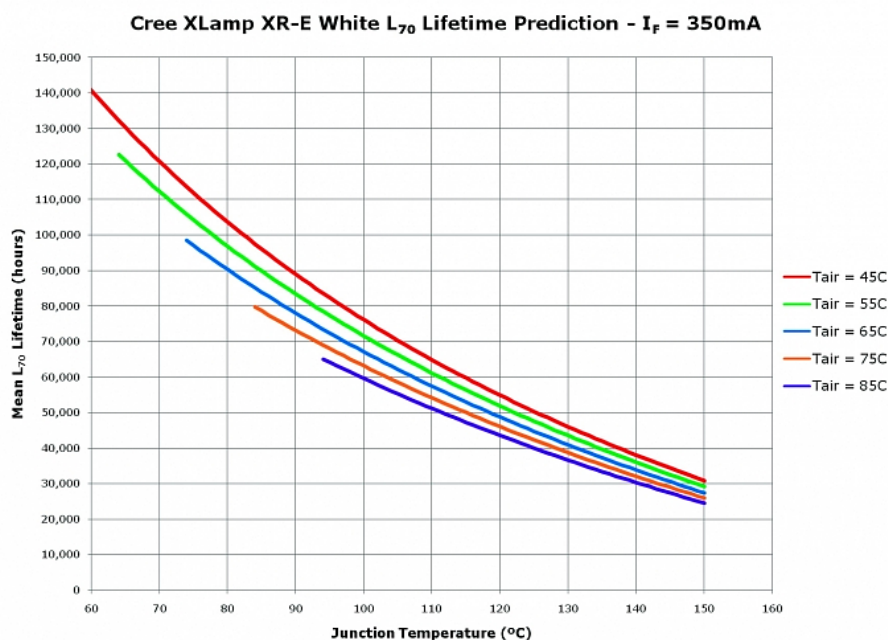


Figure 2: LED lifetime

4. LUMINAIRE TESTING CONCEPT

In a first step the luminaires were tested separately and isolated from other light sources as much as possible. The testing area was on VINLEC’s Lowman’s Bay diesel power station compound.



Figure 3: Test field at Lowman’s Bay

The installation of each luminaire type took place at daytime while the measurements were done at night. The timeframe to test and measure all products of one manufacturer was one week.

The measurement field was spun in front of one pole to analyze the illumination by one luminaire. The following picture shows a sketch of the test field at Lowman's Bay.

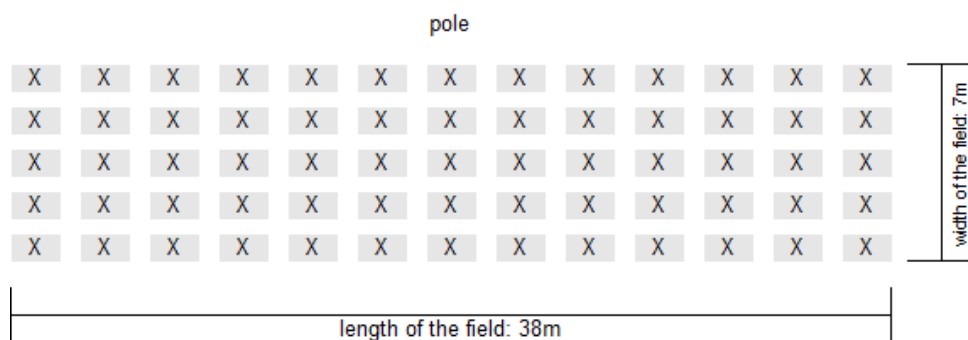


Figure 4: Sketch of the test marker pattern in Lowman's Bay

The test field consisted of 65 measurement points and had a length of 38 m and a width of 7 m. The pole allowed for a luminaire installation height of 8 m.

In the second step the luminaires were installed on a test section of road in the village of Questelles to get an impression of the interaction with neighboring lights and road environment. The test road was chosen to represent a typical road on the island with a left bend, a right bend as well as a straight part and a slope.



Figure 5: Test road at Questelles

In a subsequent phase the selected luminaires were installed in St. Vincent's capitol Kingstown and some other communities to monitor them under working conditions and make them accessible to the broad public.

The measurements of the tested luminaires provide a basis for comparison of photometrical, energetic and optical characteristics of the different types of luminaires. The following table shows a compilation of the luminaires that have been supplied.

Table 1: Summary of the supplied luminaires

Supplier	50W repl.	100W repl.	150W repl.	250W repl.	Wattage used on test road
A	36W	55W	88W	143W	55W
C	31W	41W	56W	110W	41W
E	40W	54W	127W	196W	54W
D	28W	58W	90W	130W	58W
B	30W	60W	60W	120W	60W
F	35W	70W	100W	135W	70W
H	37W	49W	n.a.	n.a.	49W
G	n.a.	45W	n.a.	n.a.	n.a.
I	n.a.	69W	n.a.	n.a.	69W

The measurement concept was divided into basic data that had to be collected and measurements to be done at night. Photos help to visualize the lighting pattern in the "view from above" to see the whole street surface and the uniformity of the light distribution. Moreover, the opinion of passers-by was included in the evaluation of the project. The tests were completed in June 2013.

4.1. Basic data

Some data on street and field characteristics and lighting point characteristics had to be collected only once. To measure the illuminance on the test stand at Lowman's Bay the required length and width of the test field had to be determined. Moreover, basic information like mounting heights and overhang had to be collected. The measured data was recorded in spreadsheets and evaluated consequently.

4.2. Parameters to be measured

It was important to start the measurement after the luminaire had warmed up and had been in a "thermally constant status" to get the actual values. The horizontal illuminance was measured on the test field at Lowman's Bay and on the test road at Questelles. The electrical parameters (energy consumption, voltage and current, and power factor) and the temperature inside and outside the luminaire were measured only at Lowman's Bay test stand. Photos of the installation work and measurement prove and illustrate the work done within the project. Furthermore photos, that have been taken at night showing the light distribution. On the test field in Lowman's Bay, photos of the light distribution were taken out of a bucket truck to get an impression of the lighting pattern, whereas photos of the light distribution on the test road illustrate mainly areas of curves and areas along the road side.

4.3. Parameters to be calculated

After all illuminance values of the measurement grid had been taken, it was evaluated how much of the luminous flux reached the surface at the test area. The results can be compared between the different products which allows to draw conclusions from their optical characteristics as to how good the luminaire can direct the light or whether it creates diffused light.

The luminous flux was calculated from the illuminance values (minimum, maximum) that were measured at the area of the test field and the resulting calculated average.

$$\Phi = E \cdot A$$

with

Φ : luminous flux

E: horizontal illuminance

A: Area of the test field (see Figure 8) $A = S [m] \cdot W [m] = [m^2]$

5. EVALUATION OF THE MEASUREMENTS

5.1. Validation of indicated wattages and current

The voltage, current, wattage and the power factor of the luminaires were measured to get their direct and indirect power consumption. These parameters were checked about ten times during a period of 10 minutes to compensate voltage or current fluctuations by using the mean or average value.



Figure 6: Arrangement to measure the electrical parameters

The measured values are compiled in the measurement reports. The following table shows a summary of the measured wattage, voltage, current and power factor.

Table 2: Results of electric parameter measurement

Supplier	50W HPS Replacement					100W HPS Replacement					150W HPS Replacement					250W HPS Replacement				
	indic. P [W]	P [W]	U [V]	I [A]	PFC	indic. P [W]	P [W]	U [V]	I [A]	PFC	indic. P [W]	P [W]	U [V]	I [A]	PFC	indic. P [W]	P [W]	U [V]	I [A]	PFC
Reference HPS lamp		65.6	226.4	0.319	0.894		120.7	225.2	0.582	0.91		155.7	221.8	0.789	0.88		230.7	223.2	1.146	0.92
A	36	36.6	225.9	0.199	0.817	55	56.3	222.2	0.258	0.99	88	85.8	219.9	0.411	0.93	143	143.2	220.5	0.68	0.95
B	30	35.26	220.7	0.182	0.851	60	64.56	220.7	0.306	0.95	60	64.56	220.7	0.306	0.95	120	125.7	219.3	0.59	0.95
C	31	32.72	219.6	0.156	0.95	41	43.68	219.9	0.203	0.976	56	60.17	220.1	0.28	0.95	110	118.9	218.8	0.553	0.96
D	28	29.03	221.6	0.144	0.92	58	58.1	221	0.271	0.95	90	90.21	218.6	0.418	0.98	130	129.8	219.4	0.597	0.986
E	40	37.38	221.5	0.174	0.97	54	54.23	219.8	0.262	0.93	127	120.5	219.4	0.563	0.951	196	194.4	221.3	0.909	0.962
F	35	35.61	220.6	0.182	0.86	70	70.28	218.8	0.332	0.951	100	99.7	220	0.47	0.97	135	136.6	218.7	0.634	0.98
G	n.a.	n.a.	n.a.	n.a.	n.a.	36.8	35.08	220.2	0.16	0.95	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
H	37	37.11	219.9	0.184	0.93	49	48.64	219.2	0.225	0.98	76	75.58	218.8	0.36	0.939	n.a.	n.a.	n.a.	n.a.	n.a.
I	n.a.	n.a.	n.a.	n.a.	n.a.	69	67.73	219.7	0.33	0.908	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

The first row shows the measured values for the wattage (P[W]), voltage (U[V]), current (I[A]) and power factor (PFC) of the reference HPS luminaires. The following rows show the measured values of the LED luminaires. In addition to the measured values, the wattage as indicated by the manufacturer (“indic. P”) is given to show whether the fixtures comply with their own target wattages. The comparison of the real energy consumption, measured on site, and the indicated energy consumption showed no significant differences. Nearly all measurements were within the range of the measuring accuracy of 10%.

