LIGHTING AFRICA
Catalyzing Markets for Modern Lighting

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IFC International Finance Corporation
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Lighting Africa Quality Test Method (LA-QTM)

Test Procedure – Version 2.0

December 2010

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1 Document History

This document is based on a report prepared by the Fraunhofer Institute for Solar Energy Systems (FISE) titled *Stand-Alone LED Lighting Systems Quality Screening* which was developed to evaluate the performance and quality of LED-based off-grid luminaires. The FISE report was modified by Lighting Africa staff in order to make the test procedures within this document consistent with those which are required by another recently released Lighting Africa document: the *Standardized Specification Sheet Guidelines.*

1.1 Norms, Specifications and Test Procedures

For the development of the LED product screening method, existing test procedures and specifications for LEDs or other off-grid lighting systems, batteries, charge controllers and solar modules, were collected and examined, such as:

- PVGAP PVRS 5/5A, batteries
- IEC 61951, NiMH batteries
- IEC 61960, Li-ion batteries
- CIE 127, LEDs
- CIE 84 Light measurement
- Indian LED lighting specifications
- PVGAP PVRS 11A, solar lights
- IEC 62124 PV stand-alone systems, design verification and others.

1.2 List of Terminology and Abbreviations

Term/Abb.	Explanation	Term/Abb.	Explanation
A	Ampere (current)	Lx	Lux, unit of illumination
A	Area	Lm	Lumen, unit for luminous flux
AC	Alternate Current	LVD	Low Voltage Disconnect (Charge Controller)
AM	Air Mass	LPS	Laboratory Power Supply
BTF	Burn Time Factor (Ratio of DBT to autonomous time)	Min	Minute
CC	Charge Controller	MPP	Point of the I-V curve of a PV panel which represents the highest power
CCC	Continuous Charging Current	NiCd	Nickel Cadmium Battery
CRI	Color Rendering Index	NiMH	Nickel Metal Hydride Battery
DBT	Daily Burn Time		
DC	Direct Current	Φ_v	Phi, used for luminous flux
DIN	German Norm	Pb	Lead
DOD	Depth of Discharge (Battery)	PCB	Printed Circuit Board
DuT	Device under Test	PV	Photovoltaic
E_v	Illuminance	PV GAP	Global Approval Program for Photovoltaics
EN	European Norm	PV RS	Recommended Specification published by PV GAP
h	Hour	ROCT	Real Operating Cell Temperature (PV panel)
HVD	High Voltage Disconnect (Charge Controller)		
I_{10}	10 hour discharge current		
I_{100}	100 hour discharge current	SOC	State of Charge (Battery)
I_{MPP}	Current at Maximum Power Point (PV panel)	SHS	Solar Home System
IEC	International Electrotechnical Commission	STC	Standard Test Conditions: Irradiation 1000 W/m^2, panel T=25 °C, AM 1.5
I_{SC}	Short circuit current of a PV panel	SSF	Simplified Solar Fraction (charge to discharge ratio)
I-V	Current – Voltage Curve (PV)	T	Temperature
IP	International Protection class system	T	Period (time)
LED	Light Emitting Diode		
Li-Ion	Lithium Ion Battery		
		UV	Ultra Violet (Radiation)
		V	Voltage
		V_{MPP}	Voltage at Maximum Power Point (PV panel)

1.3 Test Samples and Assessment

The lights are to be assessed using three main criteria: lighting service, usability and durability. At least six test samples (Devices under Test, DuT) of each type of lantern or light should be used for the assessment. For bulk tests and measurements we recommend the use of at least 12 lights to be able to perform tests in parallel. For example six samples can be started testing the lumen depreciation (long term test, see 2.10) whilst the other six samples undergoing the rest of the tests.
It is also recommended to keep additional samples in reserve in case one of the 12 DuTs shows problems (e.g. is damaged or shows results of high deviation).

The flow chart in figure 1-1 gives an overview of the entire procedure (based on 12 test samples); these tests make no use of pass/fail criteria, but report the measurement results for further evaluation.

For documentation of the results, a test report template was prepared (see Annex 3.6).

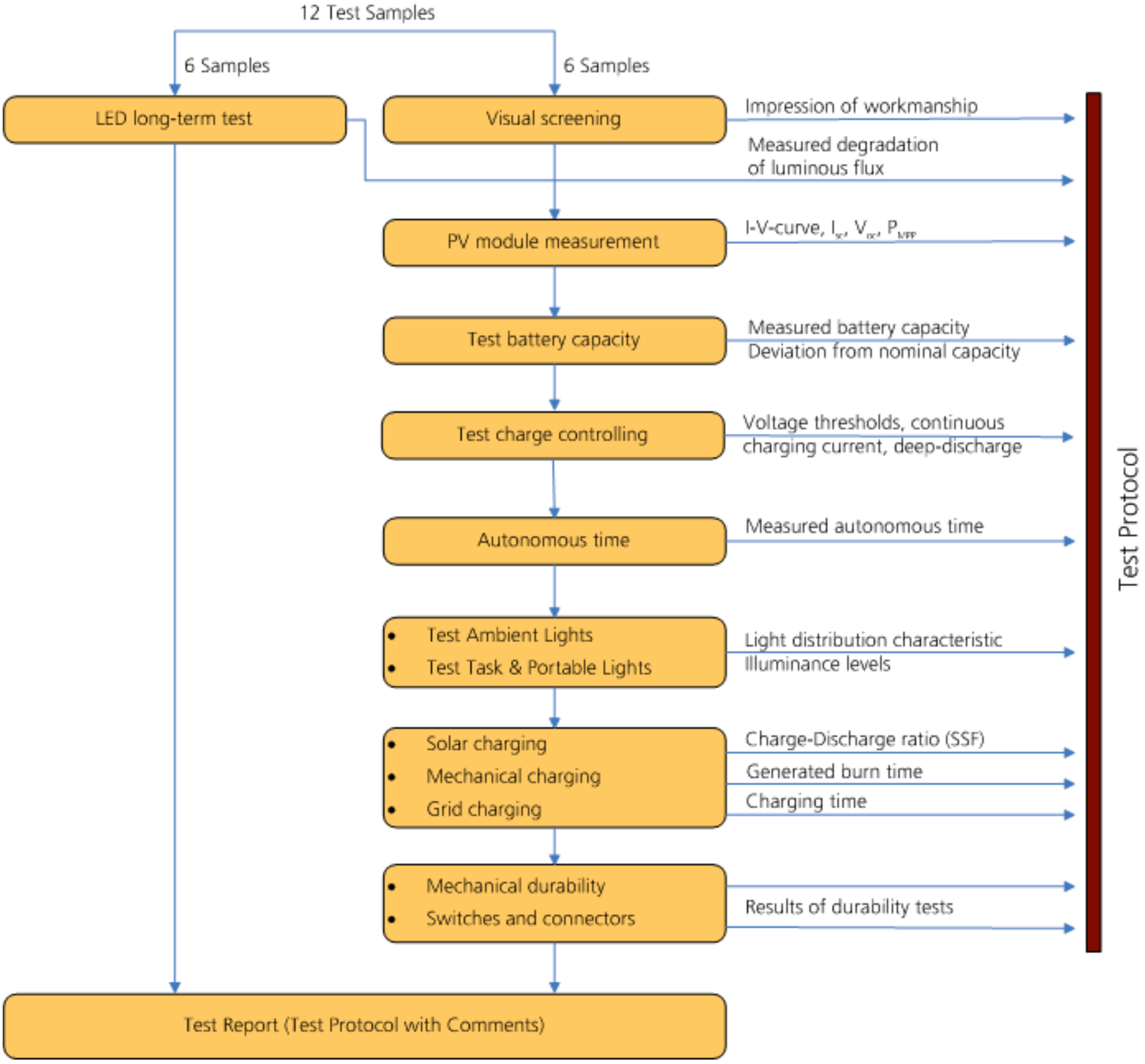

Figure 1-1: Overview of measurement and test procedures.

1.4 Lighting Africa Quality and Performance Targets

The following performance targets should be used for assessment of the test results where a subjective comparison between a measured value and target value is required. Additionally, these targets determine which brightness settings are of interest for autonomous run time measurements (i.e., those levels which meet the illumination target).

Parameter(s)	Requirement	Notes
All specified parameters from packaging or labeling (e.g., battery capacity, PV power, run time, light output, additional features etc.)	The average measured value indicates the specified rating is accurate. All specified features are present and operable.	In general, allowed to deviate according to the precision of the test results – approximately 10% in many cases.
Illumination	≥20 lumens OR ≥25 lux over a continuous 0.1 m^2 area	Assessed at each light level
Run Time	≥8 hours autonomous run time OR ≥ 4 hours run time from a standard PV charging day	Assessed at a light level for which the average light output meets the illumination target OR the highest light level if none meet the target
Lumen Maintenance	≥2000 hours L_{70} time	
IP Class	41 or better (43 or better if PV is integrated with the lamp body).	
Drop Test	Pass	
Soldering Quality	Pass (no bad joints)	
Switch durability	Pass	

2 Test Procedures

2.1 Visual Screening

This test verifies the overall "visible" quality and the technical specifications provided by the manufacturer. Furthermore, characteristics such as size and weight are recorded, and the light is evaluated with respect to its design and workmanship. The information gathered in the visual screening will be subject to availability and the skill of the screener. Ideally, the person undertaking visual screening will be skilled at assessing the quality of electronics assembly, identifying components, and detail oriented.

Useful **materials and equipment** for conducting visual screening:

- **Calipers and ruler** for measuring dimensions of product, attachment points, cables
- **Balance (scale)** for weighing product
- **Bright task light with good rendering** to adequately illuminate working area. ≥700 lux and ≥85 CRI recommended
- **Miscellaneous hand tools** to disassemble product
- **Camera** to document product characteristics with particular attention to documenting potential points of failure (e.g., cold solder joints). Any points of failure that can be photographed should be documented and included in the test report (as an appendix if necessary).
- **Multimeter** for conducting basic electronic integrity and functional tests

Pages two and three from the test report template should guide the visual screening process. The following guidance is provided to aid the process of completing the visual screening, and is presented in the order of appearance on the report template:

- **Price:** List wholesale and/or retail price if it is known. Include source of information (e.g., from field procurement agent or manufacturer's suggestion). Describe "type" of wholesale or retail price if available (e.g., FOB, CIF, retail in Kenya, etc.).

<u>External Screening</u>

- **Housing / Form Factor:** List materials and form of housing.
- **Cable:** List length and description of any cables that are included other than those used to connect an external PV module (e.g., connecting remote light sources to a base station).
- **Connectors:** List any external connections by use and type (e.g., 2 mm female barrel plug for PV module connection, mini USB for AC charging).
- **Handles:** List if there are any handles and describe them.
- **Light Distribution:** Describe the extent of the light distribution by placing it in one of the following categories: [180° horizontal, 360° horizontal, Other]. If other, note the extent of the light distribution (e.g., narrow beam).
- **Size:** Measure and record the size (cm) of the lighting product (can include several components if there are multiple interconnected parts). Do not include dimensions of an external solar module.
- **Weight:** Measure and record the mass of the entire lighting product as it would typically be used in a lighting application (not including any external solar modules or auxiliary connectors).

- **Indicators:** List any external indicators; describe their character and utility (e.g., red LED charging indicator). If it is not obvious what the utility is, note it.

Internal Screening

- **Wiring:** Inspect and describe the quality and workmanship of the electronic components. If there are cold joints, note it. Use comments to describe the findings, positive or negative.
- **Fixture of Parts:** Indicate methods used to secure parts inside the lamp.
- **Deficiencies:** Note particular deficiencies or problems from the internal screening. Use photographs to document any deficiencies.
- ***See "Internal Screening Notes" below for general guidance on internal screening***

Function

- **Switches:** Note if the switches are functional (i.e., if the light works).
- **Connectors:** Note if all the external connectors are functional (may require use of a multimeter).

Electronic Components

- **Lamp Driver:** If possible, note the type of electronic circuit that drives the lamp (e.g., PWM for LED or electronic ballast for CFL). *This assessment is optional; it is sometimes necessary to use advanced equipment or techniques to identify driver topology.*
- **Battery:** Based on the specifications, labelling, or inspection of the batteries (not including use of a battery analyzer) note the chemistry, capacity (mAh), and nominal voltage (V). If the information is unavailable, note it.
- **Light Source:** Based on specifications, labelling, or inspection, note the type and number of light sources.
- ***See "Electronic Components Notes" below for general guidance on internal screening***

Mechanical Charge

- **Robustness:** Qualitatively describe the robustness of the mechanical charging mechanism if one is present.
- **Miscellaneous:** Include any observations on the mechanical charging mechanism.

Solar Module

- **Size:** Measure and record the overall size of the solar module (cm).
- **Module ext./int.**: Note if the module is external or internal.
- **Specifications:** If they are available from labelling on the packaging or solar module, list the specifications of the module in the following areas: Module type, P_{MPP}, V_{OC}, V_{MPP}, I_{SC}, I_{MPP}.
- **Miscellaneous:** Include any additional information about the module (e.g., number of individual cells).
- **Robustness:** Qualitatively describe or categorize the solar module.

- **Cable Length:** In the case of external modules, measure and record the cable length.

Sample Record: Include information about sample acquisition by the test lab (date received and personnel who received the samples).

Documentation Available: (this section focuses solely on if information is printed on the packaging or included in documentation with the retail product.)

- **Operation Manual:** Note if there is a manual included, the type of manual it is (e.g., printed on side of box, single sheet of paper, booklet), and what language(s) the manual is composed in.
- **Charge Controller Info:** Note if there is information available about a charge control, the type, and limits.
- **Battery Info:** Note if there is information available about the battery, the type, and capacity.
- **PV Info:** Note if there is information available about the PV module, its power rating, and IV characteristics.

Run Time Specifications: (this section focuses solely on if information is printed on the packaging or included in documentation with the retail product)

- **Autonomous Time:** Note number of hours the lamp will operate on a *full battery charge* on high setting and other settings.
- **Daily Solar Run Time:** Note number of hours the lamp will operate on a *battery charge from a day of solar charging* on high setting and other settings.
- **Mechanical Run Time:** Note number of hours the lamp will operate *after a specified mechanical charge period* on high setting and other settings.
- **Grid Run Time:** Note number of hours the lamp will operate *after a specified AC/DC adapter charge period* on high setting and other settings.

Charge Indication: Note if there is a description of the charge indication meanings; describe the meaning if available.

Grid Charging: Note if there are instructions on grid charging; describe the instructions if they are available.

Estimated IP Class: Based on guidance in section 2.1.1 or additional experience, estimate the ingress protection class of the product.

Comment Visual Screening: Comments about the visual screening are critical for interpreting the results.

Photo: At the very least, provide a photo of the light and its components. Multiple photos from several angles (both external and internal) are normally included. Include photos of any deficiencies in particular.

Internal Screening Notes:

- Printed circuit boards and solder joints should be accurately finished. Cold joints, bypasses or any other incorrect connections, as shown in figure 2-1 are not permitted. A cold solder joint features both a poor electrical and a weak mechanical connection. They can be recognized by a tarnished surface and a globular shape. In contrast, good joints have a shiny surface and a pyramidal shape.

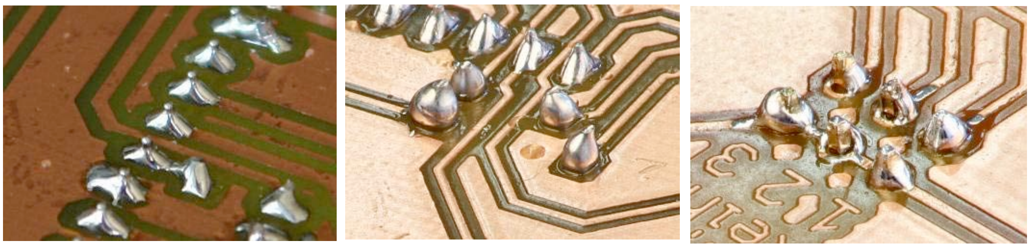

Figure 2-1: Good solder joints (*left*), cold joints (*center, in front*) and poor joints (*right*).[1]

- Components should be properly fixed, and ideally screwed. Using hot glue, sealing compound and tape to fix parts involves the risk of parts becoming loosened. It must not be possible for inserted components to move[2].

Figure 2-2: Components fixed with hot glue (*left*); with tape (*center*); a badly crimped wire (*right*)

- Corrosion, shown by a brownish discoloration of metals, must not be ascertainable.
- Cables and wires should be properly laid out (no "cable spaghetti"). They may not be wedged by any component. For examples see Figure 2-2 and Figure 2-3.

Figure 2-3: Cable spaghetti (*left*), wedged wire (*centre*) and heavily corroded components (*right*)

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[1] http://www.projektlabor.tu-berlin.de/fileadmin/fg52/onlinekurs/fehlersuche/gute_loetstellen.jpg, http://www.projektlabor.tu-berlin.de/fileadmin/fg52/onlinekurs/fehlersuche/kalte_loetstellen.jpg, http://www.projektlabor.tu-berlin.de/fileadmin/fg52/onlinekurs/fehlersuche/schlechte_loetstellen.jpg

[2] Glues and adhesives can be effective at affixing parts if they are properly used and the design includes some mechanical elements as well to hold parts in place. However, assessing the mechanical fitness of a glue or adhesive-based affixing design is outside the scope of the testing, so the presence of glues or adhesives is a yellow flag - meaning that there is potential for parts coming loose but not guaranteed.

Electronic Components Notes

- Some lights use DC/DC drivers for operation of the LEDs. To perceive those kinds of electronics Figure 2-4 could be helpful. If there are coils visible on the PCB most likely a DC/DC ballast is built in.

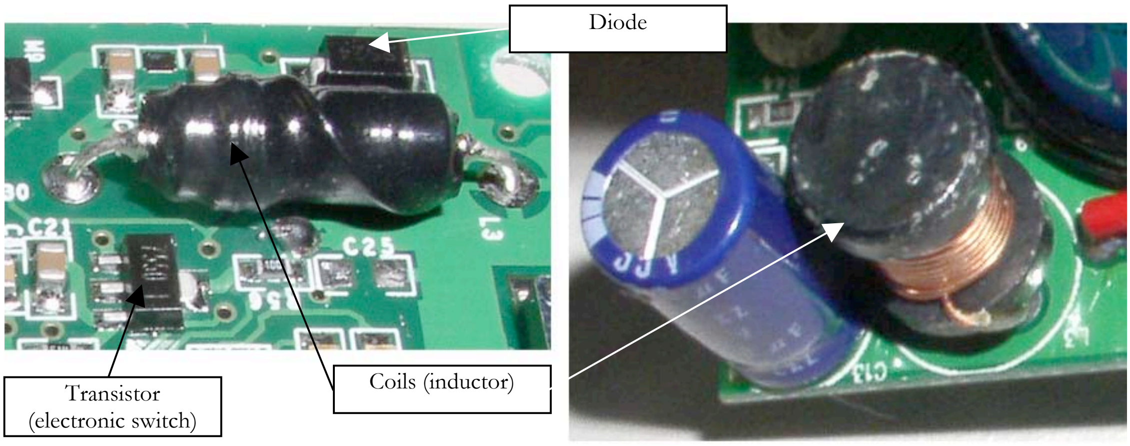


Figure 2-4: Typical components of DC/DC ballasts or controllers.

