IEC TS 62257-9-5

Edition 4.0 2018-06

TECHNICAL SPECIFICATION

Recommendations for renewable energy and hybrid systems for rural electrification –
Part 9-5: Integrated systems – Laboratory evaluation of stand-alone renewable energy products for rural electrification

IEC TS 62257-9-5:2018-06(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue
The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org
The world's leading online dictionary of electronic and electrical terms containing 21 000 terms and definitions in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC TS 62257-9-5

Edition 4.0 2018-06

TECHNICAL SPECIFICATION

Recommendations for renewable energy and hybrid systems for rural electrification –
Part 9-5: Integrated systems – Laboratory evaluation of stand-alone renewable energy products for rural electrification

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160 ISBN 978-2-8322-5693-0

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

RECOMMENDATIONS FOR RENEWABLE ENERGY AND HYBRID SYSTEMS FOR RURAL ELECTRIFICATION –

Part 9-5: Integrated systems – Laboratory evaluation of stand-alone renewable energy products for rural electrification

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a Technical Specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical Specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62257-9-5, which is a Technical Specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This fourth edition cancels and replaces the third edition issued in 2016. It constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Replaced the term "stand-alone lighting kits" with "stand-alone renewable energy products" throughout the document (including the title) to reflect that the revised document is applicable to a broader range of products with a more diverse set of capabilities.
b) Removed the distinction between Class A, Class B, and Class C procedures.
c) Added an option for the AVM method in which the AVM-VE test can be conducted with a sample size of 6 and the follow-up test can be conducted with a sample size of 2.
d) Provided guidance on how to accept test results from other approved test methods.
e) Added test methods for flooded lead-acid batteries.
f) Significantly revised the protection tests, assessment of DC ports, appliance tests, and energy service calculations based on field experience.
g) Revised the voltage operating points at which testing is carried out to better reflect actual operation and to simplify the procedures for testing products without lights.
h) Revised the energy service calculations to include the effect of multiple simultaneously connected loads on the port voltage and battery-to-port efficiency and to accommodate products with grid or electromechanical charging.
i) Removed the restriction that all connections shall be "plug-and-play."
j) Added discussion of measurement error and accuracy for DC power measurements.

This part of IEC 62257 is to be used in conjunction with IEC 62257 (all parts).

The text of this Technical Specification is based on the following documents:

Enquiry draft	Reports on voting
82/1346/DTS	82/1385A/RVDTS

Full information on the voting for the approval of this Technical Specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62257 series, published under the general title *Recommendations for renewable energy and hybrid systems for rural electrification*, can be found on the IEC website.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

IEC 62257 (all parts) provides support and strategies for institutions involved in rural electrification projects. It documents technical approaches for designing, building, testing, and maintaining off-grid renewable energy and hybrid systems with AC nominal voltage below 500 V, DC nominal voltage below 750 V and nominal power below 100 kVA.

These documents are recommendations to support buyers who want to connect with good quality options in the market:

- to choose the right system for the right place,
- to design the system, and
- to operate and maintain the system.

These documents are focused only on technical aspects of rural off-grid electrification concentrating on, but not specific to, developing countries. They are not considered as all inclusive to rural electrification. The documents do not describe a range of factors that can determine project or product success: environmental, social, economic, service capabilities, and others. Further developments in this field could be introduced in future steps.

This consistent set of documents is best considered as a whole with different parts corresponding to items for safety, sustainability of systems, and costs. The main objectives are to support the capabilities of households and communities that use small renewable energy and hybrid off-grid systems and inform organizations and institutions in the off-grid power market.

The purpose of this document is to specify laboratory test methods for evaluating the quality assurance of stand-alone renewable energy products. This document is specifically related to renewable energy products that are packaged and made available to end-use consumers at the point of purchase as single, stand-alone products that do not require additional system components to function.