This table clearly shows that some manufacturers increase the current (= energization) of the LED's to get a better light output at higher wattages. In Europe values higher than 0.75 A are generally considered as being critical due to resulting increased temperatures and thus decreased LED lifetime. Only manufacturer E exceeds that threshold with its 250 W replacement fixture.

5.2. Documentation in an evaluation matrix

To evaluate the relevant parameters of the supplied luminaire families, two sets of evaluation matrices were generated, one for the evaluation of the 50 W HPS replacement, and one for the 100 W HPS replacement that was installed on the test road in Questelles.

The evaluated parameters were

- energy consumption,
- illuminance level at the test stand and at the test road,
- components / build-up, and
- temperature.

The luminaire that met the criteria best was scored with 100%. The scores of the remaining luminaires were calculated in relation to the score of the best ranked product.

Some of the supplied luminaires did not fulfill individual criteria, i.e. in matching the existing light level. Those products happened to exceed the minimum requirement in other criteria, for example energy savings. To judge the products on a fair basis a standardization was done by interpolation. This calculation is shown in a separate chapter below.

5.3. Energy consumption

For the evaluation of the energy consumption a minimum energy saving of 40% was requested. The following table shows the evaluation of the wattage for the 50 W HPS replacement.

Table 3: Evaluation of the wattages for the 50 W replacement luminaires

Supplier	Wattage as indicated by manufacturer	Measured wattage	Scoring
	P[W]	P[W]	P[%]
A	36.0	36.60	79.3
B	30.0	35.26	82.3
D	28.0	29.03	100.0
C	31.0	32.72	88.7
F	35.0	35.61	81.5
E	40.0	37.38	77.7
G	n.a.	n.a.	n.a.
H	37.0	37.11	78.2
I	n.a.	n.a.	n.a.
reference wattage (energy saving 40%): 39W			

Usually, evaluations are based on the calculated maximum system wattages of a larger number of luminaires to compensate the variances within a lot, or different lots, of supplied luminaires. These values are compared to the system wattages indicated by the manufacturers. The theoretically calculated maximum permissible wattage to replace the 50 W HPS luminaire (50 W lamp + 10 W ballast = 60 W) with an energy saving of 40 % is 36 W.

The measured energy consumption of the reference HPS luminaire is 65.6 W, leading to a maximum wattage of 39 W to achieve the projected energy saving. All luminaires did fulfill this criteria.

Supplier D supplied the luminaire consuming the lowest system wattage at 29.03 W. Therefore it was ranked at 100 %. The rankings of the other luminaires were calculated in relation to that.

The following table shows the evaluation of the power consumption for the 100 W HPS replacement.

Table 4: Evaluation of the wattages for the 100 W replacement luminaires

Supplier	Wattage as indicated by manufacturer	Measured wattage	Scoring
	P[W]	P[W]	P[%]
A	55.0	56.30	77.6
B	60.0	64.56	67.7
D	58.0	58.10	75.2
C	41.0	43.68	100.0
F	70.0	70.28	62.2
E	54.0	54.23	80.5
G	n.a.	n.a.	n.a.
H	49.0	48.64	89.8
I	69.0	67.73	64.5
Reference wattage (energy saving = 40 %): 72.4 W			

The theoretically calculated maximum wattage to replace a 100 W HPS luminaire (100 W lamp + 20 W ballast = 120 W) with an energy saving of 40 % is 72 W. All supplied fixtures fulfill that criteria. The measured system wattage of the HPS reference was 120.7; measured and calculated values are matching.

For the 100 W luminaire G supplied the lowest wattage to replace the existing lighting fixtures and therefore got the best rank and the highest score.

5.4. Horizontal illuminance

5.4.1. Horizontal illuminance on the test field

Before the measurements on the test field could be conducted, a grid for the location of the measurement points had to be marked on the test field surface. The European norm EN 13201 describes how to calculate the distances between the measurement points. In comparison to the North American recommendation, there is no great difference between the location of the points, but the European norm gives a simple rule of thumb that can be adapted easily. It was decided to apply the European norm. The following figure shows the typical measurement grid of the European norm.

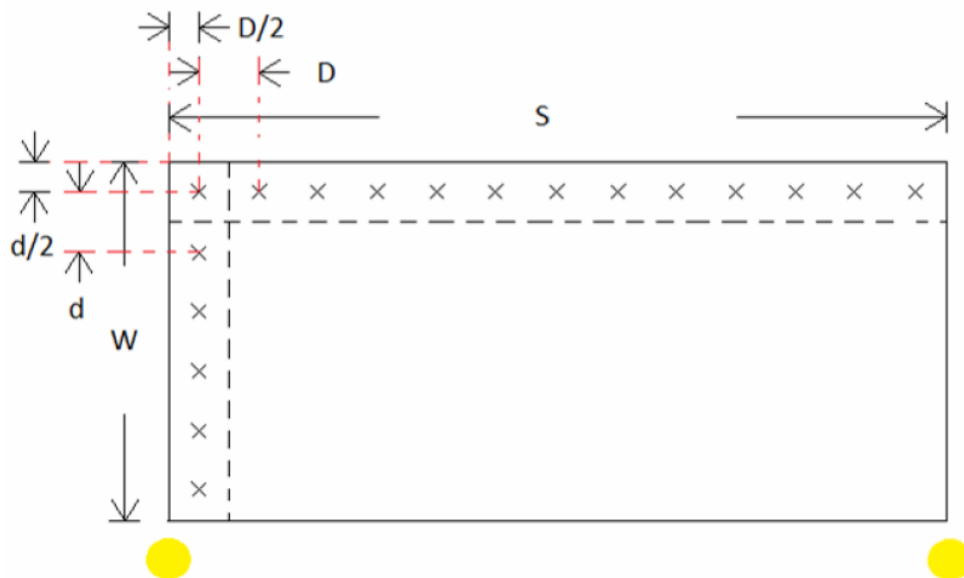


Figure 7: Evaluation grid pattern according to European Standard

Following the norm, the grid is spread out in between two poles. For this specific testing, a modified evaluation field with one pole in the middle was chosen. This allows to see, how far the lighting pattern reaches out of the 38 x 7 m grid. This is of particular interest because outside the villages pole to pole distances reach up to 60 m. Furthermore the overlapping of two lighting patterns should be eliminated to get undisturbed horizontal illuminance readings.

The size of the evaluation field was determined by the pole distances at the test road, representing a typical island road, and the maximum width on those roads, to simulate reality as much as possible. The following figure shows the grid that was used at Lowman's Bay.

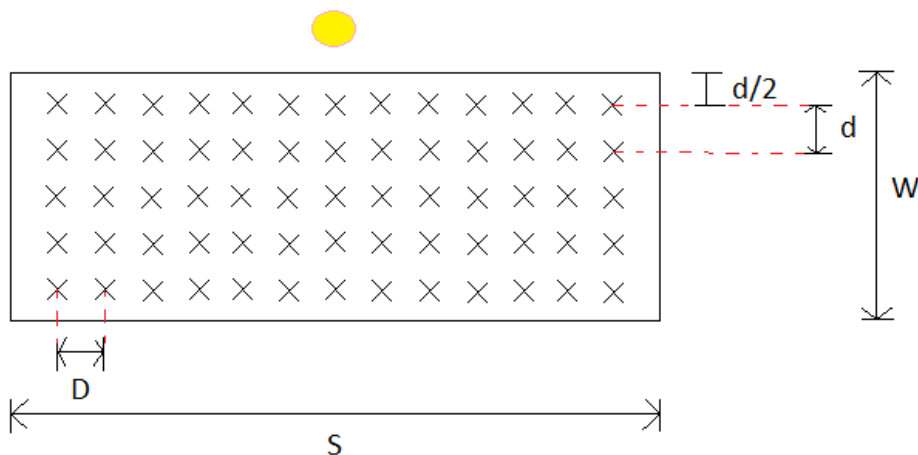


Figure 8: Evaluation grid for illuminance used in the pilot project

With the length of the test field selected as 38 m ($S = 38$ m), the lengthwise spacing between the measurement points results to 3 m ($D = 3$ m).

The width of the field is 7 m ($W = 7$ m). The spacing between the measurement points in the cross direction is 1.4 m ($d=1.4$ m). Thus, a number of 65 points determine the horizontal illuminance. The following picture shows a part of the lighting pattern taken out of the bucket truck to the left side.



Figure 9: Evaluation pattern for illuminance tests, view from bucket truck

The picture also shows the outreach of the lighting pattern on the test field.

The horizontal illuminance was measured with a luxmeter that was held 0.2 m above the test field surface with the detector head parallel to the surface. A wooden block was used to ensure the exact height and flat orientation of the detector.

After all points of the grid were measured, the maximum and minimum values were identified. Furthermore the arithmetic average of all points was used as a reference value to compare the different luminaires. To get an impression of the uniformity of the illumination, the ratio between the lowest and highest value was calculated. Moreover, the variation factor AM, which is the ratio between the minimum and the average of the measurement values, underlines the uniformity. The higher the value, the better the uniformity across the whole field.