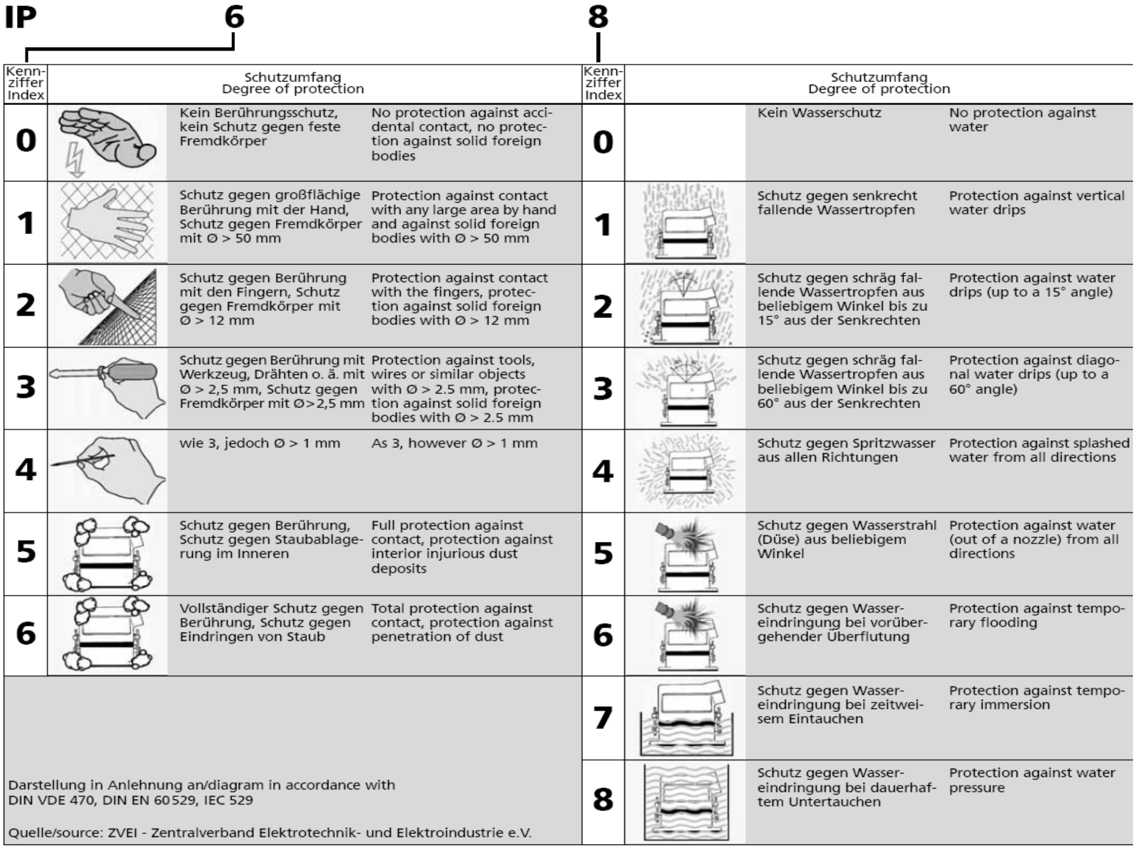
By conducting a visual examination of the internal and external quality of workmanship and robustness, an assessment can be made of the light's durability. It should be checked whether or not the lights provide an indication of state of charge (SOC) and charge progression, the cable length of external PV modules should be measured, and the IP protection class should be estimated (see chapter 2.1.1, page 13). Checks should also be conducted as to whether an electronic ballast for the LED(s) and a charge controlling device are available.

During evaluation of the internal quality of workmanship, attention should be paid to the following points:

- The use of NiCd and lead-acid batteries is not recommended due to their environmental pollution potential (an overview of different types of batteries is shown in chapter 2.3 and following).
- It is recommended that batteries be replaceable in higher priced products.
- The light may not show any recognizable damage, either inside or outside.

2.1.1 Protection against Environmental Impacts

Rechargeable LED lighting systems are exposed to environmental influences. With respect to dust and water tightness, the lights have to be assessed according to IP protection classes (DIN EN 60529/IEC 60529), see Figure 2-5.



Kennziffer Index	Schutzumfang	Degree of protection
0	Kein Berührungsschutz, kein Schutz gegen feste Fremdkörper	No protection against accidental contact, no protection against solid foreign bodies
1	Schutz gegen großflächige Berührung mit der Hand, Schutz gegen Fremdkörper mit Ø > 50 mm	Protection against contact with any large area by hand and against solid foreign bodies with Ø > 50 mm
2	Schutz gegen Berührung mit den Fingern, Schutz gegen Fremdkörper mit Ø > 12 mm	Protection against contact with the fingers, protection against solid foreign bodies with Ø > 12 mm
3	Schutz gegen Berührung mit Werkzeug, Drähten o. ä. mit Ø > 2,5 mm, Schutz gegen Fremdkörper mit Ø>2,5 mm	Protection against tools, wires or similar objects with Ø > 2.5 mm, protection against solid foreign bodies with Ø > 2.5 mm
4	wie 3, jedoch Ø > 1 mm	As 3, however Ø > 1 mm
5	Schutz gegen Berührung, Schutz gegen Staubablagerung im Inneren	Full protection against contact, protection against interior injurious dust deposits
6	Vollständiger Schutz gegen Berührung, Schutz gegen Eindringen von Staub	Total protection against contact, protection against penetration of dust

Kennziffer Index	Schutzumfang	Degree of protection
0	Kein Wasserschutz	No protection against water
1	Schutz gegen senkrecht fallende Wassertropfen	Protection against vertical water drips
2	Schutz gegen schräg fallende Wassertropfen aus beliebigem Winkel bis zu 15° aus der Senkrechten	Protection against water drips (up to a 15° angle)
3	Schutz gegen schräg fallende Wassertropfen aus beliebigem Winkel bis zu 60° aus der Senkrechten	Protection against diagonal water drips (up to a 60° angle)
4	Schutz gegen Spritzwasser aus allen Richtungen	Protection against splashed water from all directions
5	Schutz gegen Wasserstrahl (Düse) aus beliebigem Winkel	Protection against water (out of a nozzle) from all directions
6	Schutz gegen Wassereindringung bei vorübergehender Überflutung	Protection against temporary flooding
7	Schutz gegen Wassereindringung bei zeitweisem Eintauchen	Protection against temporary immersion
8	Schutz gegen Wassereindringung bei dauerhaftem Untertauchen	Protection against water pressure

Darstellung in Anlehnung an/diagram in accordance with
DIN VDE 470, DIN EN 60529, IEC 529

Quelle/source: ZVEI - Zentralverband Elektrotechnik- und Elektroindustrie e.V.

Figure 2-5: IP protection class system in accordance with DIN EN 60529 / IEC 60529[3]

This is also valid for fixed installed systems, which must be protected against dust as a priority. The LED light has to be classified visually in the IP safety class system using Figure 2-5 as a guideline.

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[3] IEC The International Electrotechnical Commission., IEC 60529, Degrees of protection provided by enclosures, Geneva 2001

2.2 PV Panel I-V Characteristic Curve

Solar LED lights are powered by PV panels, which typically have a power range from approx. 0.3 to 10 Watt peak (W_P)[4]. The majority of the panels tested so far are within the 0.5 – 3.0 W_P range, and technical data for them is often not provided. The purpose of the PV module test is to validate the manufacturer's data (if any is available) and to determine the I-V characteristic curve.

Typically, the PV panel output is measured with the help of a solar simulator ("flasher") in accordance with standard IEC 60904. This is the preferred technique for characterizing the PV panels and laboratories that have access to a solar simulator are asked to utilize this procedure.

Since solar simulators are rather expensive, the test can be performed with an instrument that is designed to make outdoor measurements of the performance of small solar modules.[5] This approach is described in detail as the "Low-Cost Procedure" below. It can be utilized by laboratories that do not have access to a solar simulator. Note that many instruments for making outdoor measurements of solar module performance are NOT designed to make accurate measurements of very small modules (e.g. modules < 3 peak Watts). When selecting an instrument, it is important to ensure that it is able to make accurate measurements of modules in the desired size range.

The hand-held meter used in the low-cost procedure measures the short-circuit current I_{SC} and the open-circuit voltage V_{OC} and is also able to plot the I-V characteristic curve of the panel. The basic uncertainty of voltage and current measurements should be $\leq$ 0.5 % of the measuring range. A current measuring range of max. 2 A and a voltage measuring range of max. 60 V is appropriate for the small lighting systems and lanterns.

A prerequisite for outdoor PV panel measurements is a sunny day. If global irradiation is less than 800 W/m², the measured parameters cannot be accurately converted to STC.

Standard Laboratory Measurement

Refer to standards:

- IEC 61215 Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval
- IEC 61646 Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval

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[4] This is the nominal power a module shows under STC. Since standard test conditions are extremely rare in practice, the achieved power is usually lower.

[5] One possible instrument that can be used for modules between approximately 1.0 peak Watts and 20 or more peak Watts is an adapted version of the Mini-KLA (www.ib-mut.de). The ranges of the modified device are: 2 A / 0.2 A and 15 V / 30 V / 60 V. When purchasing it is critical to ensure that the instrument is specified to operate with these modified ranges in order to accurately perform the necessary measurements. This instrument as specified can give inaccurate results for measurements of modules that are smaller than 1.0 peak Watts.

Low-Cost Procedure

Measurement of the I-V-Curve under ROCT Conditions (Outdoor Measurement)

Some PV panels do not allow fixing the temperature sensor (thermocouple) at the backside because of a closed plastic housing that cannot be easily removed. In this case, it is necessary to mount the sensor at the front of the panels. This leads to a slightly different procedure. In the following, both methods are described.

Prerequisites for Outdoor testing: The following atmospheric conditions are necessary for outdoor PV module testing, and apply to any outdoor solar module testing in this methods document.

- Insolation ≥ 800 W/m^2
- Air mass $\leq$ AM2
- Clouds are nonexistent to sparse with no clouds or haze in the region adjacent to the sun position.

A) Backside mounted thermocouple	**B) Front side mounted thermocouple**
• In the shade: ◆ Connect a voltage meter or multimeter (voltage range) to the panel ◆ Measurement of the panel temperature T_1 using a contact thermocouple. Fix the thermocouple at the rear side of the module. It is important to measure T_1 before the panel is exposed to the sun light. Note the temperature T_1. • Expose now the module to the sun light and measure the open circuit voltage V_{OC1} very quickly. Make sure, that this measurement is really done very quickly to avoid that the panel gets heated up! Note the open circuit voltage V_{OC1}: • After the measurement, leave the panel in the sun light until it has reached its thermal balance. Note: the thermal equilibrium is reached when the temperature measurement is stable. • Then, the panel should be connected to the I-V-curve tracer as indicated in the manufacturer's operation manual. Make sure that the irradiation is > 800 W/m^2. • Execute the measurement; the measurement must be performed as described in the PV tracer's manual. • No objects may shade the irradiation sensor or the PV panel under test during the measurement. • After the measurement of the I-V curve, measure the temperature of the module for a second time (attach again the thermocouple to the rear side of the panel). Note the temperature T_2. • Readout the measurement data of the I-V curve using the software provided by the manufacturer of the I-V-curve tracer. Extract V_{OC2} for the heated module from the measured data. • The temperature coefficients for the voltage (T_{C_VOC}) can now be calculated with the following equation: $T_{C\_VOC} = \frac{V_{OC\_1} - V_{OC\_2}}{T_1 - T_2}$ (1) • Values are then converted to STC (see Annex 3.6) and the I-V-curve is plotted with the help of for example MS Excel or Open-Office Calc. • The I-V-curves can be graphically presented as shown in Figure 2-6.	• In the shade: ◆ Connect a voltage meter or multimeter (voltage range) to the panel ◆ Measurement of the panel temperature T_1 using a contact thermocouple. Fix the thermocouple at the front side of the module. It is important to measure T_1 before the panel is exposed to the sun light. Don't forget to remove the thermocouple before taking the V_{OC1} (next step)! Note the temperature T_1. • Remove the thermocouple. Expose now the module to the sun light and measure the open circuit voltage V_{OC1} very quickly. Make sure, that this measurement is really done very quickly to avoid that the panel gets heated up! Note the open circuit voltage V_{OC1}: • After the measurement, leave the module in the sun light until it has reached its thermal balance. Note: the thermal equilibrium is reached when the temp.-measurement is stable. For this, attach again the thermocouple. • Then, the panel should be connected to the I-V-curve tracer as indicated in the manufacturer's operation manual. Remove the thermocouple if it is still attached to the front side! • Execute the measurement; the measurement must be performed as described in the PV tracer's manual. Make sure that the irradiation is > 800 W/m^2. • No objects may shade the irradiation sensor or the PV panel under test during the measurement. • After the measurement of the I-V curve, measure the temperature of the module for a second time (attach again the thermocouple to the front side of the panel). Note the temperature T_2. • Readout the measurement data of the I-V curve using the software provided by the manufacturer of the I-V-curve tracer. Extract V_{OC2} for the heated module from the measured data. • The temperature coefficients for the voltage (T_{C_VOC}) can now be calculated with the equation (1) (left column). • Values are then converted to STC (see Annex 3.6) and the I-V-curve is plotted with the help of for example MS Excel or Open-Office Calc. • The I-V-curves can be graphically presented as shown in Figure 2-6.

The calculated values for I_{sc_STC}, V_{OC_STC}, I_{MPP_STC} and V_{MPP_STC} shall be compared with the data provided by the manufacturer.

The results of the I-V-measurements are also used for subsequent tests.

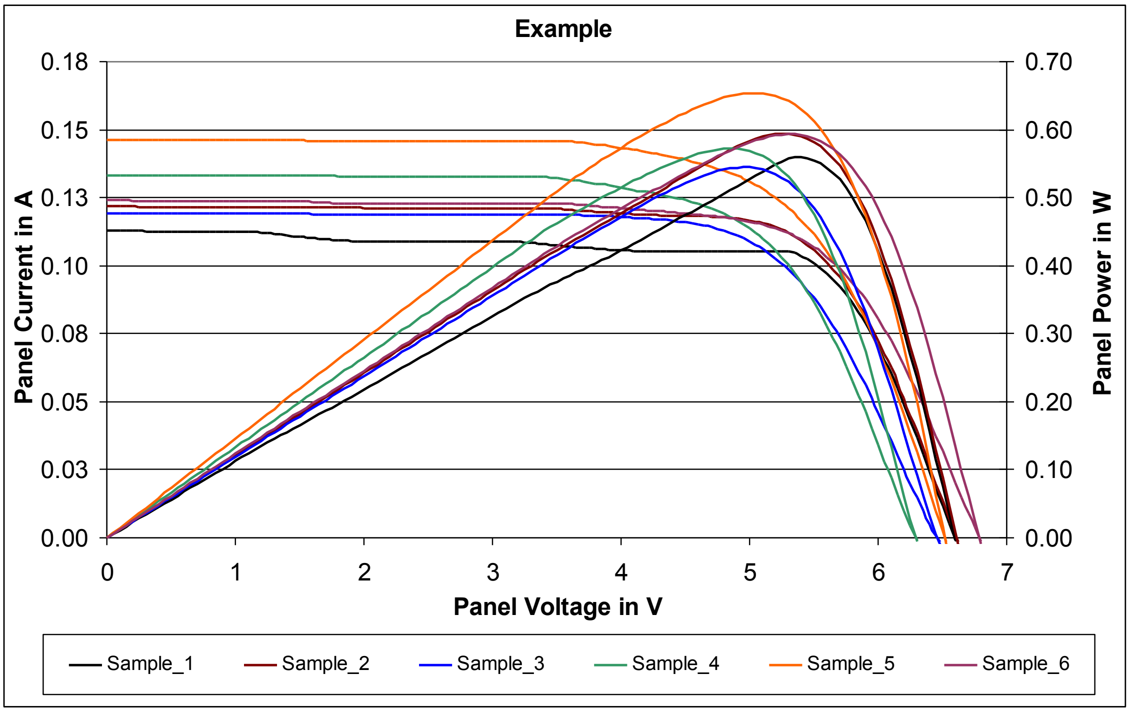

Figure 2-6: Example of I-V-curves of measured test samples.

2.3 Battery Capacity

This testing procedure provides information regarding the nominal capacity of the battery. The measured values should be compared with the technical data provided by the manufacturer. The capacity tests described below are based on the following existing standards:

- Lead-acid batteries - IEC 60896 -11 and internal FISE experience,
- PV-GAP 5/5A
- NiMH batteries - IEC 61951-2
- Lithium-Ion batteries - IEC 61960
- $LiFePO_4$ batteries – a collaboration of manufacturer specifications; no standards were found.

However, on grounds of cost, for the low-cost test procedure the tests have to be performed without a water bath – a vessel enabling the temperature to be maintained at 25±2 °C. Tests on the batteries should be performed at an ambient temperature of
25 ± 5 °C.

To examine the capacity of a battery, measurement equipment is needed which "counts" the ampere-hours charged and discharged. This job cannot be done simply using multimeters. However, professional battery test equipment is very expensive and complex to use. Nevertheless, it was possible to find one low-cost product on the market (ALC 8500[6]) which is also relatively easy to operate. In addition, it comes with PC software ("Charge Professional") to control the device and readout data. The proposed low-cost test procedures are suitable for the ALC 8500. The standard laboratory test methods require expensive battery test equipment like test benches from Digatron[7] or BaSyTec[8]

In order to run the capacity tests properly, a provisional battery capacity is needed. If the manufacturer does not provide this, the standard charging/discharging technique of the ALC 8500 battery charger is first used to determine a provisional capacity. The resulting capacity values can then be used for subsequent calculations, e.g. to determine I_{10} and I_{100}.

Please note: the battery should be detached from the light when performing capacity tests!

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[6] ELV Germany, www.elv.com;
[7] www.digatron.com
[8] www.basytec.com

The following pictures show typical sizes of NiMH, NiCd, Lead-Acid, Li-Ion and $LiFePO_4$ batteries.