The term "stand-alone renewable energy product" is used in this document to describe this class of products. Other equivalent terms, including "off-grid solar" or "rechargeable," are often used by manufacturers, distributors, and other stakeholders to describe these products. Many of these systems meet the definition of type T_2I (individual electrification systems with energy storage) in IEC TS 62257-2.

The intended users of this document are:

- Market support programmes that support the off-grid lighting market with financing, consumer education, awareness, and other services;
- Manufacturers and distributors that need to verify the quality and performance of products;
- Bulk procurement programmes that facilitate or place large orders of products; and,
- Trade regulators such as government policymakers and officials who craft and implement trade and tax policy.

This document establishes the framework for creating a product specification, the basis for evaluating quality for a particular context. Product specifications include minimum requirements for quality standards and warranty requirements. Products are compared to specifications based on test results and other information about the product. The product specification framework is flexible and can accommodate the goals of diverse organizations and institutions. The tests and inspections are designed to be widely applicable across different markets, countries, and regions.

RECOMMENDATIONS FOR RENEWABLE ENERGY AND HYBRID SYSTEMS FOR RURAL ELECTRIFICATION –

Part 9-5: Integrated systems – Laboratory evaluation of stand-alone renewable energy products for rural electrification

1 Scope

This part of IEC 62257, which is a Technical Specification, applies to stand-alone renewable energy products having the following characteristics:

- All components required to provide basic energy services are sold/installed as a kit or integrated into a single component, including at a minimum:
  - A battery/batteries or other energy storage device(s)
  - Power generating device, such as a solar panel, capable of charging the battery/batteries or other energy storage device(s)
  - Cables, switches, wiring, connectors and protective devices sufficient to connect the power generating device, power control unit(s) and energy storage device(s)
  - Loads (optional), such as lighting, load adapter cables (e.g., for mobile devices), and appliances (television, radio, fan, etc.).
- The PV module maximum power point voltage and the working voltage of any other components in the kit do not exceed 35 V. Exceptions are made for AC-to-DC converters that meet appropriate safety standards.

NOTE This voltage limit corresponds to the definition of decisive voltage classification A (DVC-A) for wet locations in Table 6 of IEC 62109-1:2010.

- The peak power rating of the PV module or other power generating device is less than or equal to 350 W.
- No design expertise is required to choose appropriate system components.

This document was written primarily for off-grid renewable energy products with batteries and solar modules with DC system voltages not exceeding 35 V and peak power ratings not exceeding 350 W. The tests contained herein are capable in many cases of adequately assessing systems at higher voltages and/or power ratings. In situations where the specifying organization agrees to apply these tests to products with higher voltages and power ratings, the test laboratory is responsible for ensuring that adequate safety measures are employed to protect technicians and test equipment. The specifying organization is also responsible for defining the consumer safety requirements of these products.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60891:2009, *Photovoltaic devices – Procedures for temperature and irradiance corrections to measured I-V characteristics*

IEC 60904-1:2006, *Photovoltaic devices – Part 1: Measurement of photovoltaic current-voltage characteristics*

IEC 61056-1:2012, *General purpose lead-acid batteries (valve-regulated types) – Part 1: General requirements, functional characteristics – Methods of test*

IEC 61215 (all parts), *Terrestrial photovoltaic (PV) modules – Design qualification and type approval*

IEC 61215-2, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures*

IEC 61427-1:2013, *Secondary cells and batteries for renewable energy storage – General requirements and methods of test – Part 1: Photovoltaic off-grid application*

IEC 61951-2:2017, *Secondary cells and batteries containing alkaline or other non acid electrolytes – Secondary sealed cells and batteries for portable applications – Part 2: Nickel-metal hydride*

IEC 61960-3:2017, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for portable applications – Part 3: Prismatic and cylindrical lithium secondary cells and batteries made from them*

IEC 62087-2:2015, *Audio, video, and related equipment – Determination of power consumption – Part 2: Signals and media*