The moonlight has also a little influence in the measurement results. In a clear night about 0.25 lx reach the earth's surface at full moon. At half-moon this is still about 0.025 lx. The corrections at full or half-moon were included in the horizontal illuminance where necessary.

The evaluation was plotted in a diagram with iso-lines visualizing the illuminance. The following figure shows an example how the results are presented. Bright colors stand for higher values and dark colors for lower ones. The iso-line diagrams are attached in the annex.

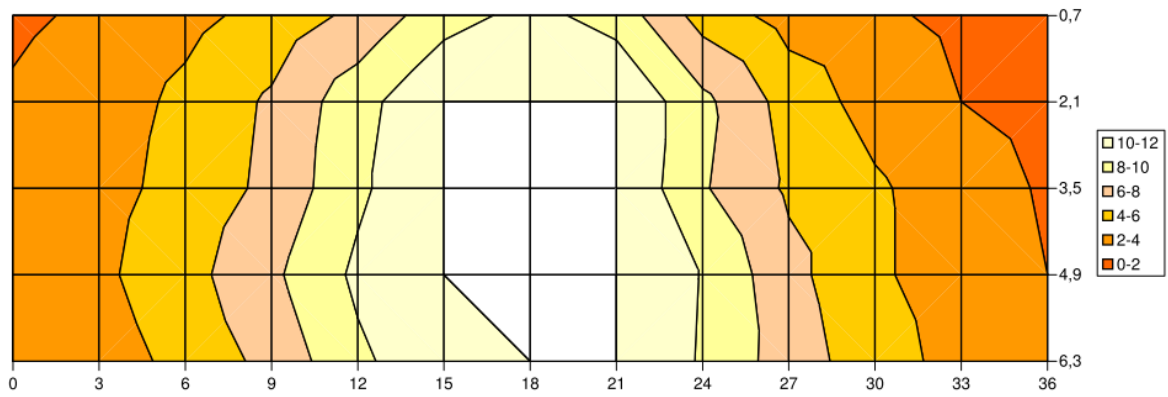
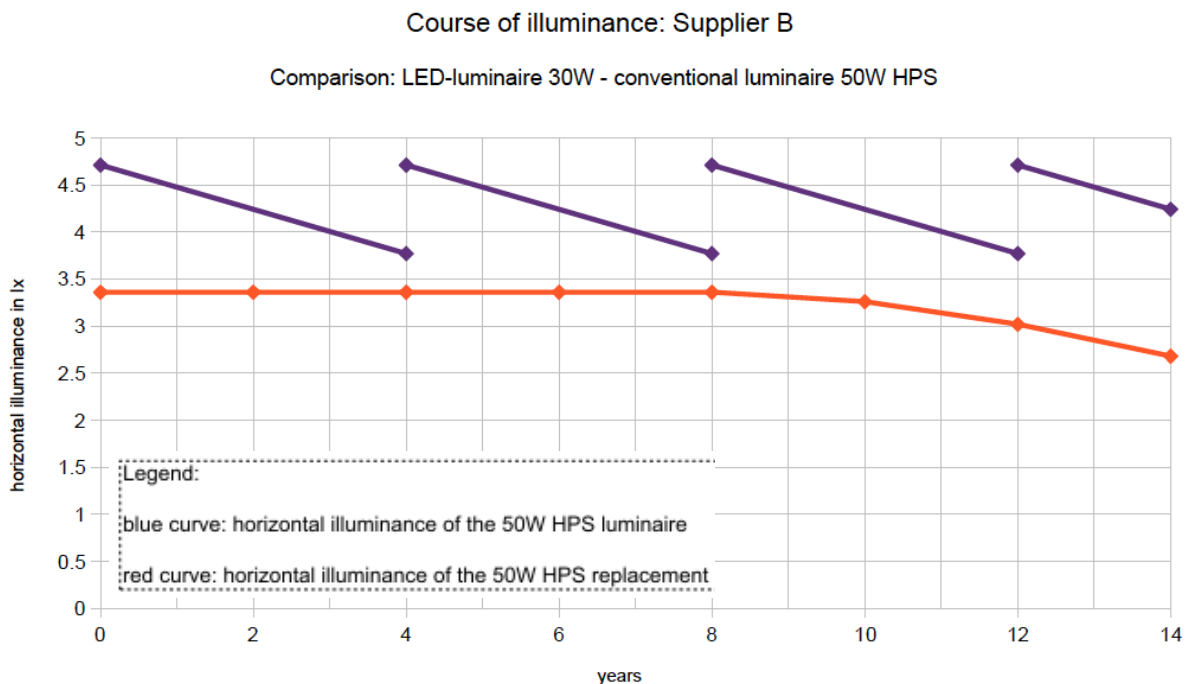


Figure 10: Example of an isolux diagram (unit: lx)

To get an impression how the illuminance level changes over the years, a graph showing the horizontal illuminance of the HPS luminaire and the LED luminaire as the replacement, was plotted. In this case the average illuminance values (E_{av}) were chosen for the beginning of lifetime.

The lifetime of an LED luminaire is described as the time slot where the luminous flux falls to 70% of its initial lighting output. The conclusion is that the illuminance decreases in the same percentage. The HPS lamp is typically replaced every four years. In this time the lighting output and also illuminance drops about 20%. The following graph shows an example of the illuminance level changing over the years.



The following table shows the measured and calculated values of the horizontal illuminance.

Table 5: Measured and calculated horizontal illuminance on the test field

Supplier	50 W HPS Replacement				100W HPS Replacement				AM corr.
	P	EnSav	Eav	AM	P	EnSav	Eav	AM	
	[W]	[%]	[lx]		[W]	[%]	[lx]		
Existing HPS	65.6		4.71	0.234	120.70		11.73	0.221	
- degr. / MF lamp (-20%)			3.77				9.38		
- degr. Luminaire (-20 %)			2.83				7.03		
A	37	44	4.35	0.276	56.30	53	7.01	0.285	0.251
B	35.26	46	3.36	0.446	64.56	47	6.73	0.401	0.384
C	32.72	50	2.13	0.329	43.68	64	2.68	0.299	0.299
D	29.03	56	4.5	0.222	58.10	52	8.03	0.187	0.187
E	37.38	43	5.66	0.283	54.23	55	8.52	0.270	0.270
F	35.61	46	4.18	0.263	70.28	42	7.79	0.398	0.398
G	n.a.	n.a.	n.a.	n.a.	35.08	71	4.83	0.207	0.207
H	37.11	43	6.47	0.170	48.64	60	9.44	0.201	0.201
I	n.a.	n.a.	n.a.	n.a.	67.73	44	4.66	0.086	0.086

Supplier	150W HPS Replacement				250W HPS Replacement				AM corr.
	P	EnSav	Eav	AM	P	EnSav	Eav	AM	
	[W]	[%]	[lx]		[W]	[%]	[lx]		
Existing HPS	155.70		14.01	0.200	230.70		23.22	0.172	
- degr. / MF lamp (-20%)			11.21				18.58		
- degr. Luminaire (-20 %)			8.41				13.94		
A	85.80	45	10.11	0.307	143.20	38	18.23	0.197	
B	64.56	59	6.73	0.401	125.73	46	13.43	0.395	
C	60.17	61	3.617	0.304	118.86	48	7.89	0.203	
D	90.21	42	12.82	0.203	129.83	44	20.36	0.196	
E	120.48	23	15.05	0.100	194.43	16	16.6	0.289	
F	99.7	36	12.52	0.288	136.57	41	15.26	0.269	
G	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	
H	75.58	51	11.61	0.198	n.a.	n.a.	n.a.	n.a.	
I	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	

Legend:

- AM = uniformity AM ($E_{min}/E_{average}$)
- Eav = Eaverage = illuminance
- EnSav = energy saving
- Degr. = degradation,
- MF = maintenance factor
- AM corr. = corrected AM
- Eav corr. = corrected Eav

The influence of full or half-moon was included in the calculation of the values for horizontal illuminance (E_{av}) and uniformity (AM) where appropriate. This correction had to be done for the luminaires of C, H and B.

In this table the uniformity is described with AM and is calculated with E_{min} divided by E_{av} . E_{av} characterizes the average of the horizontal illuminance measured in lx. The wattage is described with P [W].

The maintenance factor (MF) is used for the ageing / degradation of the lamp and thus for a decreasing of the luminous flux as well as the illuminance.

The energy saving (EnSav) is a parameter that was calculated in the table to see whether the applied wattage reaches the projected energy saving of 40%.

The installed and tested HPS reference luminaires were brand new. Luminaires in general have less lighting output over the years due to reflectors / optics becoming weak, corrosion and darkening glass. This effect is called degradation. In calculations of lighting-simulations this is factored-in by using and adapting the so called maintenance factor.

The grey cells in the table show the HPS reference values, which were reduced in terms of

the lighting level due to the age of the installed fixtures and lamps on the island, to reflect reality. 20% are subtracted from the measured horizontal illuminance of the HPS luminaires because of the **degradation of the lamps** over the lifetime. Another 20% are subtracted because of the worn condition of the luminaire due to soiled or yellowed cover glass or corroded equipment inside the fixture, which can also be defined as the **degradation of the luminaire**. Therefore a correction of the reference values of the HPS luminaires had to be done.