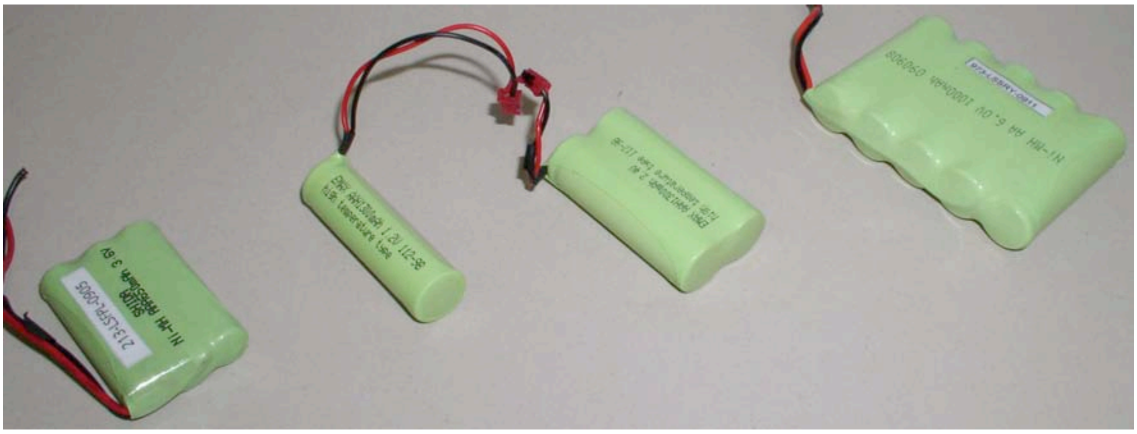


Figure 2-7: Typical NiMH batteries.

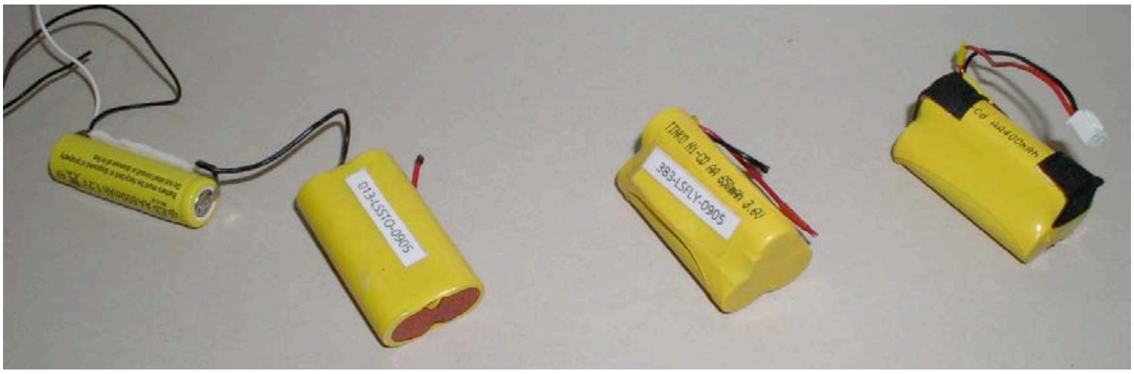


Figure 2-8: Typical NiCd batteries.

Figure 2-9: Typical Lead-Acid batteries.

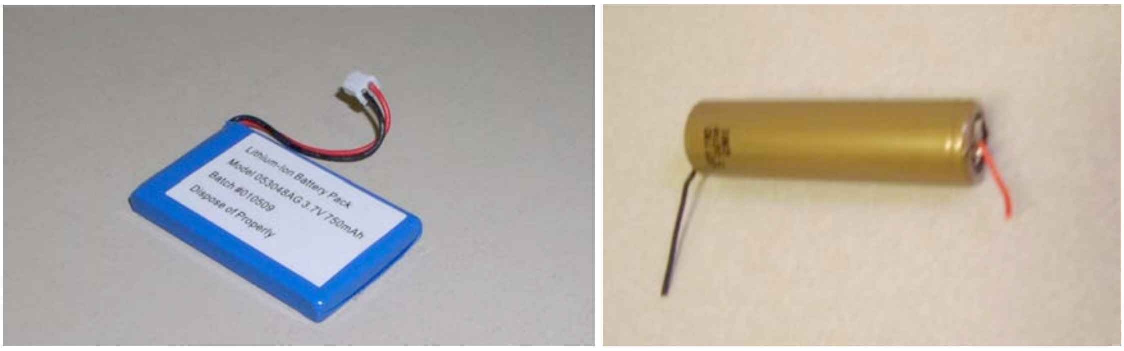


Figure 2-10: Typical Lithium-ion battery (left) and $LiFePO_4$ battery (right).

2.3.1 Lead-Acid Batteries

Standard Laboratory Measurement

Refer to the standards or recommended specifications:

- IEC 60896 -11 Stationary lead-acid batteries - Part 11: Vented types - General requirements and methods of tests
- PV GAP RS 5 / 5A

Low-Cost Procedure

- Discharge the battery at I_{10} until 1.80 V per cell is reached.
- Charge the battery with a constant current of I_{10} until the battery reaches its end of charge voltage of ≥ 2.40 V per cell.
- Subsequently, a charging period follows at a constant voltage of 2.40 V per cell and floating current. The charging period is finished when the floating current decreases to I_{100}.[9]
- Afterward, the battery is discharged at a constant current of I_{10} until the battery reaches the final discharge voltage of 1.80 V per cell.
- The battery is charged again at a constant current of I_{10} of the nominal capacity until the battery reaches its end of charge voltage of ≥ 2.40 V per cell. Subsequently, a charging period follows at a constant voltage of 2.40 V per cell and floating current. The charging period is finished when the floating current decreases to I_{100}.
- Subsequently, the battery is discharged again at a constant current of I_{10} until the battery reaches the final discharge voltage of 1.80 V per cell.
- Note the measured capacity based on the final discharge.

If the difference between measured and nominal capacity is > 20%, the battery may be considered damaged or poorly rated.

2.3.2 Nickel Metal Hydride Batteries

Standard Laboratory Measurement

Refer to the standard:

- IEC 61951-2 Secondary cells and batteries containing alkaline or other non-acid electrolytes – Portable sealed rechargeable single cells – Part 2: NiMH batteries

Low-Cost Procedure

- **New batteries often show a lower capacity than nominal values in the first cycles. To ensure that new batteries can reach their nominal capacity, the battery has to be cycled for 3 times. For conditioning the battery, the battery should be charged with a constant current of I_{10} and discharged with $2*I_{10}$. This should be repeated for 3 times.**
- **Continue cycling if the battery capacity increases by > 5 % between the cycles.**

---

[9] FISE experience: It normally takes 6-8 hours till the charging currents decreases to I_{100}

- Then discharge the battery at a constant current of $2*I_{10}$ until a final discharge voltage of 1.00 V per cell is reached.
- In the next step, a constant charging current of I_{10} is applied to the battery for > 16 h.
- After charging, the battery should be stored for at least 1 h, but not more than 4 h.
- Finally, the battery is discharged at a current of $2*I_{10}$ until a final discharge voltage of 1.00 V is reached.
- The determined capacity is noted based on the final discharge.

If the difference between measured and nominal capacity is **>** 20 % the battery may be considered damaged or poorly rated.

2.3.3 Lithium Ion Batteries

Standard Laboratory Measurement

Refer to the standard:

- IEC 61960 Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for portable applications

Low-Cost Procedure

If Li-ion batteries are used in LED lights, they are almost exclusively cobalt-based. **Please note: The capacity test described below refers to this type of Li-ion battery only![10]**

Table 2-1 may help recognizing the type of the battery. If there is no information given regarding the nominal voltage of the battery, the manufacturer of the light should be consulted before starting the tests!

Table 2-1: Nominal voltages of different Li-ion technologies.

Li-ion technology	**Nominal voltage [V/cell]**	**Test procedure can be used?**
$LiCoO_2$, $LiMn_2O_4$, $LiNiO_2$	3.6 to 3.7	yes
$LiFePO_4$ / Graphite	3.2 to 3.3	See 2.3.4
$LiFePO_4$ / $Li_4Ti_5O_{12}$	2.0	no

Throughout the test, the battery temperature should be watched to not exceed 45°C.

- Before starting the tests, please check the type of the Li-ion battery. In case there is no nominal voltage given (normally the batteries are labelled with nominal voltage and nominal capacity) please contact the manufacturer. Table 2-1 helps deciding whether the procedure can be utilised or not.
- Before charging the battery, it must be discharged at a constant current of $2*I_{10}$ until a final discharge voltage of 3.00 V per cell is reached.
- In the next step, the battery is charged according to data provided by the manufacturer. If this is not indicated, the Li-ion battery should be charged at a current of $2*I_{10}$ until the end of charge voltage of 4.10 V per cell is reached.
- Afterwards, the battery is discharged at a current of $2*I_{10}$ to the final discharge voltage of 3.00 V per cell.

---

[10] Cobalt based Li-ion batteries show a nominal voltage of 3.6 V. The procedure can also be used for Li-ion polymer batteries. For this type of battery the end of charge voltage is 4.20 V.

- In the next step, the battery is charged according to data provided by the manufacturer. If this is not indicated, the Li-ion battery should be charged at a current of $2*I_{10}$ of the nominal capacity until the end of charge voltage of 4.10 V per cell is reached.
- Thereafter, the battery should be discharged at a current of $2*I_{10}$ to the final discharge voltage of 3.00 V per cell.
- The gathered capacity is noted based on the final discharge.

If the difference between measured and nominal capacity is > 20 % the battery may be considered damaged or poorly rated.

2.3.4 $LiFePO_4$ Batteries

Low-Cost Procedure

Throughout the test, the battery temperature should be watched to not exceed 45°C.

- Before starting the tests, please check the type of the $LiFePO_4$ battery. In case there is no nominal voltage given (normally the batteries are labelled with nominal voltage and nominal capacity) please contact the manufacturer. Table 2-1 helps deciding whether the procedure can be utilised or not.
- Before charging the battery, it must be discharged at a constant current of $2*I_{10}$ until a final discharge voltage of 2.00 V per cell is reached.
- In the next step, the battery is charged according to data provided by the manufacturer. If this is not indicated, the $LiFePO_4$ battery should be charged at a current of $2*I_{10}$ until the end of charge voltage of 3.60 V per cell is reached. When 3.60 V per cell is reached, continue charging at 3.60 V while tapering the current until reaching I_{10}.
- Rest the battery for 30 minutes between the charge and discharge.
- Afterwards, the battery is discharged at a current of $2*I_{10}$ to the final discharge voltage of 2.00 V per cell.
- In the next step, the battery is charged according to data provided by the manufacturer. If this is not indicated, the $LiFePO_4$ battery should be charged at a current of $2*I_{10}$ of the nominal capacity until the end of charge voltage of 3.60 V per cell is reached. When 3.60 V per cell is reached, continue charging at 3.60 V while tapering the current until reaching I_{10}.
- Rest the battery for 30 minutes between the charge and discharge.
- Thereafter, the battery should be discharged at a current of $2*I_{10}$ to the final discharge voltage of 2.00 V per cell.
- The gathered capacity is noted based on the final discharge.

If the difference between measured and nominal capacity is > 20 % the battery may be considered damaged or poorly rated.

2.4 Charge Controller

Standard Laboratory Measurement

Refer to the PVGAP Recommended Specification:

- PVGAP RS 5 / 5A

Note: An IEC standard (IEC 62509) is under development.

Low-Cost Procedure

Three cases can be discerned:

- No charge controller built in
- Active charge controller built in
- Passive charge controller built in

To achieve a high lifetime and for safety reasons (Li-ion batteries), we strongly recommend that lights with lead-acid, Li-ion, and $\mathbf{LiFePO_4}$ batteries should have a charge controller built-in!

2.4.1 Lead-Acid, Li-Ion, and $LiFePO_4$ Batteries

2.4.1.1 Deep discharge protection

The test is performed in the following manner:

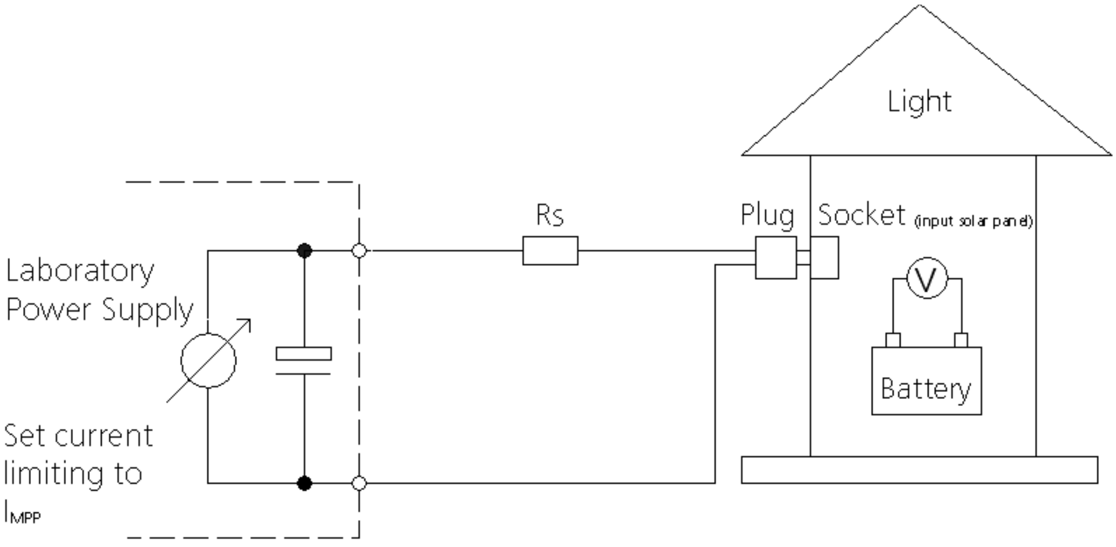
- It is best to perform this test in conjunction with the autonomous runtime test (described in Section 2.5). If that is not possible, prior to starting the test the battery must be charged enough to run the light for at least 30 minutes before reaching the light's low-voltage disconnect (LVD), or the LVD threshold voltage indicated in this testing procedure.
- The light is switched on and the battery discharged. The battery terminal voltage must be measured continuously.
- If the terminal voltage drops below the low-voltage disconnect threshold (LVD) (Lead-acid: 1.87 V±0.05V/cell, Li-ion: 3.00 V±0.05V/cell, $LiFePO_4$: 2.00 V±0.05V/cell) without the light source being cut off, no discharge protection is available.
- If a cut-off occurs, the voltage level must be noted.
- Using a data-logging device to capture the LVD voltage level is very useful, as the voltage decreases rapidly as a LVD is approached.
- If lights are operated using Li-ion batteries and a cut-off occurs during discharge, it must be checked if the cut-off was induced by an internal protective switch. If the load is switched off and a battery terminal voltage can still be measured, the cut-off was caused by a charge controlling device. If a battery terminal voltage can no longer be measured, the internal protection circuit of the battery switched the circuit off in order to protect the battery against deep–discharging.

The result of this test is noted.

2.4.1.2 Overcharge Protection

- It is best to perform this test in conjunction with the grid runtime test (described in Section 2.8.3). If that is not possible, prior to starting the test the battery must be discharged enough to run the light for at least 30 minutes before reaching the light's overcharge protection voltage, or the overcharge protection threshold voltage indicated in this testing procedure.
- To simulate PV charging, the light is charged by a laboratory power supply (using the PV panel socket of the light)
- Current limiting of the power supply should be adjusted to the I_{MPP}[11] of the PV panel. (Refer to the results of the panel measurements under chapter 2.1.1.)
- Connect the light to the power supply in series with a protection resistor[12] R_S (see Figure 2-11).

Figure 2-11: Connecting the laboratory power supply to the light using a protection resistor Rs.



- Since there is a drop in voltage owing to the blocking diode, cable losses and the voltage drop across the series resistor, the voltage at the power supply, V_{LPS}, should be adjusted to 1.25 x $V_{Battmax}$. Where $V_{Battmax}$ = max. charge voltage of the battery.
- The voltage drop in R_S should be between 10% and 15% of the voltage setting of the power supply V_{LPS}, therefore:

$$\frac{0.1 \cdot V_{LPS}}{I_{MPP}} \leq R_S \leq \frac{0.15 \cdot V_{LPS}}{I_{MPP}}$$

- Thus, the maximum required power dissipation of R_S is given by

$P_{R_S} = I_{MPP}^{2} \cdot R_S$ (which may lead to resistors of higher power dissipation).

- The battery terminal voltage of the light must be measured continuously. [13]
- To protect the battery sufficiently, cut-off levels of 2.42 V±0.05V/cell for lead-acid, 4.10 V±0.05V/cell for Li-ion, 3.60V±0.05V/cell for $LiFePO_4$ batteries are recommended.

---

[11] Point of the I-V curve which represents the highest panel power.

[12] This protection resistor is only needed in cases where a "shunt regulator" is built in. However, as a schematic of the electronic is usually not provided, for safety reasons this resistor should be used in all cases.

[13] It is recommended to use an overcharge protection device to prevent damage to the product in case of operator error.

- If the battery terminal voltage increases beyond that limit, no appropriate charge protection is available.
- In the case of Li-ion batteries and if a cut-off occurs within the limits, it must be checked if the cut-off was induced by an internal protective switching of the battery. If a voltage still can be measured on the battery terminals after the light source has been cut off, the cut-off will have been caused by a charge controlling device in the light.
  The result of this test is noted.
- **Attention: Li-ion batteries may not be charged beyond 4.25 V per cell, otherwise there is a risk of explosion!**

2.4.2 NiMH Batteries

2.4.2.1 Active Charge Controller

To test if an active CC is built in, the set-points of overcharge protection and deep-discharge protection must be measured, using a similar method to that used for lead-acid, Li-ion, and $LiFePO_4$ batteries. If the test shows no active controller, the CC must be analyzed to assess if passive charge protection is available (see 2.4.2.2 “Passive Charge Controlling”).

Deep discharge protection

The test has to be conducted in the following manner:

- It is best to perform this test in conjunction with the autonomous runtime test (described in Section 2.5). If that is not possible, prior to starting the test the battery must be charged enough to run the light for at least 30 minutes before reaching the light’s low-voltage disconnect (LVD), or the LVD threshold voltage indicated in this testing procedure.
- The light is switched on and the battery discharged. The battery terminal voltage must be measured continuously.
- If the terminal voltage drops below 0.9 V per cell without the light source being cut off, no active discharge protection is available and the CC must be analyzed to assess if passive discharge protection is available. A description of this test is given in chapter 2.4.2.2.
- If a cut-off occurs, the voltage level must be noted.
- Using a data-logging device to capture the LVD voltage level is very useful, as the voltage decreases rapidly as a LVD is approached.
- To protect the battery sufficiently, a cut-off voltage level of 1.0 V±0.05 V per cell is recommended.