IEC 62087-3:2015, *Audio, video, and related equipment – Determination of power consumption – Part 3: Television sets*

IEC 62087-6:2015, *Audio, video, and related equipment – Determination of power consumption – Part 6: Audio equipment*

IEC TS 62257-12-1:2015, *Recommendations for renewable energy and hybrid systems for rural electrification – Part 12-1: Selection of lamps and lighting appliances for off-grid electricity systems*

IEC 62509:2010, *Battery charge controllers for photovoltaic systems – Performance and functioning*

CIE 15:2004, *Colorimetry*

CIE 084, *The measurement of luminous flux*

CIE 13.3, *Method of measuring and specifying colour rendering properties of light sources*

CIE 127, *Measurement of LEDs*

CIE 177, *Colour rendering of white LED light sources*

IESNA LM-78-07, *IESNA approved method for total luminous flux measurement of lamps using an integrating sphere photometer*

IESNA LM-79-08, *IES approval method for electrical and photometric measurements of solid state lighting products*

IESNA LM-80-08, *Approved method: measuring lumen maintenance of LED light sources*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
illuminance
illuminance of an elementary surface
E
luminous flux received by an elementary surface divided by the area of this surface

Note 1 to entry: In the SI system of units, illuminance is expressed in lux (lx) or lumens per square metre (lm/m^2).

[SOURCE: IEC 60050-723:1997, 723-08-30]

3.2
capacity
capacity of a cell or a battery
electric charge which a cell or battery can deliver under specified discharge conditions

Note 1 to entry: The SI unit for electric charge, or quantity of electricity, is the coulomb (1 C = 1 A·s) but in practice, capacity is usually expressed in ampere hours (Ah).

[SOURCE: IEC 60050-482:2004, 482-03-14]

3.3
device under test
DUT
particular sample that is being measured or observed

[SOURCE: IEC TS 62257-12-1:2015, 3.29]

3.4
lux
illuminance produced on a surface of area 1 square metre by a luminous flux of 1 lumen uniformly distributed over that surface

Note 1 to entry: Lux is the SI unit of illuminance.

[SOURCE: IEC 60050-845:1987, 845-01-52, modified – The formula has been omitted, and the note has been replaced by a new note to entry.]

3.5
colour rendering index
CRI
measure of the degree to which the psychophysical colour of an object illuminated by the test illuminant conforms to that of the same object illuminated by the reference illuminant, suitable allowance having been made for the state of chromatic adaptation

[SOURCE: IEC 60050-845:1987, 845-02-61, modified – The symbol "R" has been replaced by "CRI" and the note has been omitted.]

3.6
correlated colour temperature
CCT
temperature of the Planckian radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions

Note 1 to entry: The correlated colour temperature is expressed in kelvin (K).

[SOURCE: IEC 60050-845:1987, 845-03-50, modified – Notes 1 and 2 have been replaced by a new note to entry.]

3.7
full width half maximum
FWHM
range of a variable over which a given characteristic is greater than 50 % of its maximum value

Note 1 to entry: FWHM may be applied to characteristics such as radiation patterns, spectral linewidths, etc., and the variable may be wavelength, spatial or angular properties, etc., as appropriate.

[SOURCE: IEC 60050-731:1991, 731-01-57]

3.8
multimeter
multi-range multi-function measuring instrument intended to measure voltage, current and sometimes other electrical quantities such as resistance

[SOURCE: IEC 60050-312:2001, 312-02-24]

3.9
illuminance meter
instrument for measuring illuminance

[SOURCE: IEC 60050-845:1987, 845-05-16]

3.10
photometer
instrument for measuring light

[SOURCE: IEC 60050-845:1987, 845-05-15, modified – The term "photometric quantities" has been replaced by "light".]

3.11
pyranometer
instrument for measuring incident global (direct-beam and diffuse) solar radiation

3.12
integrating sphere
hollow sphere whose internal surface is a diffuse reflector, as non-selective as possible.