All these deteriorating influences do not necessarily happen with LED luminaires. A conventional lamp is typically changed every four years because of its ageing. An LED luminaire is a lamp with optics and luminaire at the same time. Because no light bulb can be replaced, the ageing of the electrical and optical components have to be considered as one. As explained above, the electrical components have a lifetime of about 60.000 hours, the LED's up to 100.000 hours. So none of these components have to be changed over a time of more than 10 years. Furthermore the LED's and optical equipment are closed behind covering glass so that no cleaning is necessary inside the luminaire itself.

The following table shows the evaluation matrix of the horizontal illuminance of the 50 W replacement.

Table 6: Illuminance of 50 W replacements

Supplier	Luminaire	Illuminance	Uniformity	Illuminance	Uniformity				
		E[lx]	AM[min/average]	E[%]	AM[%]				
A	36,6W	4.35	0.276	67.2	61.9				
B	35,26W	3.36	0.446	51.9	100.0	max (lx):	6.47	max (g)	0.446
D	29,03W	4.50	0.222	69.6	49.8	min. (lx):	2.13	min (g)	0.17
C	32,72W	2.13	0.329	32.9	73.8				
F	35,61W	4.18	0.263	64.6	59.0	difference	4.34	difference	0.276
E	37,38W	5.66	0.283	87.5	63.5	1%	0.0434	1%	0.00276
G	n.a.	n.a.	n.a.	n.a.	n.a.				
H	37,11W	6.47	0.170	100.0	38.1				
I	n.a.	n.a.	n.a.	n.a.	n.a.				

Reference illuminance (50W HPS): 2,83lx

The Supplier H luminaire scored 100% with a horizontal illuminance of 6.47 lx. The scores of the remaining luminaires were calculated in relation.

The highest uniformity was achieved by the LED fixture of Supplier B with 0.449 and therefore scored maximum.

The following table shows the evaluation matrix of the horizontal illuminance of the 100 W HPS replacement.

Table 7: Illuminance of 100 W replacements

Supplier	Luminaire	Illuminance	Uniformity	Illuminance	Uniformity				
		E[lx]	AM[min/average]	E[%]	AM[%]				
A	56,3W	7.01	0.285	74.3	71.1				
B	64,56W	6.73	0.401	71.3	100.0	max (lx):	9.44	max (g)	0.401
D	58,1W	8.03	0.187	85.1	46.6	min. (lx):	2.68	min (g)	0.086
C	43,68W	2.68	0.299	28.4	74.6				
F	70,28W	7.79	0.398	82.5	99.3	difference	6.76	difference	0.315
E	54,23W	8.52	0.270	90.3	67.3	1%	0.0676	1.00%	0.00315
G	n.a.	n.a.	n.a.	n.a.	n.a.				
H	48,64W	9.44	0.201	100.0	50.1				
I	67,73W	4.66	0.086	49.4	21.4				

illuminance reference (100W HPS): 7,03lx

Here the illuminance reference of the 100 W HPS luminaire is 7.03 lx. The Supplier H luminaire was best with a horizontal illuminance of 9.44 lx. Supplier B reached high score with a uniformity of 0.401.

5.4.2. Horizontal illuminance at the test road

The 100 W HPS replacements were also installed on a strip of road in the village of Questelles to test them under working conditions and in interaction with neighboring lights and street characteristics. The road section was chosen to have a right and left bend and a straight part as well as a slope to include all possible road layout combinations. This was chosen because it reflects a typical through road on the island. The test road section included six poles with one luminaire each.

Measurements of the horizontal illuminance were taken in two lines going up and down the street, respectively, from the view of a road user (vehicle driver). The measurement points had a constant spacing of 3m.

The following table shows the measured and calculated values.

Table 8: Illuminance from the road tests

Supplier	Road Test 100W Replacement		
	E _{min}	E _{max}	E _{av}
	[lx]	[lx]	[lx]
A	1.3	19.7	8.71
B	2.4	20.3	9.49
C	0.5	39	3.52
D	1.2	31.8	10.04
E	1	28.1	10.69
F	2.2	21.1	10.27
G	0.6	19	5.91
H	0.4	29.8	10.07
I	0.2	20.8	5.54

The tested luminaires were equipped with a wide beam optic to illuminate the street lengthwise.

The average value of the horizontal illuminance is higher than the ones measured on the test field. The reason for this is, that the street has a smaller width of about 5 m. Furthermore, as seen on the photo taken out of the bucket truck to the left side, the lighting pattern often outreaches the grid of the evaluation field. The poles at the test road had a distance of about 38 m, so the overlapping effect of the lighting patterns from neighboring luminaires are another reason for a higher horizontal illuminance.

The influence of full or half-moon was included in the calculation of the values for horizontal illuminance and uniformity where appropriate.

The uniformity is often considerably lower than the ones measured on the test field. A reason could be that shadowing effects or road characteristics cause low values in some areas. These low values, even if it is just one out of many others, reduces the uniformity, which is calculated as the relation between the lowest illuminance value E_{min} and the average E_{av} . This effect is not the same for all manufacturers, because here the optics have a great influence.

The following table shows the evaluation matrix for the horizontal illuminance on the test road.

Table 9: Evaluation of the illuminance on the test road

Supplier	Luminaire	Illuminance	Uniformity	Illuminance	Uniformity						
		E[lx]	AM[min/average]	E[%]	AM[%]						
A	56,3W	8.71	0.149	81.5	58.9						
B	64,56W	9.49	0.253	88.8	100.0	max (lx):	10.69	max (g)	0.253		
D	58,1W	10.04	0.119	93.9	47.0	min. (lx):	3.52	min (g)	0.036		
C	43,68W	3.52	0.142	32.9	56.1						
F	70,28W	10.27	0.214	96.1	84.6	difference	7.17	difference	0.217		
E	54,23W	10.69	0.094	100.0	37.2	1%	0.0717	1%	0.00217		
G	35,08W	5.91	0.101	55.3	39.9						
H	48,64W	10.07	0.040	94.2	15.8						
I	67,73W	5.54	0.036	51.8	14.2						

Supplier E reaches 100 points with a horizontal illuminance of 10.69 lx. Supplier B reaches 100 points with a uniformity of 0.253.

5.5. Structural luminaire components

All critical components of the tested luminaires were examined, evaluated and listed in a table.

Table 10: Evaluation of illuminance structure

Supplier	Housing	Cooling device	Closing	Sealing ring	Cover glass	Optic	Comments	Ranking
A	Single piece, robust, die-cast aluminium	top, at the sides	ballast separate closed by screws	yes	no	lenses, acrylic	It is not intended to replace parts of the luminaire ('single-use')? replacement of the whole luminaire	1
C	glass and aluminium	around the whole body	screw at the top of the luminaire	yes	yes	reflector	to be opened from the top, top cover just fixed with a cable	4
E	glass and die-cast aluminium	1. around the top 2. at the sides	screw at the top of the luminaire	yes	yes	lenses	offered two different luminaire types: 1. glass just fixed with screws at the sides ? no easy way to install the luminaire on the bucket truck 2. screw connections through the glass ? if the glass is breaking, it wouldn't be fixed at the luminaire	4
D	die-cast aluminium	top	screw at the bottom of the luminaire	no	yes	reflector	cooling device is flat ? water and soil could collect in it; no well-constructed mounting of the cover; holes at the flap ? water can get into the luminaire; Cardboard inside ? no obvious reason for the mounting	7
B	die-cast aluminium	top; separated at each LED module	bracket	yes	no	lenses	cooling device like a framework ? water and soil could collect inside (no easy way to clean it)	6
F	die-cast aluminium	top	bracket	no	no	lenses	cardboard inside the luminaire ? no obvious reason for the mounting; cooling device is flat ? water and soil could collect in it; holes inside the cooling device ? maybe for collecting water to drain off; screws filled with silicone ? maybe no weather-pr	8
H	die-cast aluminium	top	screw at the bottom of the luminaire	yes	yes	lenses, reflector		1
G	die-cast aluminium	top	screw at the bottom of the luminaire	yes	yes	lenses		1
I							no evaluation available	