Overcharge Protection

- It is best to perform this test in conjunction with the grid runtime test (described in Section 2.8.3). If that is not possible, prior to starting the test the battery must be discharged enough to run the light for at least 30 minutes before reaching the light's overcharge protection voltage, or the overcharge protection threshold voltage indicated in this testing procedure.
- To simulate PV charging, the light is charged using a laboratory power supply (using the PV panel socket of the light)
- Current limiting of the power supply should be adjusted to the I_{MPP}[14] of the PV panel. (Refer to the results of the panel measurements under chapter 2.1.1.)
- The light is connected to the power supply in series with a protection resistor[15] R_S (see also Figure 2-12).

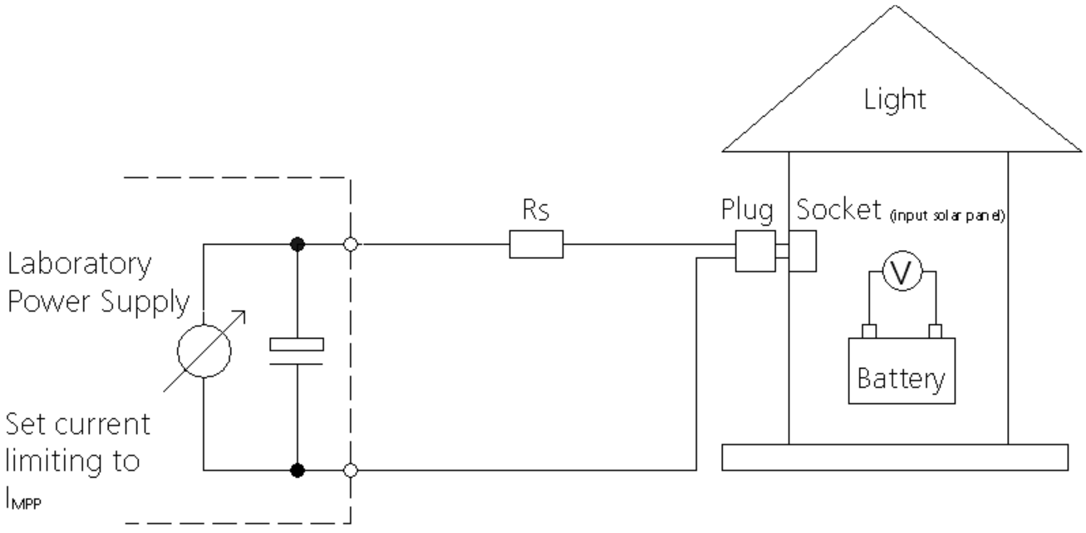


Figure 2-12: Connecting the laboratory power supply to the light using a protection resistor R_s.

- Since there is a drop in voltage owing to the blocking diode, cable losses and the voltage drop across the series resistor, the voltage at the power supply, V_{LPS}, should be adjusted to 1.25 x $V_{Battmax}$. Where $V_{Battmax}$ = max. charge voltage of the battery.
- The voltage drop across the R_S should be between 10% and 15% of the voltage setting of the power supply V_{LPS}, therefore:

$$\frac{0.1 \cdot V_{LPS}}{I_{MPP}} \leq R_S \leq \frac{0.15 \cdot V_{LPS}}{I_{MPP}}$$

- Thus, the maximum required power dissipation of the R_S is given by

  $P_{R_S} = I_{MPP}^{\ 2} \cdot R_S$ (which may lead to resistors of higher power dissipation).
- The battery terminal voltage of the light must be measured continuously.
- To protect the battery sufficiently, a cut-off level of 1.40 V±0.05V/cell is recommended.

---

[14] Point of the I-V curve which represents the highest panel power.

[15] This protection resistor is only needed in cases where a "shunt regulator" is built in. However, as a schematic of the electronic is normally not provided, for safety reasons this resistor should be used in all cases.

- If the battery terminal voltage increases up to 1.50 V/cell, no active charge controller is built in and the CC must be analyzed to assess if passive charge protection is available. A description of this test is given in chapter 2.4.2.2.

2.4.2.2 Passive Charge Controlling

This test only applies for LED lights with NiMH batteries if the charge controller test did not clearly show whether a charge controller is built in. In order to examine the lights, the panel characteristic curves are needed to check the charge controller's behavior. The charge control test must therefore be performed after measurement of the PV panel I-V curve has been made.

Passive Deep Discharge Protection

- The light must be switched on with the intention of discharging the battery.
- If there is no cut-off and the voltage drops below the final discharge voltage of 0.90 V/cell (1.00 V – 0.10 V), no active discharge protection is provided.
- In this case, the voltage should be measured again after 24 hours of further operation.
- The "24 h-battery-voltage" should not fall below 0.80 V per cell, otherwise battery cells run the risk of being reverse-poled[16].

Passive Overcharge Protection

PV panels which are commonly used for charging solar LED lights usually supply a current of 0.05 - 0.8 A at the MPP. NiMH batteries can be continuously overcharged at a current of $\leq 2*I_{10}$ without being seriously damaged.

Procedure:

- Firstly, it must be checked if the I_{SC} of the panel is less than $2*I_{10}$. If it is not, the system has passive overcharge protection and no further testing is necessary.
- If, however, there is a possible charging current $\geq 2*I_{10}$, it must be examined if the battery is at risk of being damaged.

To check the passive overcharge protection of the light, the I-V characteristic curve of the PV panel is used (refer to the gathered I-V curve under chapter 2.1.1). An examination must be made into which operation point (battery and panel voltage) adjusts at higher charging levels. A prediction may be given if the current rises beyond a critical value.

- The STC I-V curve (based on the gathered data under chapter 2.1.1, see Figure 2-14) must be plotted on a piece of paper. The calculated STC I-V-curve data (V_{panel_STC} and I_{panel_STC}) must then be converted to values which could be achieved under realistic operating conditions using either the calculated temperature coefficients of the panel (see chapter 2.1.1) or standard coefficients shown in Table 2-2; in some African countries the realistic panel temperature can reach 50 °C (or higher).
- To calculate the new values ($V_{panel\_50°C}$ and $I_{panel\_50°C}$) equations (2) and (3) can be used.

$$I_{panel\_T2} = I_{panel\_STC} \bullet \left(1 + T_{C\_ISC} \bullet \left(T_2 - T_{STC}\right)\right) \qquad (2)$$

---

[16] The condition of reverse polarity will irreversibly damage a NiMH battery cell. This can happen if a battery is very deeply discharged.

$$V_{panel\_T2} = V_{panel\_STC} \bullet \left(1 + T_{C\_VOC} \bullet \left(T_2 - T_{STC}\right)\right) \quad (3)$$

with $T_2 = 50$ °C and $T_{STC} = 25$ °C

Table 2-2: Typical temperature coefficients according to different PV technologies.

Temperature Coefficients in %/K	**Monocrystal-line Silicon**	**Polycrystal-line Silicon**	**Amorphous Silicon**	**CIS**	**CdTe**
T_{C_ISC}	0.04	0.05	0.075	0.05	0.08
T_{C_VOC}	-0.43	-0.35	-0.31	-0.29	-0.25
$T_{C\_P\_MPP}$	-0.45	-0.50	-0.23	-0.36	-0.18

- Now a second (50 °C) I-V-curve is plotted (see Figure 2-14) using the calculated values V_{panel_T2} and I_{panel_T2}.
- In the next step, current limiting and voltage of the lab power supply are adjusted to I_{SC_T2} and V_{OC_T2} of the panel.
- The power supply is then connected to the PV panel socket using an adapter plug and the voltage drop between power supply (which represents the panel) and battery is measured ($V_{drop}=V_1 - V_2$; see Figure 2-13).
- This value typically reaches 0.30 V to 0.80 V, caused by a blocking diode and line losses.
- The voltage drop as measured above is then added to the battery end of charge voltage (V_{charge} = number of battery-cells x 1.40 V) to obtain the total charging voltage: $V_{max} = V_{charge} + V_{drop}$; example: V_{max} = 3 x 1.40 V + 0.7 V = 4.9 V. The total charging voltage must also be drawn in the I-V curve graph as a vertical line (see Figure 2-14).

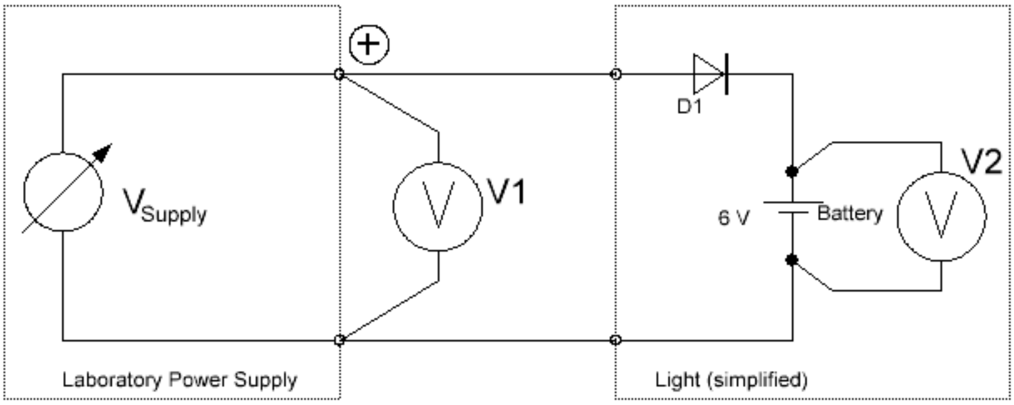


Figure 2-13: Measuring the voltage drop.

- It is possible to read the resulting charging current from the interception point of the total charging voltage (vertical line) and the $I_{50°C}$-$V_{50°C}$-curve.
- If the charging current is ≤ $2*I_{10}$, the light has a passive current limiting.

In Figure 2-14 this procedure is shown for a NiMH-battery with 3 cells, a nominal capacity of C_{Batt_nom}=1,800 mAh. This clearly demonstrates that the charging current declines with the increased charge of the battery (and thus battery voltage) owing to the typical I-V characteristic curve of the PV panel. On reaching the final charge voltage, the current amounts to 0.24 A, which is approx. $1.33*I_{10}$, in the example given. Overcharging the battery therefore causes no serious damage.

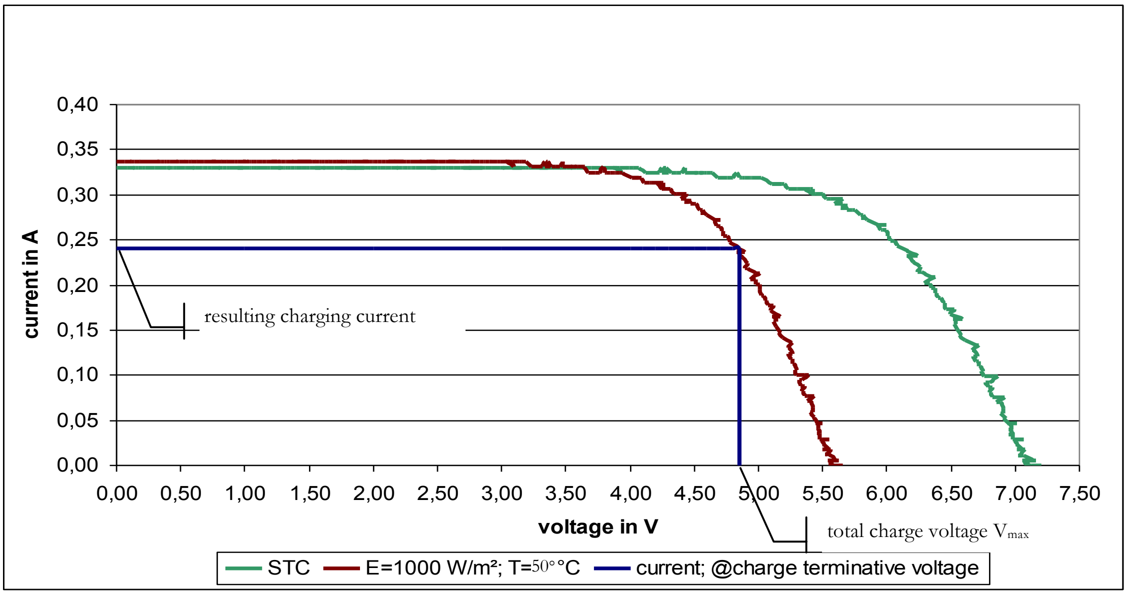


Figure 2-14: Passive charge controlling of solar powered LED lights with NiMH battery.

2.5 "Run Time" (Autonomous Time)

The relationship between battery capacity and lighting system power consumption under realistic operating conditions leads to a run time achieved by a light – one of the key performance metrics from a user perspective.

In general terms, the autonomous run time test involves operating a light with a fully charged battery until the light output has decreased to some pre-defined minimum value. Instead of using an absolute cutoff, the test method is based on measuring the variation in luminous flux in relative terms.

$$\Phi_{Vrel} = \Phi_V(t)/\Phi_V(t_i) \qquad (4)$$

Once the light output Φ_{Vrel} reaches 70% of the initial luminous flux $\Phi_{\mathrm{V(ti)}}$, the end of the luminous period is reached[17]. To ensure that the light is measured in its thermal balance and with stabilized battery voltage (after initial voltage drop), the initial luminous flux (t_i) is measured after 20 minutes (see Figure 2-15**Error! Reference source not found.**).

The autonomous run time test requires an accurate measurement of relative light output over time; in practice this means using an integrating sphere or a fixed-geometry measurement cavity to measure the illuminance level[18] under constant conditions. To ensure these constant conditions and to avoid stray light, several types of measurement cavities are possible, listed in order of preference[19]:

Most preferred: indirect (reflected) measurement cavities:
- Integrating Sphere
- A self-built photometer box with a baffled measurement of illuminance on a port (i.e., an "integrating cube"). Suggestions for the design and construction of such a box are outlined in chapter 3.2.

Allowable: direct measurement cavities:
- A darkened room or cabinet with direct illuminance measurement under fixed geometry.
- A tube with a light sensor affixed to the end that is held with the open end facing the lighting product's light source (see chapter 3.3 for construction details).

It is best to perform the appropriate charge controller test procedure (described in Section 2.4) for determining the product's use of a low-voltage disconnect in conjunction with this test.

The general requirements for the run time test and test equipment are:

- The DuT and photometer can be left in a fixed position for the entire test – up to 20 hours or more.
- The precision of the photometer in the range of expected measurements being made is sufficient to provide ≤ 5 minute resolution on run time.

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[17] This limit was chosen since a decrease of more than 30% is clearly visible for human eyes according to the Alliance for Solid-State Illumination Systems and Technologies (ASSIST). This value is still under discussion.

[18] A measurement of illuminance in a fixed geometry (such as a dark room or isolated box) is always directly proportional in a linear fashion to the luminous flux of a lamp. Therefore, fixed-geometry measurements of illuminance can be used in place of luminous flux measurements for this test, which relies on relative light output to indicate the end of a discharge cycle.

[19] Any of these cavities can result in identical estimates for autonomous run time. The preference order is related to the degree of operator care required to maintain a fixed geometry in each, with a preference for cavities whose relative measurement is less sensitive to small changes in the system (e.g., from accidentally bumping into the cavity during a test).

- The output signal of the photometer can be logged at least once per minute during the test.
- The magnitude of stray light's influence on the absolute light output measurements are less than 0.5% of the minimum light output magnitude being measured during the test.

The outputs of the test are the following, which apply to the particular light setting being tested:

- Run time to 70% (L_{70}) and 50% (L_{50}) of t_0 light output.
- The average light output over the L_{70} and L_{50} discharges.

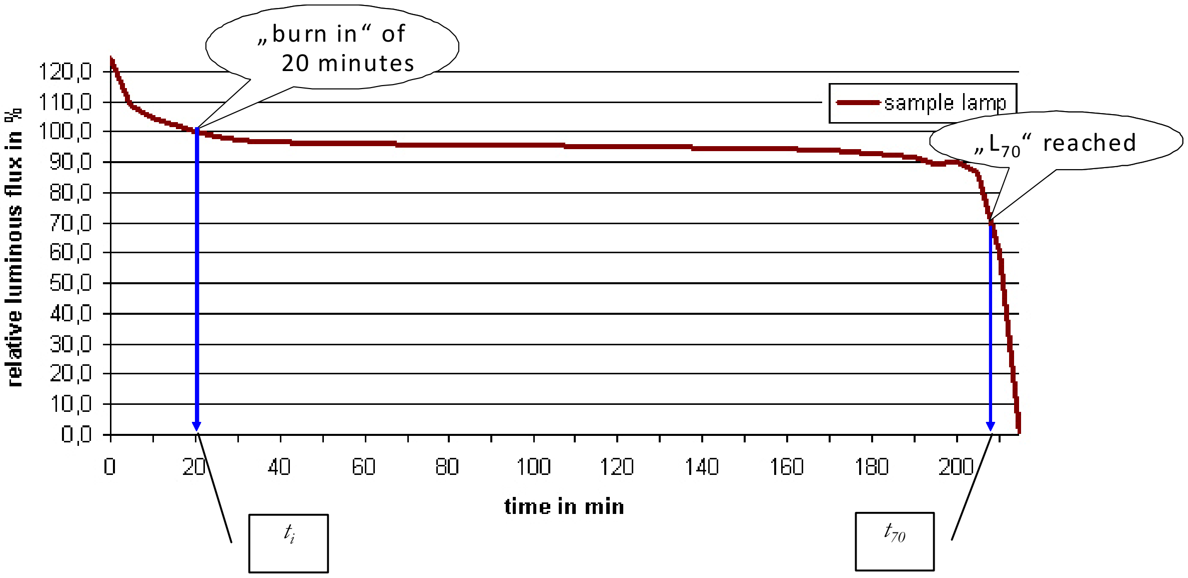


Figure 2-15: Measurement of the autonomous time of a light.

Prerequisites for testing:

- The luminous flux for each light brightness setting should be measured according to the instructions in section 2.6.
- The illuminance distribution should be measured at each light brightness setting that is appropriate according to instructions in section 2.6 (i.e., the measurements should be made for brightness settings that result in task-style lighting that meets the standard listed below).

Determining which brightness settings should be measured:

The autonomous run time should be measured at **up to two brightness settings**:

1. The "brightest" (highest luminous flux) light setting, regardless of the absolute value of the illumination.
2. The "dimmest" light setting that still meets the Lighting Africa performance target for illumination specified in section 1.4 (repeated below):
   - ≥20 lumens measured according to instructions in section 2.6.
     OR

- ≥25 lux on ≥0.1 m^2 surface measured according to the appropriate illuminance distribution test in section 2.6.