Note 1 to entry: An integrating sphere is used frequently with a radiometer or photometer.

Note 2 to entry: An integrating sphere is used to determine the total luminous flux (lumen output) of a lighting device.

[SOURCE: IEC 60050-845:1987, 845-05-24, modified – A second note to entry has been added.]

3.13
goniophotometer
photometer for measuring the directional light distribution characteristics of sources, luminaires, media or surfaces

[SOURCE: IEC 60050-845:1987, 845-05-22]

3.14
power supply
electric energy converter which draws electric energy from a source and supplies it in a specified form to a load

[SOURCE: IEC 60050-151:2001, 151-13-76]

3.15
overvoltage protection
protection intended to operate when the power system voltage is in excess of a predetermined value

[SOURCE: IEC 60050-448:1995, 448-14-32]

3.16
IP class
IP rating
degree of protection provided by enclosures for electrical equipment against penetration by foreign bodies and dust/water

Note 1 to entry: IP classes are defined in IEC 60529.

3.17
portable
connected in a way that makes a product or subsystem easy for an individual to carry

Note 1 to entry: Products or subsystems are portable when two or more of the main components (energy source, energy storage, and light source) are connected in this way.

3.18
fixed
designed for permanent or semi-permanent mounting and use in place

Note 1 to entry: Products or subsystems are fixed when the main components (energy source, energy storage, and light source) are designed in this way.

3.19
separate
without solar module or with a solar module connected to other components via a cable that is sufficiently long to allow the solar module to collect energy outdoors while the other product components remain indoors

3.20
integrated
with a solar module integrated into the same casing as the other components or connected to other components via a cable that is too short to allow the solar module to collect energy outdoors while the other product components remain indoors

3.21
metadata
information that relates a test result to a specific sample and provides context about the result (e.g. specific test method used)

3.22
light emitting diode
LED
solid state device embodying a p-n junction, emitting optical radiation when excited by an electric current

[SOURCE: IEC 60050-845:1987, 845-04-40]

3.23
low-voltage disconnect
LVD
battery voltage at which the load terminals of the charge controller are switched off to prevent the battery from over discharging

Note 1 to entry: This is a specific case of a "load disconnect point" as defined by IEC 62509:2010, 3.11.

3.24
standby loss
quantity of electricity (electric charge), expressed as a fraction of the total battery capacity, drawn from a product's battery with the product switched off over a specific length of time

3.25
coefficient of variation
ratio of the standard deviation to the mean

3.26
appliance
device that performs a specific function providing service to an end user, such as a light, radio, or television set

3.27
mobile device
basic mobile phone, feature phone, smartphone, tablet computer, or similar portable communication and/or computing device having an internal rechargeable battery

Note 1 to entry: Larger portable devices, such as laptop computers, can also be considered mobile devices, but some provisions (e.g. related to charging current and ports) may not be applicable.

3.28
port
connector (typically a socket) on a component that can supply power to an appliance

3.29
power control unit
component of a stand-alone renewable energy product that includes a battery and one or more ports plus, typically, the associated battery management, voltage regulation and overload protection components

Note 1 to entry: In the case of a product with a single power control unit, the power control unit is often referred to as the "main unit" or "control box." A power control unit can include appliance functionality such as a light or built-in radio. A portable appliance (such as a light) with internal battery is a power control unit if it includes a port.

3.30
main unit
component or assembly including an input for connecting the primary energy source (e.g. solar, grid or mechanical charger), a battery, and one or more built-in appliance(s) or port(s).

Note 1 to entry: A power control unit can be a main unit, though a main unit does not necessarily have a port.

3.31
standard operating voltage
standardized voltage corresponding to a typical battery operating point during discharge

3.32
typical battery discharge voltage
battery voltage corresponding to the "typical operating point" (e.g. the operating point resulting in the average value of power) during discharge

Note 1 to entry: The typical battery discharge voltage is an outcome of the full-battery run time test, while the standard operating voltage depends only on the battery chemistry and number of cells.