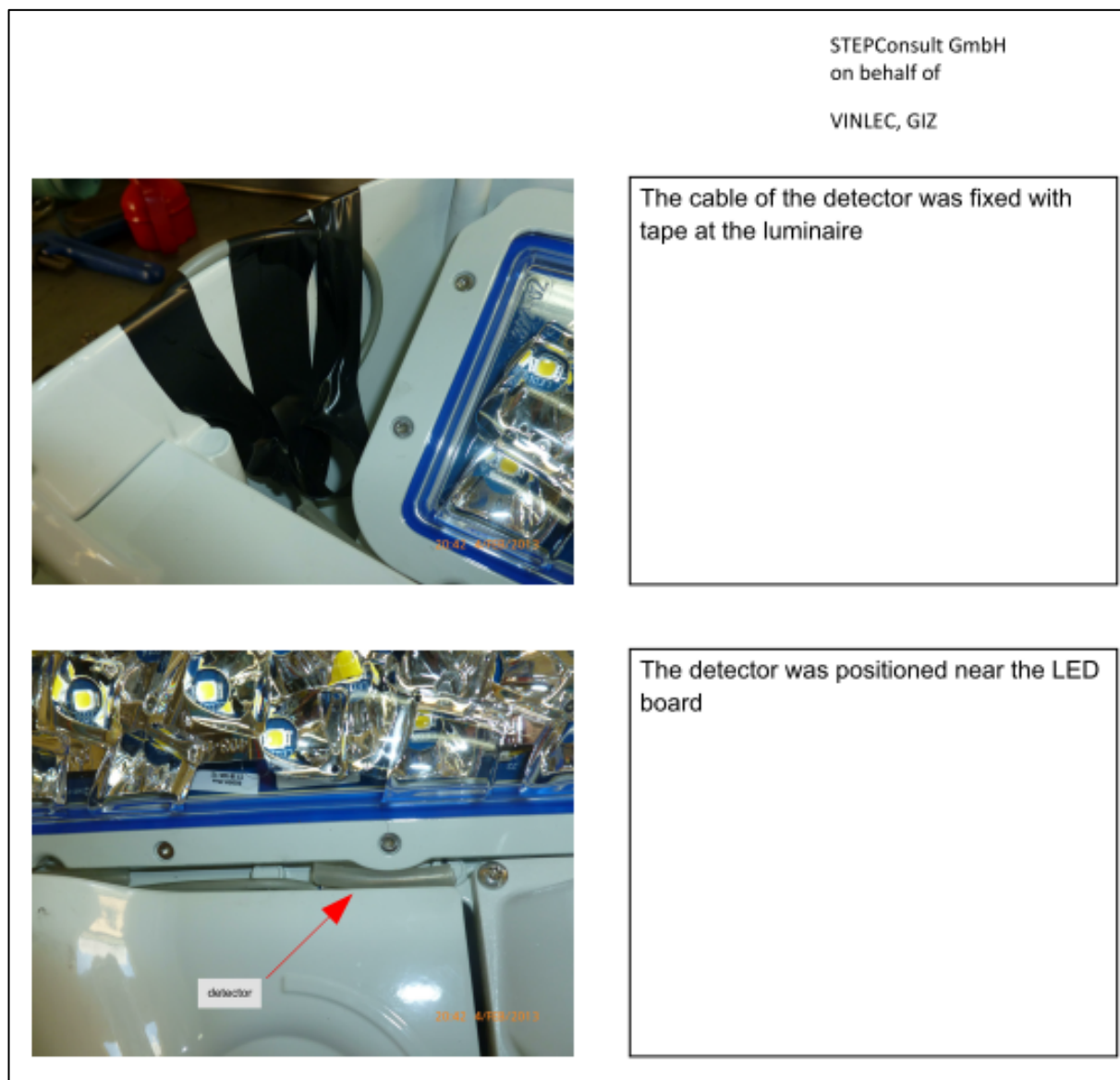
Within the lifespan of an LED luminaire no lamps have to be replaced. Therefore the tightness of the luminaire is much more critical in terms of a longer lifetime than for conventional fixtures like HPS. The tightness usually is classified by the protection class IP, which should be minimum IP 65 for the Caribbean.

Some critical aspects were noticed at a few luminaires. For example missing sealing rings lead to less protection against water or dust intrusion. Furthermore there were holes in some of the luminaires, through which water and sea breeze can get easily into the luminaire and lead to corrosion of the electrical equipment. Both factors result in a lower IP class.

A flat horizontal cooling device can cause the effect that water and soil cannot drain off with the consequence that the heat cannot be conducted optimally and the luminaire needs more cleaning work or loses lifetime. All photos taken of the different parts of the luminaires can be found in the Annex.

5.6. Temperature

To get an impression of the heat conduction of the LED luminaire, the temperature was measured inside the housing near the electronic board and on the surface of the housing at the cooling element. The following picture shows an example of the placement of the sensor inside the housing near the board.



The temperature was measured for one full day whereby the influence of the temperature at daytime was also measured. The following table shows the measured values.

Table 11: Compilation of temperature measurements

Supplier	Luminaire / wattage [W]	Temperature inside [°C] (daily average)	Temperature outside [°C] (daily average)	Temperature [°C] (in usage) inside	Temperature [°C] (in usage) outside
A	36.6	29.48	28.05	27.12	26.18
	56.3	29.32	29.09	27.25	27.12
	85.8	30.54	28.99	31.28	29.38
	143	30.47	29.63	29	28.04
B	35.26	28.77	27.22	28.09	26.41
	64.56	27.57	27.09	26.68	26.6
	125.73	32.15	27.21	31.12	27.26
F	35.61	33.5	30.5	n.a.	n.a.
	70.28	34.01	30.45	34.02	30.62
	136.57	32.72	30.78	32.86	30.39
C	32.72	30.13	27.76	28.07	26.69
	43.68	30.26	28.16	28.95	27.13
	60.17	28.97	28.16	28.87	28.63
D	29.03	29.63	28.73	27.07	26.69
	58.1	29.6	28.7		
	90.21	39.49	28.71	29.47	27.56
E	129.83	29.97	29.08	29.05	28.09
	37.38	29.41	28.65	27.2	27.73
	54.23	28.37	29.11	27.78	29.6
	120.48	32.3	30.21	31.62	29.93
H	194.43	31.67	28.12	32.3	28.19
H	48.64	28.96	28.5	27.93	
G	n.a.	n.a.	n.a.	n.a.	n.a.
I	67.73	72.77	41.79	72.4	42.86

Often, the solar radiation during daytime caused a higher temperature than the LED luminaire at night. This effect can be recognized at most of the fixtures. Only the LED luminaire of Supplier F had a constant temperature over day and night independent from solar radiation.

The following table shows the evaluation matrix of the temperature of the 50 W HPS replacement.

Table 12: Evaluation of temperature measurements of 50 W replacements

Supplier	Luminaire	Temp. 1 (inside)	Temp. 2 (outside)	Temp. 1	Temp. 2	Comment
		[°C]	[°C]	[%]	[%]	
A	36,6W	29.48	28.05	97.6	97.0	
B	35,26W	28.77	27.22	100.0	100.0	
D	29,03W	29.63	28.73	97.1	94.7	
C	32,72W	30.13	27.76	95.5	98.1	
F	35,61W	33.5	30.5	85.9	89.2	Error → transferred data
E	37,38W	29.41	28.65	97.8	95.0	
G	n.a.	n.a.	n.a.	n.a.	n.a.	
H	37,11W	28.9	28.5	99.6	95.5	Error → transferred data
I	n.a.	n.a.	n.a.	n.a.	n.a.	

Supplier B reaches 100 points with both measured temperatures. Suppliers F and H are marked yellow. Here, mean values of the temperatures measured at the fixtures of other wattage were used because of faulty measurements. A reason for the faulty values could be the incorrect installation of the detectors.

The following table shows the evaluation matrix of the temperature of the 100W HPS replacement.

Table 13: Evaluation of temperature measurements of 100 W replacements

Supplier	Luminaire	Temp. 1	Temp. 2	Temp. 1	Temp. 2	Comment
		[°C]	[°C]	[%]	[%]	
A	56,3W	29.32	29.09	94.0	93.1	
B	64,56W	27.57	27.09	100.0	100.0	
D	58,1W	29.6	28.7	93.1	94.4	Error → transferred data
C	43,68W	30.26	28.16	91.1	96.2	
F	70,28W	34.01	30.45	81.1	89.0	
E	54,23W	28.37	29.11	97.2	93.1	
G	n.a.	n.a.	n.a.	n.a.	n.a.	
H	48,64W	28.96	28.5	95.2	95.1	Error → transferred data
I	67,73W	72.77	41.79	37.9	64.8	

Supplier B reached 100 points with both measured temperatures. Suppliers D and H are marked yellow. Mean values of the temperatures measured at the other fixtures were used due to faulty values again.

5.7. Summary of the results

The following table shows the summary of the evaluation of the 50 W HPS replacement.

Table 14: Rating matrix, 50 W replacements

Rating matrix 50W HPS replacement

Supplier	30%			30%			10%			20%			5%			5%			100.00%
	Power consumption			Illuminance			Uniformity			Components			Temperature			Temperature			
	P [W]	P [%]	P [% x factor]	Eav [lx]	Eav [%]	Eav [% x factor]	AM	AM	AM [% x factor]	Rank	[%]	[% x factor]	Inside [°C]	Inside [%]	Inside [% x factor]	Outside [°C]	Outside [%]	Outside [% x factor]	
A	36.60	79.3	23.8	4.35	67.2	20.2	0.276	61.5	6.1	1.0	100	20	29.5	97.6	4.9	28.05	97.0	4.9	79.8
B	35.26	82.3	24.7	3.34	51.6	15.5	0.449	100.0	10.0	6.0	75	15	28.8	100.0	5.0	27.22	100.0	5.0	75.2
D	29.03	100.0	30.0	4.50	69.6	20.9	0.222	49.4	4.9	7.0	87.5	17.5	29.6	97.1	4.9	28.73	94.7	4.7	82.9
C	32.72	88.7	26.6	1.88	29.1	8.7	0.372	82.9	8.3	4.0	50	10	30.1	95.5	4.8	27.76	98.1	4.9	63.3
F	35.61	81.5	24.5	4.18	64.6	19.4	0.263	58.6	5.9	8.0	0	0	33.5	85.9	4.3	30.5	89.2	4.5	58.5
E	37.38	77.7	23.3	5.66	87.5	26.2	0.283	63.0	6.3	4.0	50	10	29.4	97.8	4.9	28.65	95.0	4.8	75.5
G	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.0	100	20	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
H	37.11	78.2	23.5	6.47	100.0	30.0	0.170	37.9	3.8	1.0	100	20	28.9	99.6	5.0	28.5	95.5	4.8	87.0
I	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

The table shows the evaluated six categories. To get a final result these six categories were weighted. The electricity consumption / wattage (P) as measure of energy efficiency is weighted at 30%, the horizontal illuminance (E_{av}) and uniformity (AM) as measure of lighting quality at 30% and 10%, respectively, components as measure for durability and ease of installation and maintenance with 20%, and the outside and inside temperatures as measure of longevity of the LEDs at 5% each.