Measurement procedure:

- Before measurement, the battery must be fully charged according to the type of battery, as described in chapter 2.3. Allow the battery to rest for at least 1 hour, but not longer than 10 hours, before initiating the test.
- Place the DuT securely in the measurement device.
- The light is switched on **at the correct brightness setting** and the measurement is started. Light output (luminous flux for the integrating sphere; illuminance for other measurement devices) should be recorded every minute.
- The initial light output is measured after 20 minutes (t_i). This defines the point at which relative light output (RLO) is 100%.
- The test should be continued until the RLO reaches 25% (i.e., the light output measurement is 25% of the value at t_i).

Data Processing:

Analyze the time series light output data to estimate the L_{70} and L_{50} run times and the average light output during each period.

Estimating Run Times:

- The end of the L_{70} discharge period is reached when the RLO is 70% of the initial value at t_0 (i.e., the light output is 70%). The result shall be noted; this is the "L_{70}" run time, measured in hours.
- The end of the L_{50} discharge period is reached when the RLO is 50% of the initial value at t_0 (i.e., the light output is 50%). The result shall be noted; this is the "L_{50}" run time, measured in hours.

Estimating average luminous flux during discharge:

- If an integrating sphere was utilized, use the luminious flux averaged over the L_{70} and L_{50} run times. *Note: this should include the full discharge, beginning at 0 minutes.*
- If a measurement device other than an integrating sphere was utilized, the average RLO (in percentage or fractional terms) is averaged over the L_{70} and L_{50} run times. *Note: this should include the full discharge, beginning at 0 minutes, and may include values greater than 100%.* To estimate the average luminous flux over each period (L_{70} and L_{50}), multiply the average RLO for each period by the previously or subsequently measured luminous flux measurements at the appropriate light setting.

Presenting data:

- The recorded data can be presented in a graph as shown in Figure 2-15**Error! Reference source not found.** for each brightness level (Figure 2-15 shows only the result of one brightness level). If more than one brightness level was tested, prepare a separate graph for each test.

Notes on low-cost procedure using a self-built Photometer Box

- The light is suspended in the box in such a way that it illuminates the box from the center, see Figure 2-16**Error! Reference source not found.**. If the lamp has a narrow beam (as is the case with many torches) the light should not illuminate the photometer sensor directly.
- Section 3.2 describes the design and construction of photometer boxes.

Figure 2-16: Photometer box (*left:* exterior view, *right:* interior view with suspended light)

Notes on low-cost procedure using a darkened room or cabinet

- Only one light should be measured at a time in the room or cabinet.
- It is ideal if the walls of the room or cabinet have zero to low reflectance and are matte finish (e.g., black felted fabric).
- The DuT should be arranged approximately 1 meter from the illuminance meter sensor so that the sensor is measuring the peak illuminance at a direct normal incidence angle. Other distances are OK as well.
- Because the illuminance will be a strong function of geometry for most lighting products, it is critical that the arrangement of the lighting product relative to the illuminance sensor and the surroundings remains constant throughout the test. This is also the case with using an integrating sphere or photometer box, but is much more critical with direct relative illuminance measurements that have not been reflected off the walls of the cavity.

2.6 Lighting Service of Ambient Lights

The lighting service of ambient lights can be assessed in two ways:

1) Luminous flux measurement with an Integrating Sphere or Goniophotometer
2) Measurement of the light distribution characteristics (in one plane).

Laboratories that are capable of conducting luminous flux measurements are asked to do so. These procedures are described in section 2.6.1.

Laboratories that do not currently have the capability to conduct integrating sphere luminous flux measurements but wish to add this capability should reference Annex 3.4. This section provides a detailed procedure for conducting luminous flux measurements with a specific low-cost integrating sphere.

Regardless of whether luminous flux was measured, single plane light distribution measurements are required to be made and these procedures are described in section 2.6.1.

An alternative to the single plane light distribution measurements is to use the multi-plane light distribution procedure (forthcoming 1st Quarter 2011). This method results in an estimate of luminous flux and the light distribution characteristics; however, the method is still under development and not yet validated.

2.6.1 Luminous Flux Measurement Procedures

The accurate measurement of total luminous flux (the amount of light emitted by a light source) requires specialized equipment and a good understanding of the principles of light measurement. Care must be taken to account for possible sources of error, and equipment must be frequently maintained and calibrated.

A complete procedure for measuring luminous flux (or flux) is beyond the scope of this document. Rather, references to standard testing protocols and an overview of basic measurement principles will be given as an introduction to test labs that decide to make these equipment investments. Refer to the following standard test methods for the measurement of luminous flux:

CIE084 -1989 : The Measurement of Luminous Flux
IESNA LM-78-07 : IESNA Approved Method for Total Luminous Flux Measurement of Lamps Using an Integrating Sphere Photometer
IESNA LM-79-08 : Electrical and Photometric Measurement of Solid State Lighting Products

Luminous flux is measured with either an ***Integrating Sphere*** or a ***Goniophotometer.***

2.6.1.1 Integrating Sphere

2.6.1.1.1 *Description*

An Integrating Sphere is a hollow sphere with a highly diffuse, spectrally flat white paint on the inside. Lamp holders, light detectors, baffles, and other ports are placed on and inside the sphere (these are also painted white). In what is called a 4□ measurement, the device under test (DuT) is placed in the center of the sphere and powered on. After the lamp has stabilized, a measurement is taken from the detector on the sphere wall (a baffle prevents direct light from the DuT from reaching the detector). This measurement is then processed to calculate the total luminous flux and other light properties (color rendering index CRI, correlated color temperature CCT, etc.)
An integrating sphere 'averages' or 'integrates' the light from the DuT evenly over the internal sphere wall through multiple reflections of the light. This results in a nearly equal illumination at any point on the wall surface; when compared with a calibrated flux measurement (see calibration below), an illumination measurement is therefore directly proportional to the total light output. The total flux is thus calculated relative to the calibrated standard lamp.

2.6.1.1.2 *Calibration*

A sphere must be calibrated to allow for absolute flux measurements. A 'standard reference' lamp is a light source that has been measured by an approved test laboratory; this standard calibrated lamp has a known flux output and comes with an associated lamp file (with flux and color properties); the standard will also be traceable to a national standards organization. Standard lamps are typically tungsten halogen, although other lamp types can be used. To calibrate a sphere, the standard lamp is measured in the sphere. This measurement is then related to the standard lamp file, and the sphere 'throughput' is calculated. Any subsequent measurements of a DuT can then be compared with the standard calibrated lamp and an absolute flux is obtained.
Calibrated lamp standards are typically provided in sets of three to allow for cross checking between the standards. Standard lamps must be handled with extreme care. Gloves should be worn when handling tungsten halogen bulbs as finger grease can alter the output. Lamps should also be powered up and down slowly to reduce thermal stress on the filament, and operated in the same burn position that they were tested in. Lamps should be stored in padded containers and disturbed as little as possible. The power supply used for lamp standards should be accurate and stable. Changes to the drive current (always use a constant current to drive the standard lamp) will alter the standard lamp output and produce errors in subsequent measurements (see the referenced test procedures for a description of the required power supply output accuracies).

2.6.1.1.3 *Detector Types*

Integrating spheres use either photometers or spectroradiometers (also: spectrometer) as the detector. For LED light sources, a spectroradiometer is generally considered the best choice because it is able to accurately capture spectral data and spectral mismatch errors can be captured and corrected. Quality photometer heads, however, can produce good results and may be preferred to lower quality spectrometers.

2.6.1.1.4 *Warm Up Time*

Light sources tested in an integrating sphere must have stable outputs for the flux measurement to be accurate and repeatable. This means that the power supply to the light source must be stable and the DuT must reach thermal equilibrium before a measurement is recorded. The best way to assure that the light source is stable and has a constant output is to take periodic measurements until the result falls within a preset tolerance. For LED light sources, this level is achieved when 3 successive tests 15 minutes apart all fall within .5% of each other (IESNA LM79-08).

For most low power LED lights, the luminous flux will fall slightly when the light fixture warms up. Testing performed by Lighting Africa indicates that the large majority of this flux drop occurs within the first 20 minutes of operation, and therefore 20 minutes has been established as an acceptable warm up time for these types of products to facilitate the testing of multiple samples. In some cases, however, it may be necessary to allow for longer warm up times, in which case the above procedure for determining luminous flux stability may be called for.

2.6.1.1.5 *Sources of Error*

There are several sources of error in these types of measurements, and care must be taken to produce accurate, reliable results.

2.6.1.1.5.1 Calibration error

The sphere must be calibrated regularly (dust collecting on the inside can alter the throughput, and the reflective properties of the sphere paint may change over time) and *ALWAYS* recalibrated when changes are made to the inside surfaces (including mounting post changes and anytime the detector head or spectrometer fiber optic cable is disturbed in any way). Multiple lamp standards should be used to cross check the measurement accuracy of the sphere on a regular interval, and any noticed changes in throughput should be corrected with a new calibration. With frequent testing, weekly (or even daily) calibrations should be performed to ensure accuracy. Note, however, that lamp standards have a minimum number of hours of operation (50 burn ours a common), and will need to be changed for new sets. With proper care, a set of 'working standards' can be calibrated and used for daily or weekly calibrations, and the set of three standard lamps can be saved for more infrequent use (see IESNA LM-54-99 Guide to Lamp Seasoning).

2.6.1.1.5.2 Self Absorption (Auxiliary Correction)

Auxiliary measurements should be made to correct for changes to a sphere's throughput with different lamp and fixture geometries tested inside the sphere. An auxiliary lamp (aux lamp) is mounted inside the sphere, often opposite the detector. A measurement is made with the calibrated standard lamp and lampholder mounted in the sphere (but not turned on) and the auxiliary lamp powered on and stabilized. Another measurement is made with the aux lamp on and the DuT mounted inside the sphere (but not turned on). These two measurements are used to compare the sphere throughput in each case – a correction factor based on the ratio of the two tests can then be applied to the DuT flux measurement to correct for this self absorption error.

The size of the integrating sphere limits the maximum size of the DuT. A large, strongly colored light fixture can absorb too much light for the auxiliary measurement to properly correct. For linear type fixtures, light sources placed too close to the sphere wall will generate near field absorption that cannot be reconciled with the calibration.

It is recommended that the sphere diameter be 10 times greater than the longest dimension of a compact lamp and 3/2 times the length of a linear lamp (these size recommendations apply to the emissive surfaces of the DuTs) . Further, the surface area of the DuT is recommended to be no more than 2% the surface area of the sphere.

2.6.1.1.6 *Spectral Mismatch*

Differences in the spectral qualities of the DuT and the standard lamp used for calibration can lead to errors in measurement, especially in the case of a photometer detector used with an LED DuT (and tungsten halogen standard lamp). The sharp blue spike present in a phosphor based white LED light output falls within a wavelength range where photometers are susceptible to error (where V(□) correction of the photometer tends to be poor).

2.6.1.1.6.1 Spatial Non-uniformity

The integrating sphere wall will have some degree of non-uniformity due to slight differences in the reflectivity of the sphere coating. In addition, the sphere mounting post, aux lamp holder, baffles and ports will also contribute to a non-uniform response over the interior surface. During calibration, the standard lamp light distribution for a typical tungsten halogen source is approximately isotropic. For DuT's with isotropic distributions (ie focused light sources typical of LED products), the sphere non-uniformity can lead to errors in the measurement that cannot be corrected unless a standard lamp of the same light distribution is used for the sphere calibration.

2.6.1.2 Goniophotometer

A goniophotometer (also goniometer) is a device that moves a light detector (typically a photometer) relative to the DuT and takes multiple measurements at all angles surrounding the light source. Some goniometers physically move the detector around the light source, collecting enough data points to get an accurate picture of the light distribution AND the total luminous flux. Other setups use a mirror mounted on a swing arm that reflects light to the detector; the mirror swings around the light source, and by taking successive measurements of the DuT from different angles, a composite picture can be constructed of the distribution and the flux.

A goniometer will typically require more physical space to operate than an integrating sphere, and in many ways is a more complex measurement technique. The advantage of using a goniophotometer over an integrating sphere is that the goniometer provides light distribution information as well as total luminous flux information, and avoids spatial non-uniformity issues associated with integrating spheres.

Goniophotometer measurements of total luminous flux can be accurate and reliable provided proper testing procedures are followed. Many of the same precautions taken with integrating spheres also apply to goniophotometers; stabilized light outputs, electric power supplies, proper baffling, and accurate calibrations etc. Given these precautions, goniophotometer measurements of total luminous flux are considered acceptable.

2.6.2 Light Distribution Characteristic

This test procedure measures the light distribution characteristic of an LED light in one plane. This test will be performed with the help of a “rotary disk”. The light is placed on the rotary disk and illuminance is measured at a distance of one meter (center point LED/LEDs to sensor).
For lighting systems with “bulbs” as a light source (mainly with micro SHS), the light source is placed horizontally on the disk.

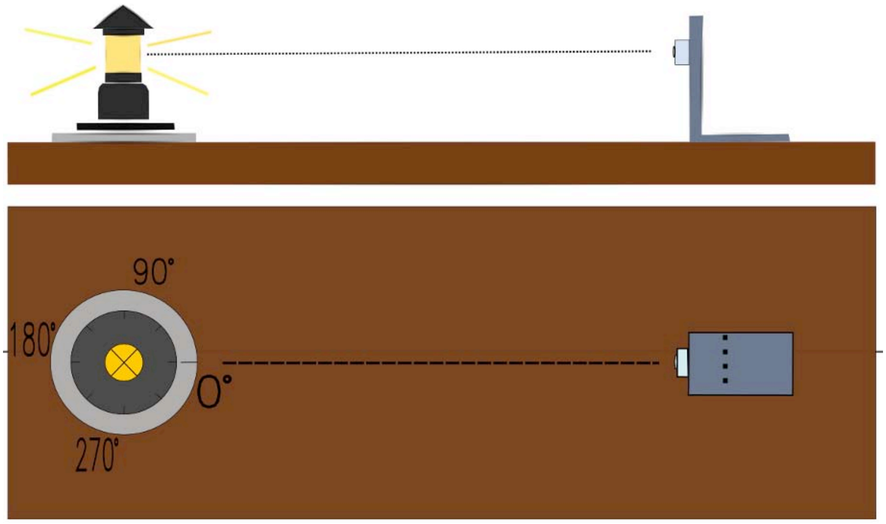


Figure 2-17: Sketch of the rotary disk measurement setup (*above*: side view, *below*: top view).

Test Procedure:

- Before measurement, the battery has to be replaced by a power supply.
- Set the voltage of the power supply to the nominal voltage of the battery.
- If in nominal voltage the light will not perform in its desired setting, increase the power supply voltage by increments of 0.05V until the product can perform in its desired setting.
- Operated the light at least for 20 minutes before the first measurement is started.
- Measure illuminance levels at every 10° sweep for the full 360° angle (see Figure 2-17).
- Present the light distribution characteristics in graphic format as shown in Figure 2-18.

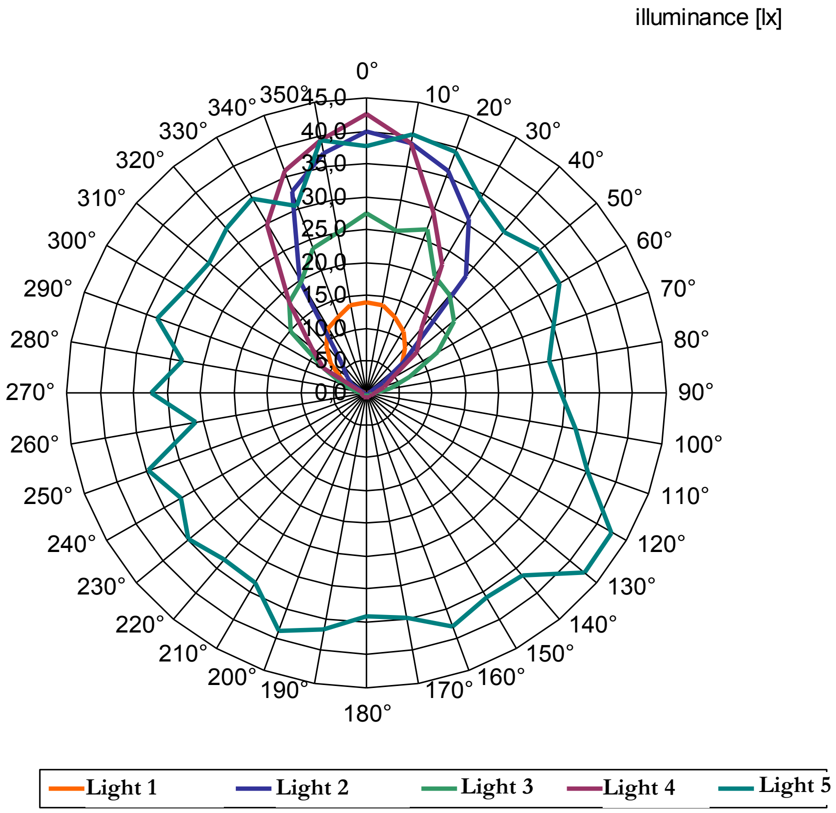


Figure 2-18: Example of light distribution characteristics of different solar lights.

Figure 2-18 shows an example of measured light distribution characteristics over a range of 360° for different LED lighting products. As is clearly demonstrated here, most of the lights may only serve conditionally as ambient lights owing to their small distribution angle. Only one light is able to illuminate the whole 360° angle consistently.

2.7 Lighting Service of Task and Portable Lights

The lighting service of task and portable lights can be assessed in two ways:

1) Luminous flux measurement with an Integrating Sphere or Goniophotometer
2) Measurement of the light distribution characteristics on a surface plane

Laboratories that are capable of conducting luminous flux measurements are asked to do so. These procedures are the same that have been previous described in section 2.6.1.

Regardless of whether luminous flux is measured, surface plane measurements are required to be made and these procedures are described below.

In this test, an examination is made and a report given of the illumination level on a surface of 1 m².

Procedure:

- Before measurement, the battery of the light must be replaced by a power supply.
- Set the voltage of the power supply to the nominal battery voltage.
- If in nominal voltage the light will not perform in its desired setting, increase the power supply voltage by increments of 0.05V until the product can perform in the desired setting.
- How the light is positioned on the measurement surface is dependent upon the type of light (see Figure 2-19):
  - Lanterns which are intended to be used as task lights are placed on the surface using a spacer to compensate for errors owing to the height of the photometer head,
  - Task lights / portable lights are suspended at a distance of 0.75 meters from the top of the photometer head in a manner commensurate with the mounting device (preferably vertical),
  - Desktop lamps (such as lamps with goosenecks) are placed on the surface using a spacer to compensate for errors owing to the height of the photometer head in such a way that the widest area of the surface with ≥ 25lx is illuminated
- If the light features different brightness levels, the highest level is to be set. With lights which have a special task light function, this feature must be chosen.
- The light must be operated for 20 minutes before the first measurement is started.
- Illuminance is measured in the center of each square as shown in Figure 2-19.
- The average illuminance is calculated for the square meter working surface and noted.
- Illuminance distribution is presented graphically as shown in Figure 2-20.

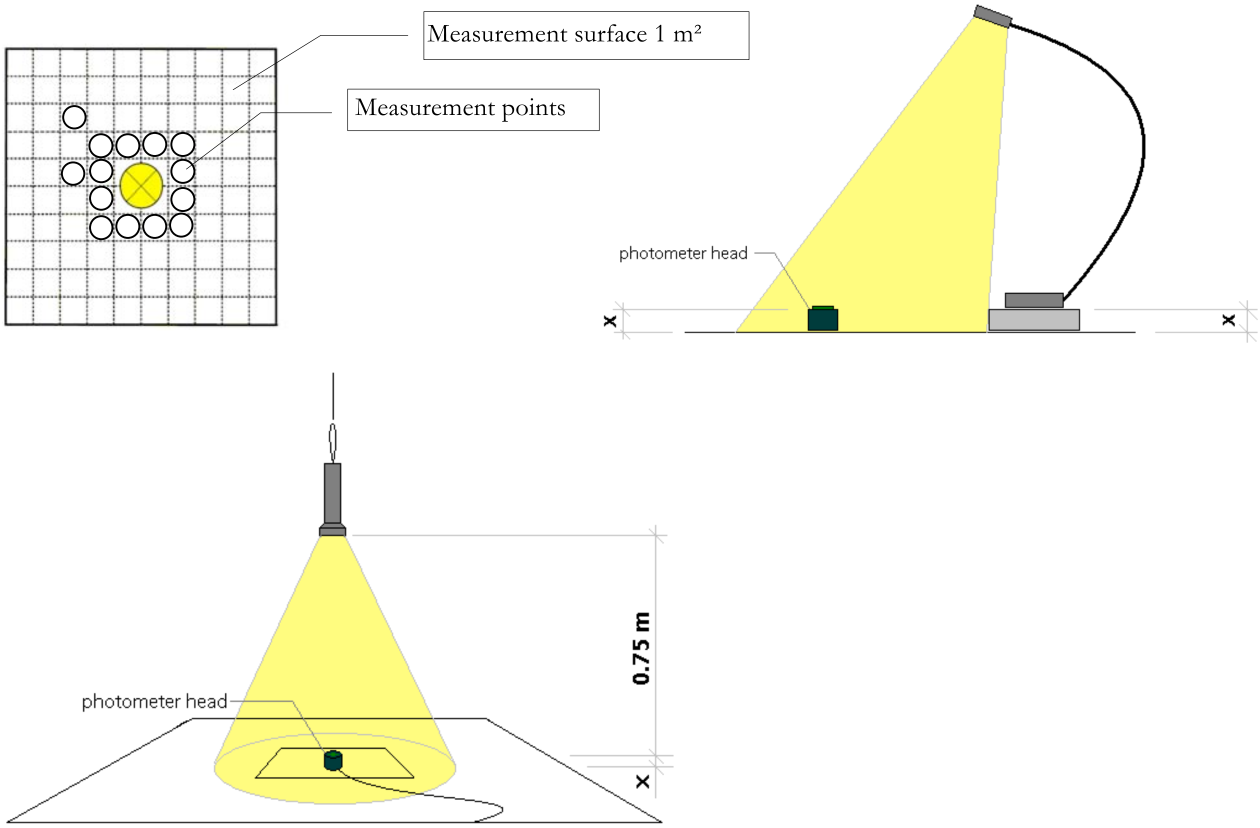
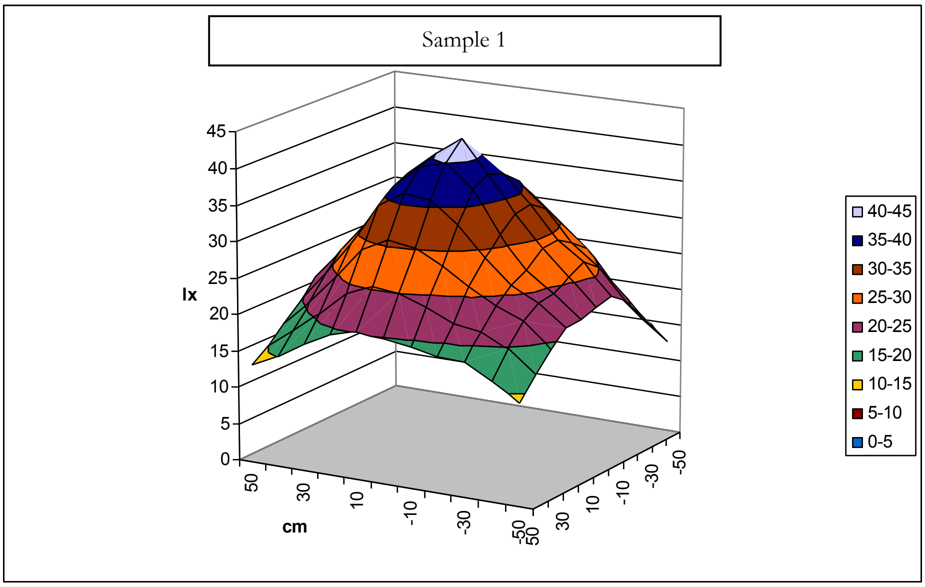


Figure 2-19: Sketch of the measurement scheme for measuring task and portable lights. Upper left: desk lights such as lanterns, upper right: desktop lights with goosenecks; bottom left: Portable Lights. “x” represents the height of the photometer head and therefore the spacer.

Figure 2-20 shows examples of the measured illuminance levels of two lights. As displayed here, the sample 1 shows a fairly moderate decrease of illuminance from the center to the edges. Almost every square in the measured area shows an illuminance level of 25 lx or more. Sample 2 (multi purpose light used in task mode) shows a somewhat high light intensity in a limited angle sweep that corresponds to a high illuminance of around 400 lx in the center of the measured area. However, it declines rapidly away from the center, and only an area of about 0.2 m^2 shows values above 25 lx.



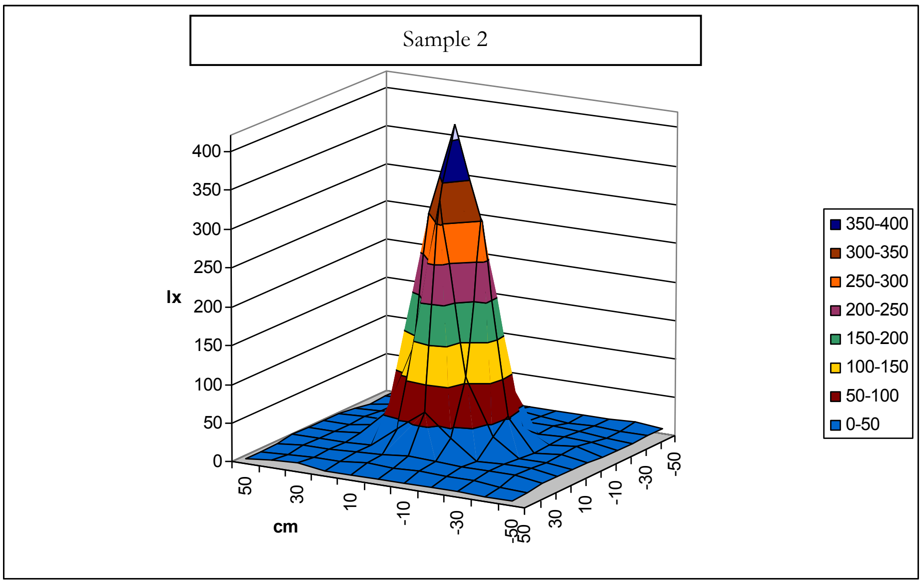


Figure 2-20: Illumination levels of sample 1 (lantern) and sample 2 (multi purpose light) used in task mode.

2.8 Charging Behavior

In this test procedure, LED lights are screened with regard to their charging behavior.

2.8.1 Solar Charging

Standard Laboratory Simulation

Refer to commercially available simulation tools like PV Sol, PV Syst, Homer and others.

Low-Cost Procedure (Simplified Solar Fraction):

The test procedure results in an estimate of the useful run time a user should expect from a day of solar charging. It is based on the following measured and observed results from other tests:

- PV module power (measured from LAQT 2.2)
- Battery characteristics: chemistry (LAQT 2.1), nominal voltage (LAQT 2.1 and 2.3), and capacity (measured from LAQT 2.3)
- Autonomous run time (measured from LAQT 2.5)

A special tool based on an Excel sheet was developed to perform these calculations easily.

A standard solar day is typically defined as 5,000 Wh/m^{2}day, and should be used to estimate the run time.

Irradiance values other than 5,000 Wh/ m^{2}day can also be used with the tool for location-specific estimates. With the help of PV simulation software, the following irradiation values were calculated for a standard day for the countries examined in Sub-Saharan Africa:

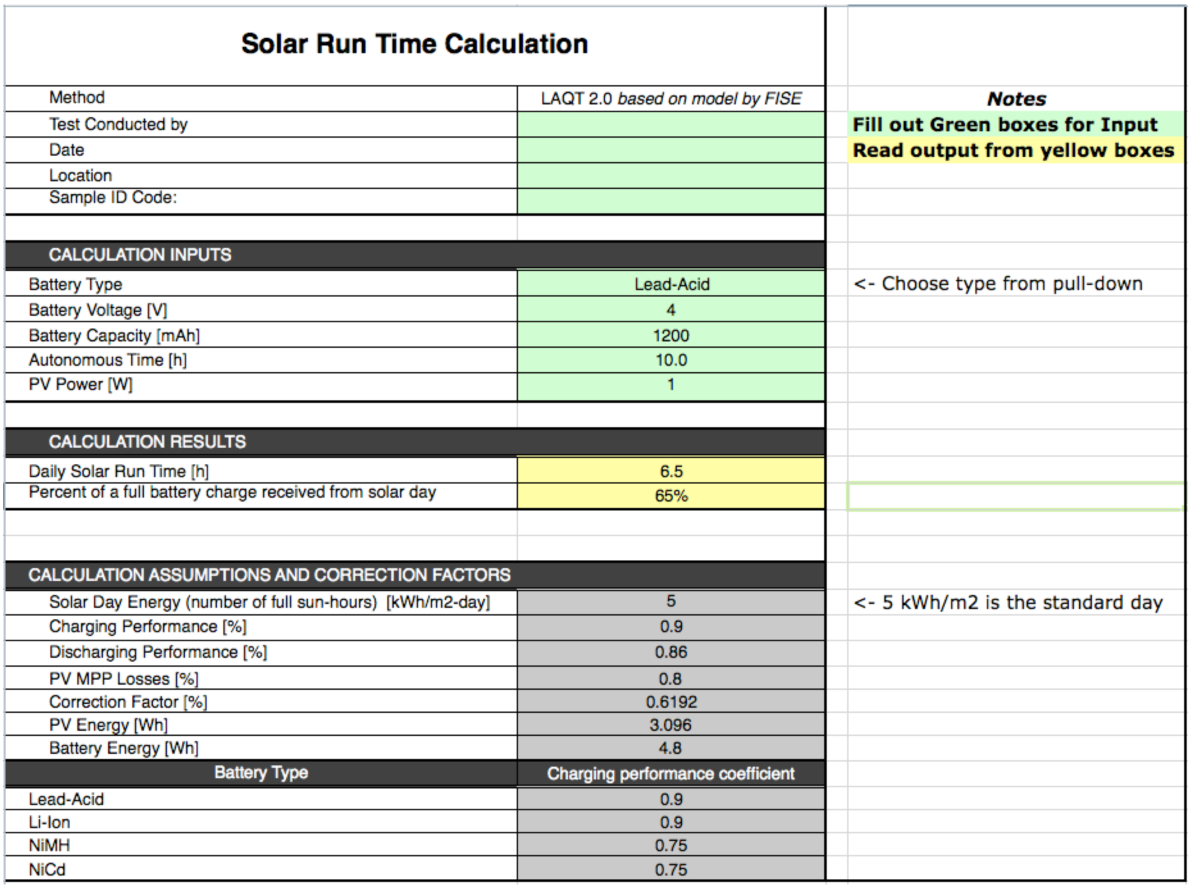
- Ethiopia [Addis Abeba]: 5,194 Wh/m ^{2}d
- Ghana [Accra]: 4,912 Wh/m ^{2}d
- Kenya [Nairobi]: 5,382 Wh/m ^{2}d
- Zambia [Lusaka]: 5,170 Wh/m ^{2}d
- Tanzania [Dodoma]: 5,618 Wh/m ^{2}d

The average irradiation is 5,255 Wh/m^{2}d.

Since many countries in Sub-Saharan Africa are located in proximity of the equator, an inclination angle of 0° is acceptable. Furthermore, no shading losses are assumed.

2.8.1.1 Excel Tool

Screen Shot of the Excel Tool



Solar Run Time Calculation

Method	LAQT 2.0 *based on model by FISE*	***Notes***
Test Conducted by		**Fill out Green boxes for Input**
Date		**Read output from yellow boxes**
Location		
Sample ID Code:		
CALCULATION INPUTS		
Battery Type	Lead-Acid	<- Choose type from pull-down
Battery Voltage [V]	4	
Battery Capacity [mAh]	1200	
Autonomous Time [h]	10.0	
PV Power [W]	1	
CALCULATION RESULTS		
Daily Solar Run Time [h]	6.5	
Percent of a full battery charge received from solar day	65%	
CALCULATION ASSUMPTIONS AND CORRECTION FACTORS		
Solar Day Energy (number of full sun-hours) [kWh/m2-day]	5	<- 5 kWh/m2 is the standard day
Charging Performance [%]	0.9	
Discharging Performance [%]	0.86	
PV MPP Losses [%]	0.8	
Correction Factor [%]	0.6192	
PV Energy [Wh]	3.096	
Battery Energy [Wh]	4.8	
Battery Type	**Charging performance coefficient**	
Lead-Acid	0.9	
Li-Ion	0.9	
NiMH	0.75	
NiCd	0.75	

Figure 2-21: Screenshot of the Excel Tool for calculating the daily solar run time with example inputs.

Equations employed by the Excel tool are documented in chapter 3.4.

How to use the tool:

1.) Input test –related information in the green boxes.
2.) Input characteristics of the battery, PV module, and autonomous run time in the green boxes in the “Calculation Inputs” section. Note that there is a drop-down selection box for battery type (chemistry).
Read the results from the “Calculation Results” section.

2.8.2 Mechanical Charging

The mechanical charging test is intended to inspect crank-charged lights for their charge effectiveness. After 5 minutes of cranking at a frequency of approximately 120 rotations per minute, the light should provide an autonomous time of at least 20 minutes for a suitable daily application.

Procedure:

- The light must be discharged before starting the test. If the product has a low-voltage disconnect built into its charge controller, then let the product discharge by turning it on until its low-voltage disconnect automatically turns it off. Else, discharge using the following discharge rates to the following voltages by battery chemistry:

Battery Chemistry	Discharge Rate	End of Discharge Voltage (V/cell)
SLA	I_{10}	1.87
NiMH	$2*I_{10}$	1.00
Li-ion	$2*I_{10}$	3.00
$LiFePO_4$	$2*I_{10}$	2.00

- The crank light has to be charged for 5 minutes with a frequency of approx. 120 rotations per minute.
  - Using a digital timer, stopwatch or similar device, commence cranking at a rate of 2 revolutions per second for the charge duration (5 minutes)
    - Practicing first with the timer and a dynamo product NOT under test is helpful
    - Having an additional person counting the revolutions is another way to ensure that the proper number of cycles have been achieved
- Once cranking is completed, conduct an autonomous time (run time) test (described in Section 2.5).

2.8.3 Grid Charging

The possibility of grid charging improves the usability of an LED lighting product, even if it is designed for use in remote areas. If a light features this kind of charging, it is recommended that the charge time should not exceed 8 hours since the battery should be fully charged by sunset.

Procedure:

- It is best to perform the appropriate charge controller test procedure (described in Section 2.4) for determining the product's use of an overcharge protection disconnect in conjunction with this test.
- The light must be discharged before starting the test. If the product has a low-voltage disconnect built into its charge controller, then let the product discharge by turning it on until its low-voltage disconnect automatically turns it off. Else, discharge using the following discharge rates to the following voltages by battery chemistry:

Battery Chemistry	Discharge Rate	End of Discharge Voltage (V/cell)
SLA	I_{10}	1.87
NiMH	$2*I_{10}$	1.00
Li-ion	$2*I_{10}$	3.00
$LiFePO_4$	$2*I_{10}$	2.00

- The power adapter provided is plugged into a grid socket. It must be checked that the grid voltage is suitable for the LED light. If not, another adapter should be used.
- If the product was not previously tested to have over-charge protection built it, then the battery terminal voltage of the light must be measured continuously. [20]
- To protect the battery sufficiently, cut-off levels of 1.40 V±0.05V/cell for NiMH, 2.42 V±0.05V/cell for lead-acid, 4.10 V±0.05V/cell for Li-ion, 3.60V±0.05V/cell for $LiFePO_4$ batteries are recommended.
- After 8 hours, it is examined whether or not the battery is charged to its full capacity in keeping with the measured value described in chapter 2.3

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[20] It is recommended to use an overcharge protection device to prevent damage to the product in case of operator error.

2.9 Mechanical Durability

2.9.1 Drop Test

Portable LED lights are exposed to mechanical stress in daily use. To check a light with regard to its mechanical durability, a drop test is implemented in accordance with IEC 60598-1[21].

Procedure:

- The test is performed at an ambient temperature of 25±5°C.
- The light is dropped six times on a concrete floor from a height of 1 m. This is done from six different angles and sides, meaning that the light is turned by 90° following each drop and drop it also on its front (bottom) and back (top) side (if possible). Consideration should be made to drop the light on parts which are assessed as mechanically weak, e.g. handles and other loose parts.
- If the light has any protective glass, this should remain on the light during the test.
- Beware of glass splinters!
- Note the results in the test protocol

After the test, the light must function properly and must not provide any source of potential danger for the user. No parts protecting the light against damage may be destroyed or loosened. Small elements of damage are to be reported, e.g. a light with a broken handle, as shown in Figure 2-22.