With 87.0% in total Supplier H achieved the best result, closely followed by Supplier D (82.9%), Supplier A (79.8%), Supplier E (75.5%) and Supplier B (75.2%).

The following table shows a summary of the evaluation matrix of the 100 W HPS replacement. Here the criteria from the road tests were considered in addition to the criteria used for the 50 W replacements.

Table 15: Rating matrix, 100 W replacements

Rating matrix 100W HPS replacement

Supplier	30% Power consumption			15% Illuminance road			5% Uniformity road			15% Illuminance test stand			5% Uniformity test stand		
	P	P	P	Eav	Eav	Eav	AM	AM	AM	Eav	Eav	Eav	AM	AM	AM
	[W]	[%]	[% x factor]	[lx]	[%]	[% x factor]		[%]	[% x factor]	[lx]	[%]	[% x factor]		[%]	[% x factor]
A	56.30	62.3	18.7	8.7	81.5	12.2	0.149	58.9	2.9	7.01	74.3	11.1	0.285	71.1	3.6
B	64.56	54.3	16.3	9.5	88.6	13.3	0.253	100.0	5.0	6.73	71.3	10.7	0.401	100.0	5.0
D	58.10	60.4	18.1	10.0	93.9	14.1	0.119	47.0	2.4	8.03	85.1	12.8	0.187	46.6	2.3
C	43.68	80.3	24.1	3.3	30.5	4.6	0.153	60.5	3.0	2.43	25.7	3.9	0.329	82.0	4.1
F	70.28	49.9	15.0	10.3	96.1	14.4	0.214	84.6	4.2	7.79	82.5	12.4	0.398	99.3	5.0
E	54.23	64.7	19.4	10.7	100.0	15.0	0.094	37.2	1.9	8.52	90.3	13.5	0.270	67.3	3.4
G	35.08	100.0	30.0	5.9	55.3	8.3	0.101	39.9	2.0	4.83	51.2	7.7	0.207	51.6	2.6
H	48.64	72.1	21.6	9.8	91.9	13.8	0.041	16.2	0.8	9.19	97.4	14.6	0.207	51.6	2.6
I	67.73	51.8	15.5	5.5	51.8	7.8	0.036	14.2	0.7	4.66	49.4	7.4	0.086	21.4	1.1

(Continued)

Supplier	20% Components			5% Temperature			5% Temperature			100%
	Ranking			Inside			Outside			Total
	Rank	[%]	[% x factor]	[°C]	[%]	[% x factor]	[°C]	[%]	[% x factor]	%
A	1.0	100	20	29.3	94.0	4.7	29.09	93.1	4.7	77.9
B	6.0	75	15	27.6	100.0	5.0	27.09	100.0	5.0	75.3
D	7.0	87.5	17.5	29.6	93.1	4.7	28.7	94.4	4.7	76.5
C	4.0	50	10	30.3	91.1	4.6	28.16	96.2	4.8	59.0
F	8.0	0	0	34.0	81.1	4.1	30.45	89.0	4.4	59.5
E	4.0	50	10	28.4	97.2	4.9	29.11	93.1	4.7	72.7
G	1.0	100	20	n.a.	n.a.	n.a.	n.a.	n.a.	0.0	70.5
H	1.0	100	20	29.0	95.2	4.8	28.5	95.1	4.8	82.9
I	n.a.	n.a.	n.a.	72.8	37.9	1.9	41.79	64.8	3.2	37.6

With 82.9% in total Supplier H achieved the best result, followed by Supplier A (77.9%), Supplier D (76.5%), Supplier B (75.3%), Supplier E (72.7%) and Supplier G (70.5%).

5.8. Evaluation of questionnaires

Measured and calculated results are important for the comparison of products, but the subjective impression of passers-by sometimes seems to be different. According to the subjective impression, the LED SL is sometimes described as a very bright and glaring light source. The light intensity is often felt much higher than it actually is. To have a good combination between measured facts and subjective impressions, passers-by were asked to fill in a questionnaire. The questionnaire interviews were made by VINLEC.

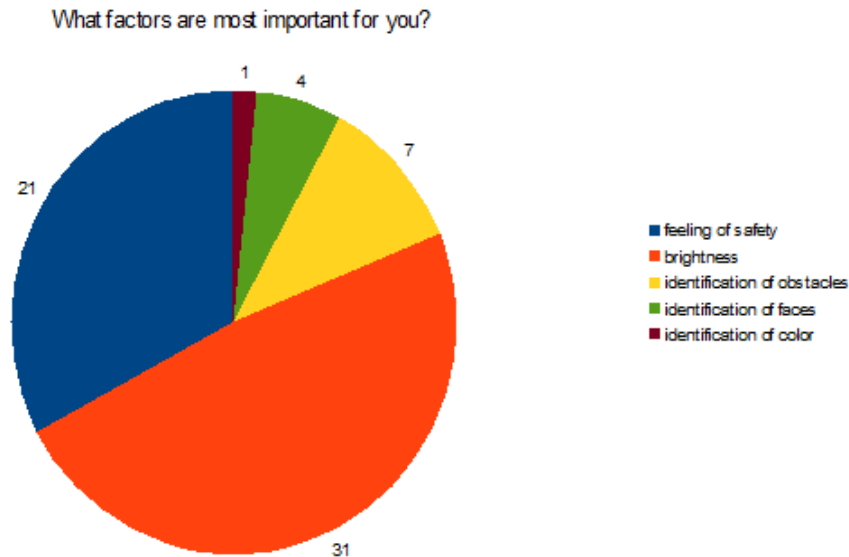
As mentioned, not only the objective light output based on technical results were taken into consideration, but also the subjective good-feeling and safe-feeling factor of passers-by had to be considered. This was done by handing out a standardized questionnaire to 10 probands and evaluating their answers. The questionnaire contained some general questions to evaluate the sensitivity of the probands in regards to energy saving and LED lighting and some specific questions to be able to evaluate the resulting light output of the luminaires.

The general question *'Is climate protection and energy saving an important factor for you?'* was answered by 82% with 'Yes, really important' and another 8% with 'yes, a bit'. In general, the public is sensitive to this subject.

Very often the glare of the LED SL is criticized by passers-by. In this evaluation 65% answered the question *'Does the amount of light from the fixture affect your eyes?'* with 'no, not at all' and another 15% with 'no, I don't think so'. The possible answer 'yes, a bit' was chosen just once, the answer 'yes, a lot' was not chosen. All luminaires seem not to cause excessive glare.

The question '*What kind of lighting color do you prefer?*' was answered by 80% with 'white (in different grades)' and the rest with 'don't know'. The answer 'yellow' was not chosen by any proband.

To find out what subjectively felt factors are important to the public, the probands were asked '*What factors are most important for you?*'



The answers were not very surprising and typical for this kind of question related to street lighting. For about 48% of the probands the factor 'brightness' is most important, followed by 'feeling of safety' with 33% and the identification of obstacles and faces with 17%. The factor 'brightness' was rated by the probands subjectively, based on the good feeling and/or safe feeling.

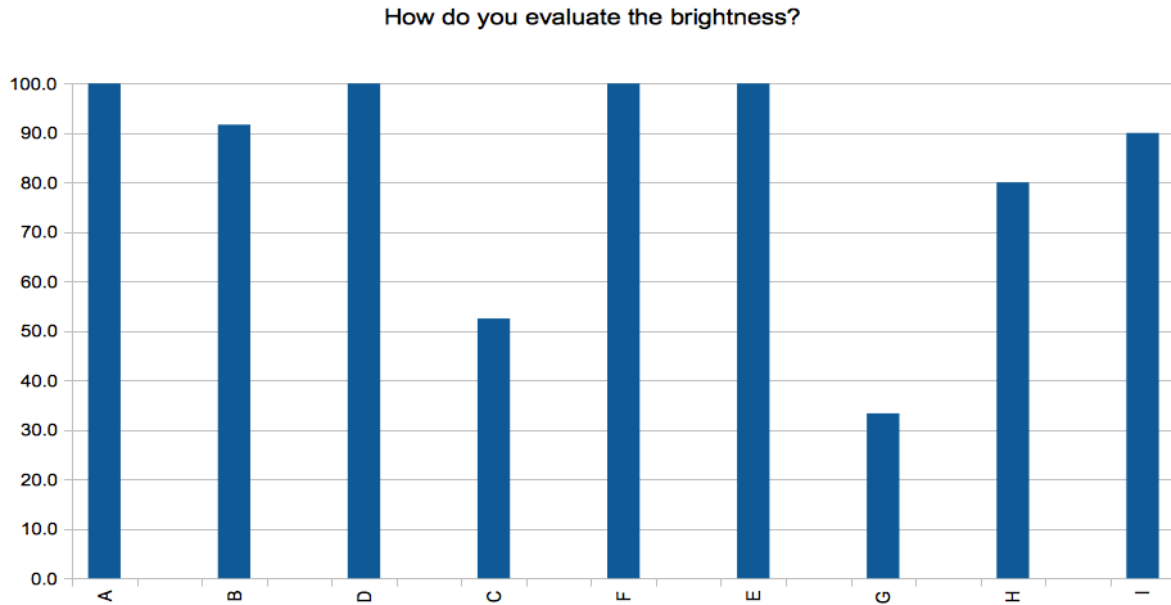
To be able to derive the results from the questionnaire, the rating was converted into percent with

Okay = 100%

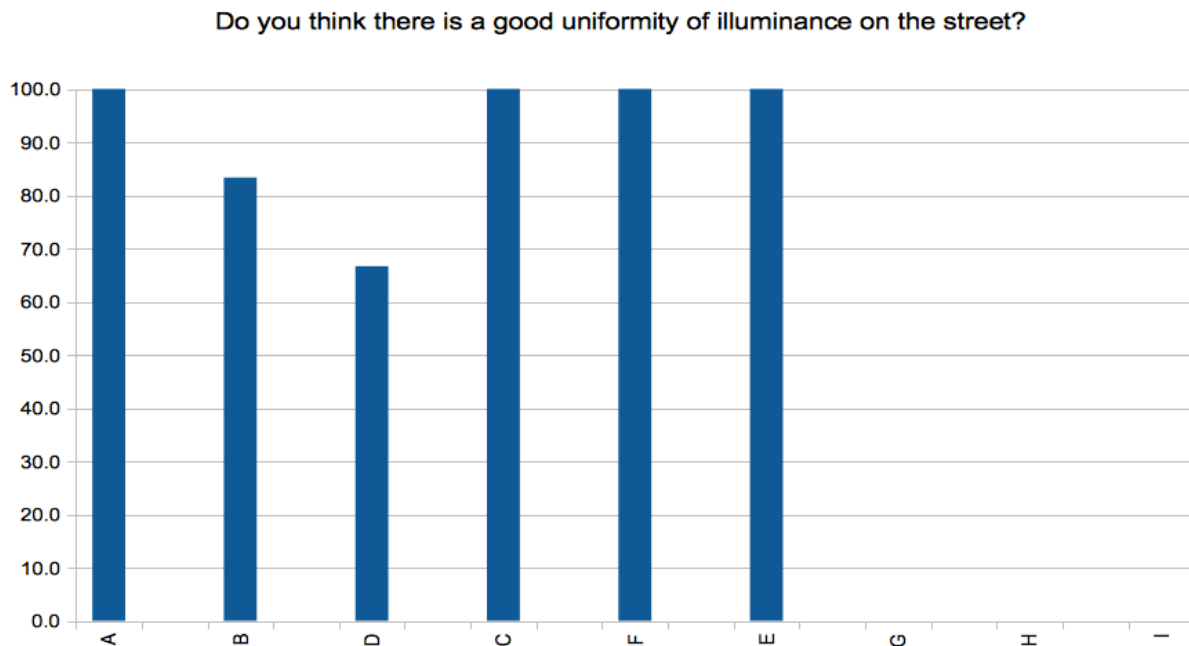
Too bright, too dark = 50%

Much to bright, much to dark = 0%

The possible answer 'don't know' was not chosen by any proband.



If brightness is rated subjectively by probands, uniformity is rated automatically at the same time because usually the overall impression is rated. To separate this somehow, the specific question 'Do you think there is a good uniformity of illuminance on the street?' was asked.



The rating was converted into percent with

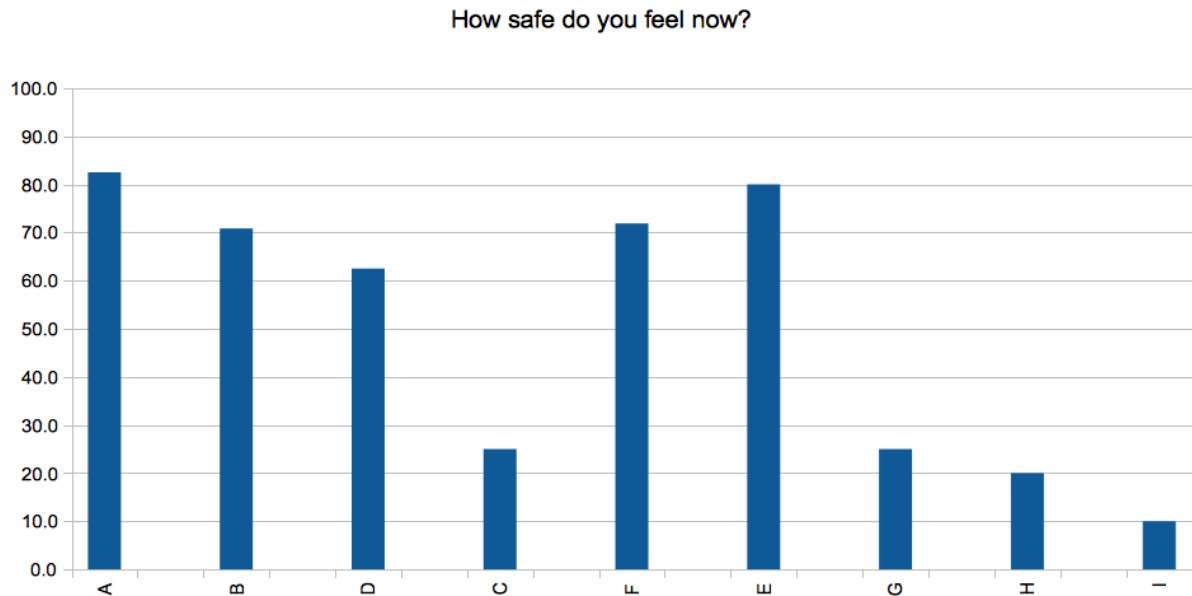
yes = 100%
no = 0%

The graph clearly shows, that the resulting uniformity at the test road for the luminaires of G, I and H was considered as being bad. For the luminaires of G and I this might be due to the low overall illuminance level, whereas for H this is somehow surprising, because they got the best rating based on the technical results.

The general question 'How much does street lighting influence your feeling of safety?' was

answered by 83% of the probands with 'a lot' and by 8% with 'a bit'.

To find out, how safe the probands felt with the illuminance level for each luminaire they were asked 'How safe do you feel now?' The following graph shows their responses.



Again the rating was converted into percent with

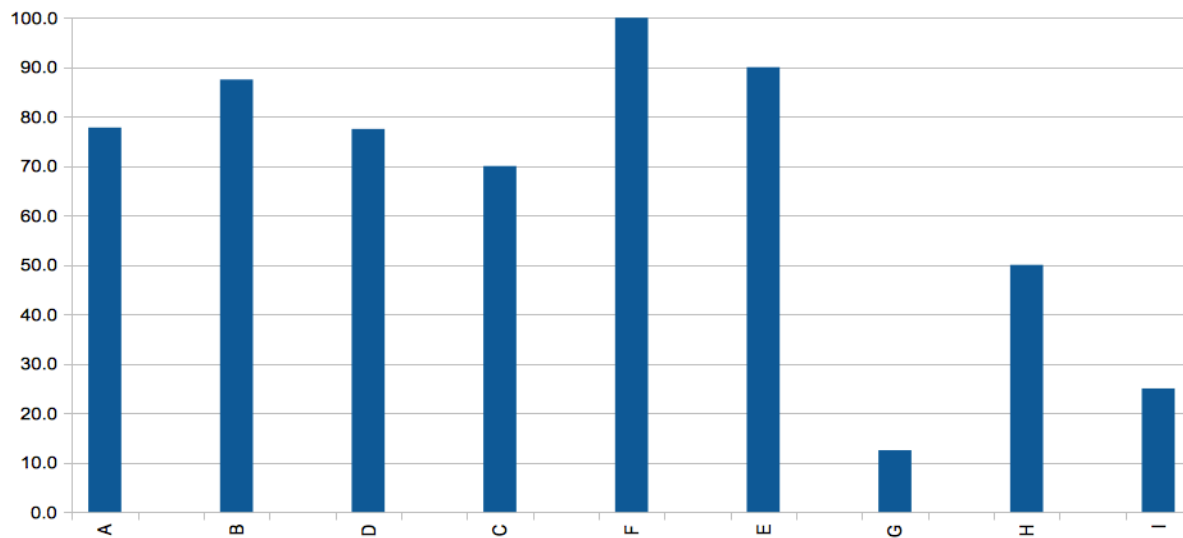
- really safe = 100%
- safe = 75%
- neutral = 50%
- a bit unsafe = 25%
- really unsafe = 0%

The answer 'don't know', chosen by about 10%, was not converted into percent.