Figure 2-22: Broken handle following drop test.

This test is not performed for micro-SHS and other immobile systems. In this sense immobile systems means that the main use of the system is stationary. For example lanterns, torches and desktop lights are “mobile systems”, micro-SHS are immobile because the battery box normally is not moved.

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[21] International Electrotechnical Commission; IEC 60598-1 Luminaires Part 1, General requirements and tests, Geneva 2008

2.9.2 Switches and Connectors

The test procedure for switches, connectors for the PV panel and for optional equipment such as cell phone chargers has to be performed in accordance with PV GAP[22]. The aim of this test is to examine whether the switches and connectors meet the requirements of daily usage.

Procedure:

- Assure that the light is fully charged and operational.

For testing the switches:

- The light is switched on. If several switches are present, all switches are used.
- The light is switched off.

For testing the connector:

- The PV panel connector is plugged into the light.
- The PV panel connector is unplugged.
- If additional plugs/connectors are available, proceed with the same technique.

This cycle must be repeated 1000 times for each switch and connector. Following the test, the switches and connectors must be in good working order. Components may not exhibit any signs of being a potential cause of danger.

2.9.3 Cable Length

Cable length is measured for PV powered LED lights with an external panel. It is recommended that the cable should be at least 2 meters in length.

In order to be able to keep the light inside during solar charging, to protect it against theft and environmental impacts, the cable should be longer (up to 5 meters).

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[22] PV GAP, PVRS 11A, Portable Solar Photovoltaic Lanterns – Design qualification and Type Approval, Geneva 2004

2.10 Long-Term Lumen Degradation Test

An important performance metric for LED lights is consistent luminous flux over the product's lifetime. The lifetime of LEDs is mainly influenced by electrical operating conditions and thermal management. Further criteria, which accelerate degradation, include the quality of the phosphor used in white LEDs and the UV resistance of the housing. Assuming that an overall lifetime of 5 years and a DBT of 4 hours are achieved, this results in a total operation time of 7,300 hours. Examination of the lumen maintenance is performed in a long-term test. Owing to time constraints, it is recommended that the degradation be examined over a period of 12 weeks, which corresponds to approximately 2,000 hours. The test should be performed at an ambient temperature of 25 °C ± 3 °C.

Similar to the autonomous run time test (section 2.5) the lumen depreciation test requires an accurate measurement of relative light output over time; in practice this means using a fixed-geometry measurement cavity to measure the illuminance level[23] under constant conditions. To ensure these constant conditions and to avoid stray light, several types of measurement cavities are possible, listed in order of preference[24]:

1) Dedicated Photometer. If a laboratory has the capability of dedicating an illuminance meter to each test sample, this is the preferred approach as errors related to repositioning the DuT are avoided. In this approach the DuT is to be placed in a photometer box (see chapter **Error! Reference source not found.**) or a photometer tube (see chapter 3.3) and remains there for the duration of the lumen depreciation test.
2) Non-dedicated photometer. It is recognized that laboratories testing a large number of samples may not be able to dedicate a measurement device to each sample that they are testing during the duration of the 2,000 lumen depreciation test. Thus it may be necessary to operate the DuT outside of the measurement device and then place the DuT into the measurement device multiple times during the duration of the test. If the DuT must be moved to a measurement device at the time of each measurement, then the following devices can be used, listed in order of preference:
    1) Integrating Sphere
    2) A self-built photometer box with a baffled measurement of illuminance on a port (see chapter 3.2).
    3) A self-built photometer tube (see chapter 3.3).

Degradation Measurements using an Integrating Sphere

- The DuT battery is replaced by a laboratory power supply that is set to deliver the DuT nominal battery voltage.
- The long-term test is carried out at a constant voltage (nominal voltage of the battery). Some products may operate at a voltage slightly greater than the nominal battery voltage. In this case,

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[23] A measurement of illuminance in a fixed geometry (such as a dark room or isolated box) is always directly proportional in a linear fashion to the luminous flux of a lamp. Therefore, fixed-geometry measurements of illuminance can be used in place of luminous flux measurements for this test, which relies on relative light output to indicate the change in useful power emitted by a light source over time.

[24] Any of these cavities can result in identical estimates for autonomous run time. The preference order is related to the degree of operator care required to maintain a fixed geometry in each, with a preference for cavities whose relative measurement is less sensitive to small changes in the system (e.g., from accidentally bumping into the cavity during a test).

incrementally increase the power supply voltage by 0.05 V until the DuT is operational at the highest setting.

- The luminous flux is measured using a photometer-integrating sphere system that conforms to the technical specifications in Table 3-1.
- For all luminous flux measurements, the DuT shall be located in exactly the same alignment and orientation within the integrating sphere. For all luminous flux measurements, the integrating sphere internal air temperature, current and voltage of the DuT are measured and recorded.
- The initial luminous flux measurement is taken after 20 minutes of illumination.
- Luminous flux of the DuT shall be measured **at least** as frequently as the following intervals:
- The second luminous flux measurement is taken 24 hours after the initial measurement.
- The following four luminous flux measurements are taken every 48 hours.
- Subsequently, the measurements are taken every 168 hours (i. e. once a week).

The final luminous flux measurement is taken at 2000 hours. The relative luminous flux ($F_{FINAL}/F_{INITIAL}$) of the DuT after 2000 hours of operation is reported. The time intervals and cumulative time of measuring the DuT luminous flux are shown in Table 2-3.

Table 2-3: Long-term lumen degradation test minimum frequency of measurement.

Measurement Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Time interval (hr)	0.33 (20 min.)	24	48	48	48	48	168	168	168	168	168	168	168	168	168	168	104
Cumulative time (hr)	0	24	72	120	168	216	384	552	720	888	1056	1224	1392	1560	1728	1896	2000

Low-Cost Procedure using a Self-Built Photometer Box:

- The DuT battery is replaced by a laboratory power supply that is set to deliver the DuT nominal battery voltage.
- The long-term test is carried out at a constant voltage (nominal voltage of the DuT battery). Some products may operate at a voltage slightly greater than the nominal battery voltage. In this case, incrementally increase the power supply voltage by 0.05 V until the DuT is operational at the highest setting.
- The relative illuminance is measured using the photometer box[25] (see Annex 3.2).
- The location of the DuT in the photometer box must be accurately noted to ensure exact replication of alignment and orientation for each measurement. A printed photograph of the DuT placement within the box is a useful reference. Alignment marks may also be used to ensure repeatability[26].
- For the following measurements, the DuT must be placed in the photometer box with exactly the same alignment and orientation.
- Refer to Table 2-3 in Section 2.10 for the minimum frequency at which the relative illuminance of the DuT, ambient temperature, DuT voltage and current are measured and recorded.
- In the case that the DuT remains in the box throughout the duration of the test, a data logger or a luxmeter with a data logging function can be used to record the illuminance every hour.

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[25] It is also possible to conduct the same test in an integrating sphere, which has the advantage of being less sensitive to misalignment. For labs that have an integrating sphere available, it is therefore not necessary to construct a photometer box.

[26] A test jig fitted to the DuT should ideally be used to hold the device in the same orientation. Small changes in orientation can (potentially) lead to large changes in test results.

- The relative luminous flux ($F_{FINAL}/F_{INITIAL}$) of the DuT after 2000 hours of operation is reported.

Low-Cost Procedure using a Self-Built Photometer Tube:

- The DuT battery is replaced by a laboratory power supply that is set to deliver the DuT nominal battery voltage.
- The long term test is carried out at a constant voltage (nominal voltage of the DuT battery). Some products may operate at a voltage slightly greater than the nominal battery voltage. In this case, incrementally increase the power supply voltage by 0.05 V until the DuT is operational at the highest setting.
- The relative illuminance is measured using the photometer tube[25] (see Annex 3.3).
  Light from the DuT is directed into the open end of the photometer tube. The DuT is fixed to the photometer tube for the duration of the test. Care must be taken to ensure that the DuT is secured to the photometer tube such that exactly the same alignment is maintained for each measurement. Care must also be taken when securing the DuT to the photometer tube that the DuT does not have its thermal environment altered significantly. If airflow around the DuT is significantly reduced due to the connection to the photometer tube (ie if entire DuT is placed inside the tube), the test results could show a higher lumen depreciation rate than would actually result from normal use.
- Alternatively, a photometer with the capability to display the maximum illuminance reading can be used. For each measurement, the DuT orientation is adjusted until the maximum illuminance measurement is determined. In this case, the maximum illuminance measurement is recorded at the specified runtime interval.
- Refer to Table 2-3 in Section 2.10 for the minimum frequency at which the relative illuminance of the DuT, ambient temperature, DuT voltage and current are measured and recorded.
- The relative luminous flux ($F_{FINAL}/F_{INITIAL}$) of the DuT after 2000 hours of operation is reported.

3 Annex

3.1 Recommended Testing Equipment and Instruments

Institutes with a limited budget may wish to use relatively inexpensive equipment. Table 3-1 lists recommended “low-cost” equipment for measurement of luminous flux, relative illuminance, and spectral measurements.

Table 3-1: Recommended testing equipment. The examples given usually have better technical specifications than the recommended specifications. The table also includes information regarding measuring equipment for luminous flux (Integrating Sphere) and spectral measurements (Spectrometer).

#	Device	Measurement Parameter	Recommended Technical Specifications
1	Luxmeter with data logger	Illuminance	Illuminance uncertainty < 1% full scale; Cosine correction, low error $V(\lambda)$ filter.
1	Photometer box	Autonomous time lumen maintenance	Minimum internal dimensions 600 x 600 x 600 cm^3
1	Integrating Sphere with photometer	Luminous flux	1 m diameter; 0.5 – 10,000 lm; $\rho(\lambda)=80\%\pm2\%$ (380nm to 780nm).
1	Set of calibration lamps	---	Traceable calibration.
1	Spectrophotometer with optical fiber	Spectral distribution of light, CRI, color and color temperature	Scan speed < 1 s; Spectral range 380nm-780nm; Linearity 0.5%; Interface RS 232 or USB; Software should be incl.
2	DC power supply	---	Output voltage drift ≤ 0.05% of setting / h; Output current drift ≤ 0.05% of setting / h.
2	Digital multimeter	Current, voltage	Voltage uncertainty ≤ 0.05% full scale; Current uncertainty ≤ 0.05% full scale.
1	Thermometer Thermocouples	Temperature	± 1 °C (-50°C – 99,9°C)
1	Optionally: Data logger	Voltage, temperature	Voltage uncertainty ≤ 0.1% of measurement range; Temperature uncertainty ≤ 1% full scale; Interface RS 232 or USB; Software should be incl.
1	Battery charging and analyzing device	Battery capacity	15 V / 2 A output per channel; Capacity uncertainty ≤ 1%. Multiple channels (4 or more).
1	PV panel analyzer	Panel data I-V characteristic curve	Basic uncertainty ≤ 0.5% full scale; Interface RS 232 or USB; Software should be incl.
1	Personal Computer	---	---
1	Rotary disc	---	---

3.2 Photometer Box

Luminous flux is usually measured with an integrating sphere in accordance with CIE 84. However, if an integrating sphere is not available, a self-made device, referred to as a photometer box, can be used for measuring luminous flux. The photometer box is designed to be simple and economical to produce. The interior view and a three dimensional rendering of the photometer box are shown in Figure 3-1.

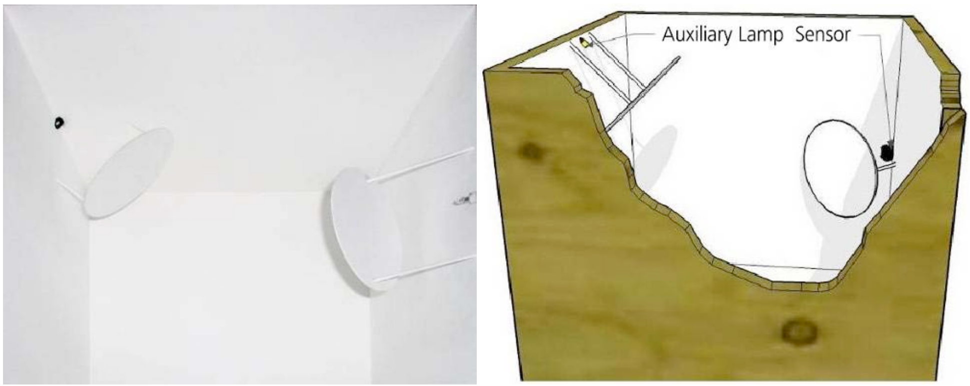

Figure 3-1: Photometer box (*left:* Interior view, *right:* 3-D-view)

3.2.1 Construction Manual

This chapter is intended to assist in the construction of a photometer box. CIE 84 should be taken as a basis for determining internal dimensions. In order to enable multiple reflections of light within the volume, a minimum diameter of the area diagonal that will still ensure sufficient distance from the light to the walls is recommended. In order to meet the requirements of CIE 84, and to ensure that the device is easily manageable, internal dimensions of 60 x 60 x 60cm were chosen for the length, width and height of the box. Based on this edge length, the resulting area diagonal is approximately 85 cm. Objects measured in a photometer box with the aforementioned dimensions should not exceed a maximum height and width of 30 cm in order to ensure properly reflected light. The given photometer box geometries and measurements are based on the work of G. Krenzke, who studied how to optimize the measurement of luminous flux in angular cavities[27]. The recommended dimensions for the photometer box are given in Figure 3-2.

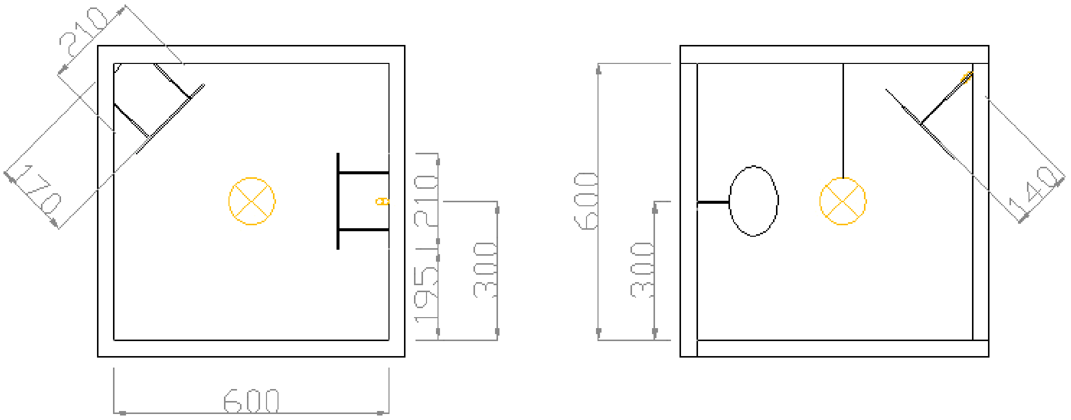

Figure 3-2: Construction plan for photometer box (*left:* top view, *right:* sectional drawing)

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[27] Dr. Ing. G. Krenzke; Die Optimierung der Meßanordnung in runden und eckigen Hohlräumen zur Lichtstrombestimmung ausgedehnter Lichtquellen; German Academy of Sciences Berlin (East), 1965

The box is constructed of basic materials that are generally available in developing countries. Due to the availability, relatively low cost and ease of manufacture, the specified materials are considered appropriate for building a photometer box. Functionally similar materials may be used in place of the recommended materials, according to local price and availability.

- The box is built from plywood, but other strong wood or timber materials can also be used. A thickness of at least 2.5 cm is recommended to ensure clean processing.
- On grounds of cost and procurement difficulty, a highly reflective special coating (which is normally used for Integrating Spheres) should not be used. Instead, the inner surfaces should be painted with white emulsion paint. Multiple coats of paint (5 more) improve the uniformity and reflection of the walls.
- The finished surface should reflect light as diffusely and homogeneously as possible. Paint should ideally be applied with foam paint rollers, as fur rollers create a surface texture that is too rough.
- The baffles are built using wooden dowels (5 mm diameter) and plastic screens (3 mm thick). These components are also painted with white emulsion paint.
- A 10 W halogen light is used as an auxiliary lamp.
- In the case that absolute measurements of luminous flux are not desired, the auxiliary lamp and associated baffle can be omitted from the photometer box.

3.3 Photometer Tube

The photometer tube is a self-made device for taking measurements of relative luminous flux. Like the photometer box, the photometer tube also consists of low-cost materials that are readily available in developing countries. A photo and basic rendering of a photometer tube are included in Figure 3-3.

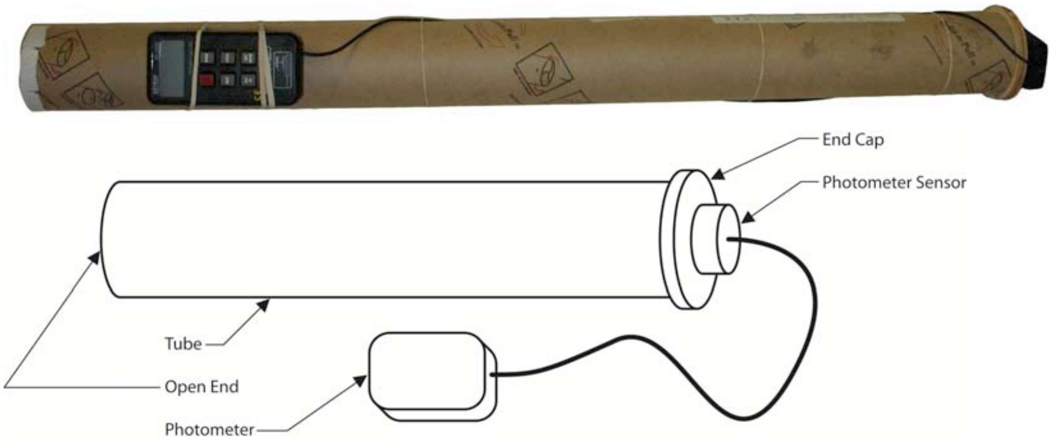

Figure 3-3: Photometer Tube (*top:* photo of typical device, *bottom:* computer rendering of device components).

3.3.1 Construction Manual

The photometer tube is assembled of simple, low-cost materials that are available in developing countries. Due to the availability, extremely low cost and ease of manufacture, the specified materials are appropriate for a photometer tube. Functionally similar materials may be used in place of the recommended materials, according to local price and availability.