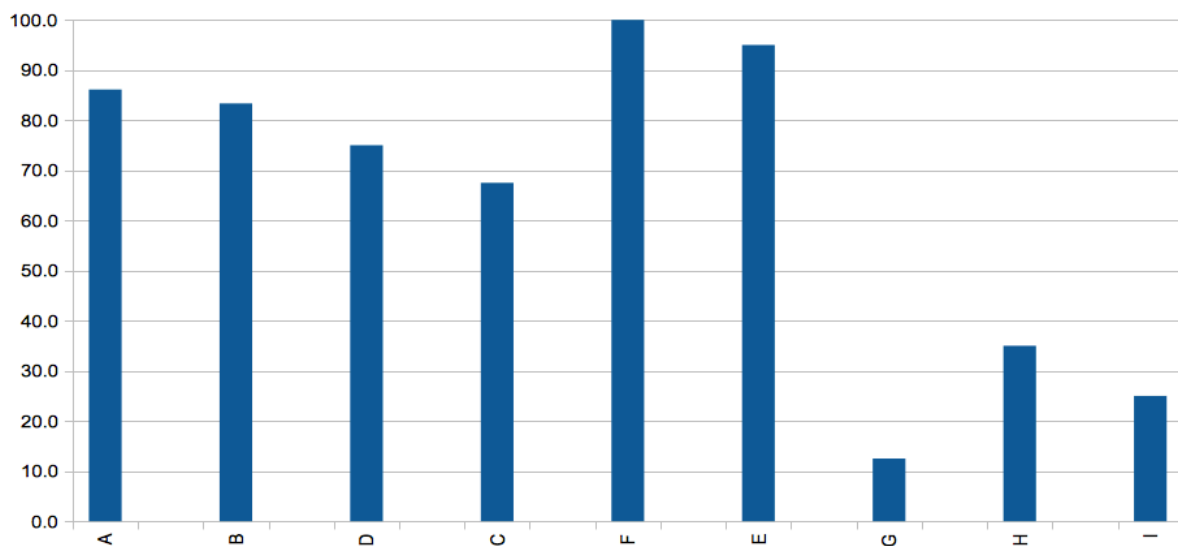
The graph shows a clear Top 5 in the subjective rating of the passers-by.

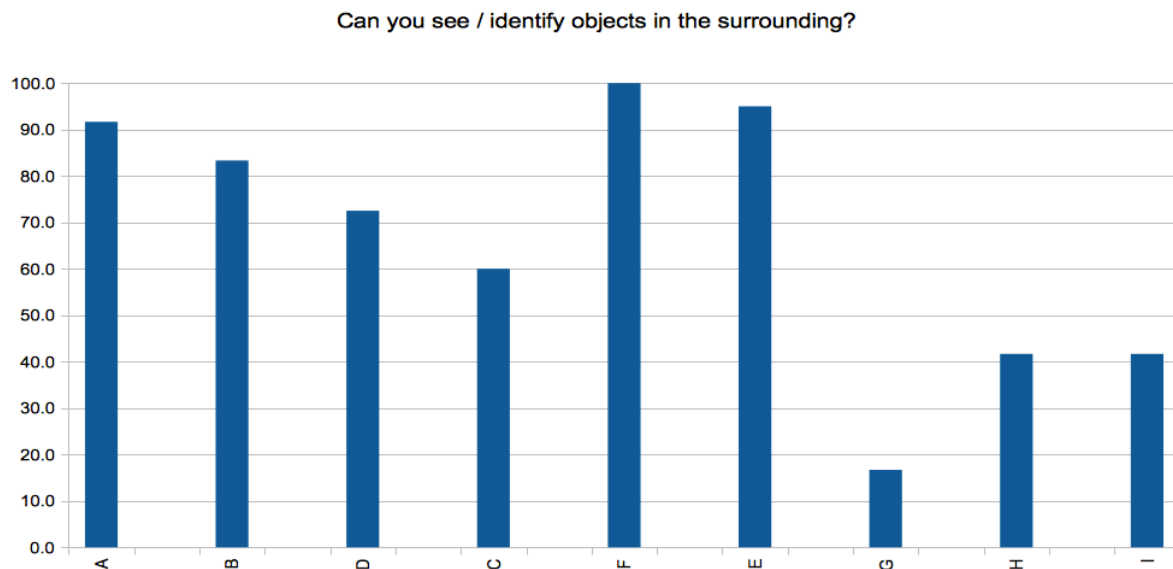
The questions concerning the identification of obstacles, people and their faces and objects follow the same tendency.

Can you see obstacles?



Can you see / identify people and their faces?





Again the rating was converted into percent with

- yes, really good = 100%
- yes, a bit = 75%
- neutral = 50%
- no, I don't think so = 25%
- no, not at all = 0%

The possible answer 'don't know' was not converted into percent.

The evaluation of the questionnaires clearly shows the importance of taking both, the objective technical results and the subjective factors good-feeling and safe-feeling into account. The technically top rated luminaires of Supplier H are clearly the losers of the subjective impression. The luminaires of D are within the Top 5 in the subjective ranking, but yet losing their ranks #2 and #3 in the technical evaluation. On the other hand the fixtures of Supplier F, that got a weak rating on energy consumption, due to a high wattage, and less than average components, mainly due to a missing sealing ring, were subjectively rated high. Supplier A was in the Top 3 of the technical and the questionnaire evaluation.

5.9. Correction of the horizontal illuminance

With the request for proposals the LED SL suppliers were asked to select their most appropriate lamp model for replacement of the HPS lamps in the described road situations. As a consequence of this specification, the various suppliers delivered various types of luminaires. While some suppliers focused on higher light output and lower energy savings, others did the opposite.

For LED luminaires there exists a correlation between current through the LED and luminous flux. This correlation allows a conversion of the measured results to a standardized illuminance that is the same for each luminaire. This allows to compare the power consumption of the luminaires with each other and can be considered to be a more objective evaluation of the technical parameters.

The conversion, or interpolation, is based on a rule of thumb derived from data of leading German LED-manufacturers using different LED chips. A good rule of thumb for the ratio between 'turning up the current' and 'increased luminous flux' is about 1:0.9, which means if

10% more current is sent through the LED the luminous flux increases by 9%. With the increase of the current the LED efficiency is reduced because a greater part of the energy is transformed into heat.

This correlation is used as well in the CLO or CLOU function (Constant Light Output) of lamps to keep the illuminance level more or less constant.

The following table is shown as an example for the interpolation.

Table 16: Standardization of appliance illuminance (example)

Supplier	Luminaire wattage [W]	Illuminance E [lx]	Uniformity AM [min/aver]	Illuminance corrected Ecorr [lx]	Wattage corrected [W]
A	56.30	8.71	0.149	10.00	65.47
B	64.56	9.47	0.253	10.00	68.53
D	58.10	10.04	0.119	10.00	57.89
C	43.68	3.26	0.153	10.00	143.02
F	70.28	10.27	0.214	10.00	68.62
E	54.23	10.69	0.094	10.00	51.08
G	35.08	5.91	0.101	10.00	61.79
H	48.64	9.82	0.041	10.00	49.62
I	67.73	5.54	0.036	10.00	127.71

The results of the interpolation show that the luminaires of Supplier C and I do not reach the projected energy saving of 40% while maintaining the targeted illuminance level.

This underlines the necessity of specifying the desired maximum wattage to achieve the requested energy saving and the targeted illuminance level at the same time.

6. CONCLUSIONS

The data of the different parameters that have been measured and analyzed were documented and evaluated in matrixes. The analyzed parameters are:

- horizontal illuminance,
- uniformity of illuminance,
- energy efficiency (wattage, power factor),
- current as indicator for longevity,
- temperature inside and outside the luminaire and
- build-up of the luminaires.

The 50 W HPS replacements were evaluated because most of the luminaires on the island are equipped with that wattage. The 100 W HPS replacements were also evaluated because they were selected for installation on the test road. In both evaluation matrixes Supplier H reached the highest score, followed by D and/or A.

In addition to the technical evaluation a subjective evaluation based on the impression of passers-by was conducted to incorporate the emotional factors in the evaluation. Here, the results are different to the technical evaluation. It therefore is suggested to use a combined method to include the technical evaluation and the subjective questionnaire evaluation, and eventually include luminaire prices, too. The weighting factors should be decided by the evaluating team and adjusted to the specific needs or requirements. A reasonable approach should be in the range of:

Price	35-50%
Objective technical evaluation (including energy consumption)	40-50%
Subjective evaluation (emotional factors)	10-25%

Table 17: Example for a weighted evaluation matrix

Rating matrix St. Vincent 100W HPS replacement

Supplier	Price 35%		Technics 50%		Subjective opinion 15%		Total 100%
	Price		Evaluation matrix		Questionnaires		
	[\$]	weighted [%]	[%]	Weighted [%]	Average [%]	Weighted [%]	Total [%]
A	0.00	0.00	77.90	39.0	89.7	13.5	52.4
B	0.00	0.00	75.30	37.7	83.3	12.5	50.1
D	0.00	0.00	76.50	38.3	75.7	11.4	49.6
C	0.00	0.00	59.00	29.5	62.5	9.4	38.9
F	0.00	0.00	59.50	29.8	95.3	14.3	44.0
E	0.00	0.00	72.70	36.4	93.3	14.0	50.3
G	0.00	0.00	70.50	35.3	16.7	2.5	37.8
H	0.00	0.00	82.90	41.5	37.8	5.7	47.1
I	0.00	0.00	37.60	18.8	32.0	4.8	23.6

The luminaire that is scored highest in VINLEC’s pilot project is not necessarily meant to be the selected supplier for LED luminaires in the Caribbean. It is more meant to be the luminaire that fulfills most criteria for an LED street lighting fixture in the Caribbean at this time. Nevertheless the test results should provide some relevant information for future tendering processes.

7. REFERENCES

- [1] “VINLEC LED Street Lighting Project – Measurement Evaluation”, STEP Consult, May 2013

Annexes