- The recommended tube for this application is made of cardboard, often available free of cost from fabric or paper rolls. PVC pipe is also a relatively inexpensive and appropriate for use as a photometer tube. The tube inside diameter should be between 5 and 7 cm. The tube should be at least 50 cm in length.
- An end cap is fit snugly to one end of the tube. The end cap holds the light meter sensor in a fixed position at the end of the tube and restricts stray light from entering. Due to material cost and ease of manufacture, wood is the recommended material for the end cap.
- No reflective coating is necessary on the internal surface of the photometer tube.

3.4 Luminous Flux Measurements with the EVERFINE Integrating Sphere

These are additional notes for working with the EVERFINE Integrating Sphere measurement system. The Integrating Sphere comes with a not very comprehensive manual. The following chapters will provide additional information to overcome difficulties due to missing information and they are intended to use it together with the Sphere's manual. Regarding sourcing of the EVERFINE equipment see Annex 3.1.

3.4.1.1 The Minimum Configuration

The minimum configuration for luminous flux measurements is:

- Integrating Sphere (≥ 1 m diameter recommended)
- Photometer (PHOTO-2000J)
- Standard calibration lamps D204 (set of 3)
- DC Power supply (WY305)
- Auxiliary lamp

Optionally available:

- Spectrometer PMS 80[28]
- Power meter

Figure 3-4: The Integrating Sphere from EVERFINE.

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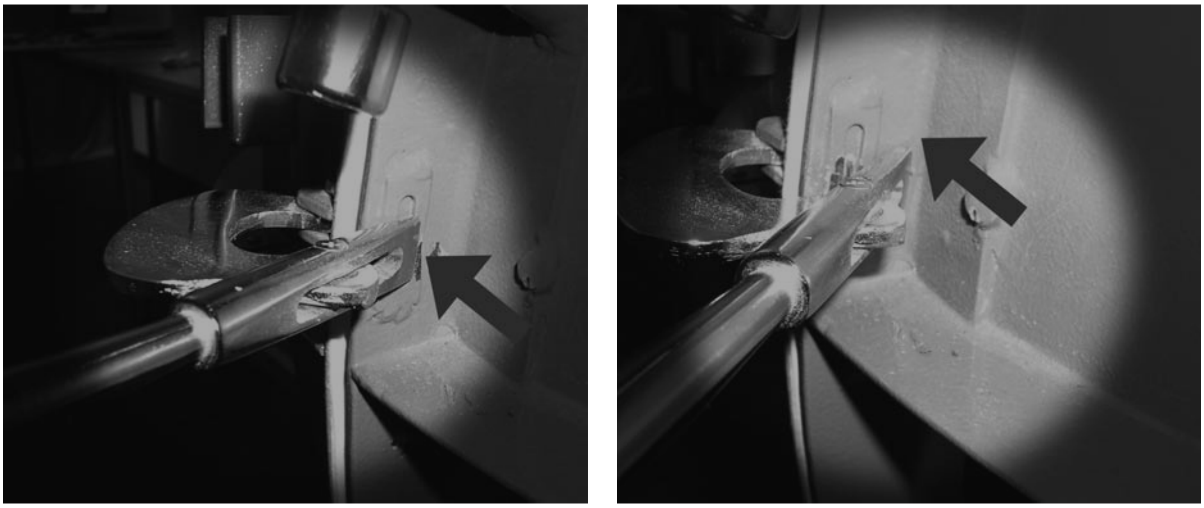
[28] Unfortunately, the temperature measurement of the Sphere can only be used in combination with the Spectrometer. In case that the Spectrometer is not available, an additional (external) temperature measurement device has to be used to monitor leastwise the temperature of the room.

3.4.1.2 The Lock of the Integrating Sphere

Working with the Sphere showed a source of trouble with the mechanical lock. There are two possible positions of the Sphere's lock shown in Figure 3-5. It's important to shut the lock correctly, because shutting it the wrong way will damage or bend the shut mechanism and make the sphere "light-leaky".



Correct lock position Wrong lock position

Figure 3-5: The lock of the sphere.

3.4.1.3 Connecting the System's Components

Before the measurement device can be used all components must be connected to the system. The images below are showing, how the single components must be connected.

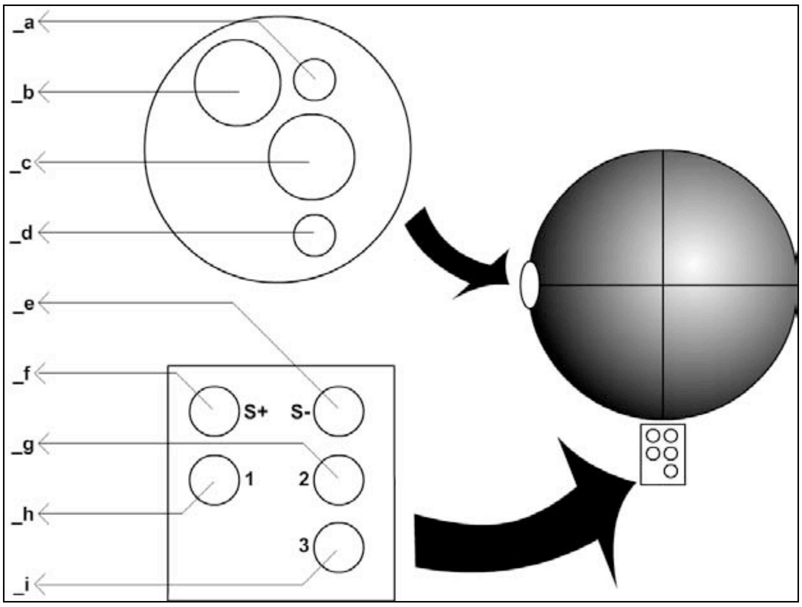


Figure 3-6: The connectors and adaptors of the Sphere.

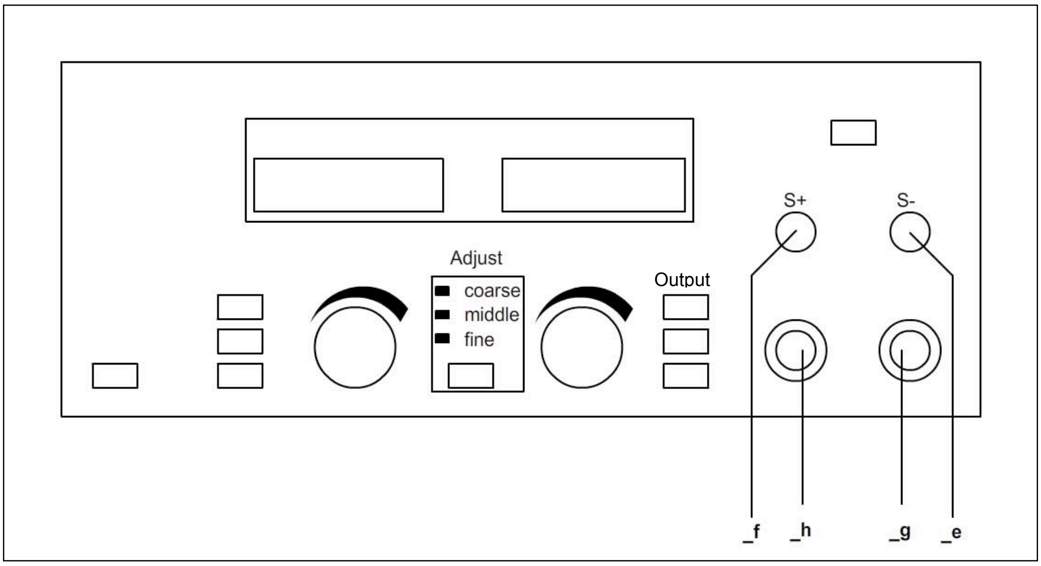


Figure 3-7: The DC power supply WY305.

_a:	The optical fiber interface. (Only necessary if a spectrometer like the PMS-80 of EVERFINE is used.)
_b:	Additional photometer head for the PMS-80 spectrometer. (Only necessary if a spectrometer like the PMS-80 of EVERFINE is used.)
_c	Photometer head is connected to input 2 of the PHOTO-2000J photometer
_d:	The thermometer is connected to the thermometer plug on the backside of the PMS-80 spectrometer (see footnote 28 at page 55)
_e	S- (sense wire -) of the Integrating Sphere is connected to the S- of the DC Power Supply
_f	S+ (sense wire +) of the Integrating Sphere is connected to the S+ of the DC Power Supply
_g	The connector with the number 2 of the Integrating Sphere is connected to the minus output on the front panel of the DC Power Supply
_h	The connector with the number 1 of the Integrating Sphere is connected to the plus output on the front panel of the DC Power Supply
_i	Is not needed for measurements of LED lights.

3.4.1.4 The Standard Calibration Lamp

The EVERFINE measurement system is delivered with a set of standard calibration lamps. The special handling and using of it is described in the following chapters 3.4.1.5 and 3.4.1.6. An image of the calibration lamp is shown in Figure 3-8.

3.4.1.5 Handling of the Standard Calibration Lamp

Before starting to calibrate the measurement system using the calibration lamp please read the following notes carefully. The first rule is:

HANDLE WITH CARE!

It’s strictly prohibited to touch the lamp without gloves (there comes a pair of gloves with every calibration lamp), because the lamp’s surface is very sensitive. Touching the lamps without gloves can cause damages and influence the luminous flux causing measurement errors! The images below are showing the correct handling of the calibration lamp.

Incorrect handling

Correct handling with **gloves** on

Figure 3-8: Handling of the calibration lamp.

It is also important to store the lamps in its special boxes after finishing the calibration.

3.4.1.6 Installation of the Calibration Lamp

To calibrate the measurement system, the standard lamp must be installed in the centre of the Integrating Sphere using the provided socket (see Figure 3-9).

Figure 3-9: Standard calibration lamp correctly installed in the sphere’s lamp socket.

3.4.1.7 Calibrating the System

Before taking any measurement the Integrating Sphere has to be calibrated. Unfortunately, the instruction of the manual is not detailed enough in this regard. The following "step by step" instruction helps with the calibration.

Step1: Connect the system components like described in chapter 3.4.1.3. (The PMS-80 Spectrometer is not needed for the calibration.)

Step2: Install the standard calibration lamp in the Sphere as described in chapter 3.4.1.6

Step3: Switch on the photometer and let it allow to achieve its thermal equilibrium (30 min.).

Step4: Switch on the power supply. Set the voltage of the power supply to the lamp's nominal value. The nominal operating voltage can be found inside the lid of the protection box of the lamp.

Step5: Switch the output of the power supply on by pressing the button "output" (see Figure 3-7). The calibration lamp is now on.

Step6: Set the current limiting of the DC power supply to the value of the operating current of the calibration lamp (see inside the lid of the protection box). If the current cannot be set to the nominal value, the voltage has to be **slightly** (!) increased. Make always sure, that the **nominal current of the lamp is not exceeded!** Otherwise damages of the lamp can occur leading to calibration failures.

Step4: The calibration lamp should now be operated at least 30 minutes until the light output of the lamp is stable.

Step5: Now switch the key on the backside of the Photo-2000J photometer to the "CAL" (calibration) position.

Step6: Run the calibration procedure as described the in "*PHOTO-2000 Multiphotometer USER'S MANUAL*" (page 11, step 4) of the PHOTO-2000J.

Step7: After calibration switch of the power supply.

Step8: Let the calibration lamp cool down to room temperature.

Step9: Un-mount the standard lamp very carefully.

Step10: Now the Sphere is ready for luminous flux measurements (see section 3.4.1.9).

3.4.1.8 Zero Adjusting

After using the instrument for a long time the photometer may show a drift (the display is not showing "zero" lumens with a covered (dark) photometer head). In this case the instrument has to be "zeroed". A description for "zero adjusting" of the Sphere's photometer can be find in the manual of the PHOTO-2000J Multiphotometer on page 10.
After zero adjusting, the Sphere must be calibrated!

3.4.1.9 Measuring the Luminous Flux

In general, luminous flux measurements should be performed in accordance with CIE 84. In the following, a simplified measurement procedure is described.

Before starting the first lumen measurements, make sure that all electrical connections are made (following section 3.4.1.3) and that the Integrating Sphere was calibrated following the steps under section 3.4.1.7. The lights under test has to be prepared: remove the battery and connect a thin cable or 2 wires to the power terminals of the light. Hold ready a power supply able to supply the required voltage and current of the devices under test. In addition, a temperature measurement device should be available[29]. All measurements have to be done at an ambient temperature of 25 °C ± 2 °C.

Step1: Switch the photometer and the temperature-measuring instrument on and make sure that it has reached it thermal equilibrium before taking the first measurement (minimum 30 minutes).

Step2: Place the light under test inside the Sphere. Make sure, that the light is located in the centre of the Sphere. With lights with a directed light output (for example torches, desktop lights) it is recommended that the light's beam direction is diametrical opposed to the baffle of the Sphere (or downwards).

Step3: Switch the power supply on and adjust the voltage to the nominal voltage of the light under test (e.g. 3.6 V or 6 V). Switch the power supply off.

Step4: Now connect electrically the light to the power supply and switch it on again. Check, if the voltage fits the desired operating voltage of the light under test (if applicable adjust the voltage slightly). Close the Sphere.

Step5: Allow the light to operate until it reaches its thermal equilibrium (minimum 20 minutes).

Step6: The luminous flux is displayed at the photometer.
The values of the flux and the ambient temperature have to be noted.

Step7: Repeat Steps 5 and 6 with different brightness levels if desired.

Step8: Switch the light off and remove it from the Sphere.

Step9: If further measurements have to be done leave the photometer switched on and repeat Steps 2 to 8.

Step10: After the measurements, switch the photometer off, remove all lights from the Sphere and make sure that the Sphere is closed to avoid intruding dust and dirt.

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[29] If also the EVERFINE Spectrometer PMS80 is available the temp. measurement of the Spectrometer can be used. The temperature sensor measures the temperature inside the Sphere.

3.5 Excel Tool for Examining Daily Charge / Discharge

3.5.1 Equations

The following equations are used to estimate the daily solar run time:

Battery Energy Capacity

The capacity of the battery in energy terms is estimated from the battery voltage and capacity:

$$E_{batt} = V_{batt} \cdot C_{batt} \tag{5}$$

Inefficiency Correction Factor

A correction factor that accounts for non-ideal battery charge/discharge performance and PV MPP losses is calculated based on the battery chemistry. The battery discharge performance and PV MPP losses are the same for all batteries: 86% and 80% respectively. The battery charging performance is a function of battery type, as listed in the excel tool.

$$\delta_{cor} = \delta_{PVMPP} \cdot \delta_{batt,dis} \cdot \delta_{batt,ch} \tag{6}$$

Daily Available Energy

The energy generated per day E_{avail} is derived from daily global horizontal irradiance G_{day}, PV module power, P_{PV}, and the correction factor.

$$E_{avail} = G_{day} \cdot P_{PV} \cdot \delta_{corr} \tag{7}$$

Percent of Full Charge

Based on the daily available energy and the battery energy capacity, the percentage of a full battery charge realized from a day of solar charging is determined, with a maximum value of 100%.

$$C_{\%} = \min(100\%, E_{avail} / E_{batt}) \tag{8}$$

Solar Run Time

The solar run time is estimated based on the percent of full charge and the autonomous (full charge) run time.

$$t_{solarday} = C_{\%} \cdot t_{autonomous} \tag{9}$$

3.6 Simplified Method for Converting Measured I-V Values to STC

Equations recommended by IEC 60891 and G. Blässer for converting I-V measured values into STC are, in practice, not entirely suitable. Normally, the required solar panel parameters (K and R_S) are not provided by manufacturers. The determination of these parameters is complex and is therefore not to be recommended because the test procedure should be kept short and uncomplicated.

We therefore propose a simplified method[30] which does not require the panel factors K and R_s. Comparative tests conducted using laboratory (flasher) measurements have so far showed negligible differences. However, to minimize error, the equations should only be used under the following conditions:

- The measurement should be performed with irradiations levels > 800 W/m^2
- The recommended test conditions are: $G = 1000\ W/m^2 \pm 15\ \%$; $T_{amb} = 25\ °C \pm 10\ °C$
- Constant atmospheric conditions, meaning clear skies with no clouds
- Air mass ≤ 2, normally meaning +/- 2 hours from solar noon

$$I_{SC,STC} = I_{SC} \cdot \frac{1000W/m^2}{G} \cdot (1 + T_{C\_I_{SC}} \cdot (25°C - T)) \tag{1}$$

$$V_{OC,STC} = V_{OC} \cdot \left(1 + T_{C\_VOC} \cdot \left(25\,^{\circ}C - T\right)\right) \tag{2}$$

$$P_{MPP,STC} = P_{MPP} \cdot \frac{1000W/m^2}{G} \cdot (1 + T_{C\_P_{MPP}} \cdot (25°C - T)) \tag{3}$$

I_{SC}	Measured short circuit current in A
V_{OC}	Measured open circuit voltage in V
P_{MPP}	Measured MPP-power in W
$I_{SC,STC}$	Calculated short circuit current under STC in A
$V_{OC,STC}$	Calculated open circuit voltage under STC in V
$P_{MPP,STC}$	Calculated MPP-power under STC in W
T_{C_Isc}	Temperature coefficient for I_{SC} in 1/°K
T_{C_Voc}	Temperature coefficient for V_{OC} in 1/°K
T_{C_Pmpp}	Temperature coefficient for P_{MPP} in 1/°K
G	Measured global irradiance in W/m^2
T	Measured panel temperature

---

[30] A more simplified set of equations for converting current and voltage values to standard test conditions (STC) can be found in Jacobson, et al, 2000. Source: http://www.humboldt.edu/~aej1/ASES2000_Kenya_aSi.pdf

With regard to temperature coefficients, values measured / calculated (see chapter 2.1.1) or provided by panel manufacturers should be used. If these values are not given, the standard temperature coefficients shown in the following table can be used.

Table 3-2: Standard temperature coefficients for different kinds of PV cell technologies.

Temperature coefficient in 1/°K	Monocrystalline Silicon	Polycrystalline Silicon	Amorphous Silicon	CIS	CdTe
T_{C_Isc}	0.0004	0.0005	0.00075	0.0005	0.0008
T_{C_voc}	-0.0043	-0.0035	-0.0031	-0.0029	-0.0025
T_{C_PMPP}	-0.0045	-0.005	-0.0023	-0.0036	-0.0018

3.7 Test Protocol Template

3.7.1 Comments for using the template

The report template is attached as a Microsoft Excel Spreadsheet. Page 1 provides a summary of results. The cells of the table in Page 1 are filled automatically from the content input into the correlative cells in pages 2 to 7. Pages 2 and 3 require the input of record data from the product, such as product specifications. Pages 4 through 7 require the input from testing protocol. Pages 1 through 7 are formatted to fit on a single paper each, and can easily be transferred into a .pdf file.