3.33
appliance operating voltage
voltage supplied to an appliance by a port when the appliance is operating at a particular setting and the power control unit battery is at the typical battery discharge voltage

4 Product components and characteristics

4.1 Components

4.1.1 Overview

A stand-alone renewable energy product typically comprises:

- The main components:
  - an energy source:
    a) solar photovoltaic module (integrated, supported by or completely separate from the casing),
    b) electromechanical charger (hand crank, pedal power, or other), and/or
    c) general DC power input (normally used with a central charging station or AC-DC converters to charge via grid power).
  - one or several light sources (typically CFL or LED),
  - power control unit(s) (see 3.29), which can be integrated into the same casing as the light sources or in a separate enclosure,
  - battery/batteries, and
  - loads (optional), such as appliances (lighting, television, radio, fan, etc.), and load adapter cables (e.g. for mobile devices).

NOTE In more complex products, some loads can include their own battery and power control unit.

- The enclosure and other components:
  - casing or several casings (including some translucent parts in many cases),
  - circuits (battery charge and discharge controller, regulated voltage and current sources),
  - wiring to connect the circuits to each other and the main components,
  - fasteners to secure components in the casings,
  - switches for light control/selection,
  - cables and connectors,
  - protective devices,
  - status indicators/user feedback,
  - accessories (auxiliary power outlet, mobile device charging or other appliance interface, radio, fan, television set, etc.), and/or
  - hardware for mounting.

Throughout this document, the terms "product" and "stand-alone renewable energy product" refer to the complete product or kit as described in 4.1.1.

4.1.2 Component categories

Components of stand-alone renewable energy products can be placed into five categories based on the arrangement of components. The four general categories are fixed indoor, fixed outdoor, portable separate, and portable integrated; photovoltaic modules are in an additional, separate category. It is important to categorize components because components in different categories have different inherent utility to the user and will encounter different environmental conditions based on their design.

Different quality standards may apply to different categories.

Each product can contain components from multiple categories. Appliances included with the product may also be categorized according to this same system.

The first word in each category name refers to the portability of the system.

- Fixed components are designed for permanent or semi-permanent mounting and use in place. In addition to many large battery packs and installed light points, certain appliances, such as television sets, are typically considered to be fixed.
- Portable components are inherently portable and generally contain an internal energy source. For example, a stand-alone renewable energy product can include a portable light with a battery that can be charged from the solar module or from another battery in a fixed enclosure.

Fixed components are further classified based on the expected use location:

a) Fixed indoor components are not inherently portable and are used indoors. If a fixed indoor component is connected to a component that is intended to be used outdoors (such as a PV module), the cable connecting the two components shall be sufficiently long to place the outdoor component outdoors in an appropriate location while the indoor component remains indoors. Otherwise, the fixed outdoor category shall apply. See Figure 1 for an example.

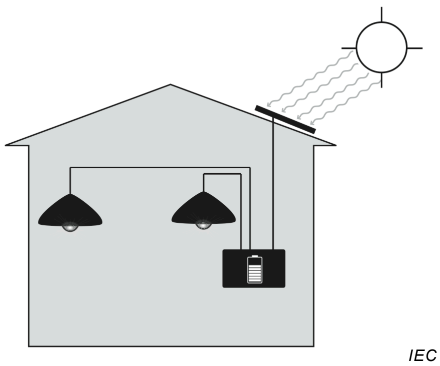


Figure 1 – Fixed indoor components and PV module – Example

b) Fixed outdoor components are not inherently portable and are intended to be used outdoors, or are connected to components intended to be used outdoors by a cable that is too short to allow the component in question to be placed indoors. Fixed outdoor components may contain integrated PV modules; however, PV modules without additional components form their own category. See Figure 2 for an example.

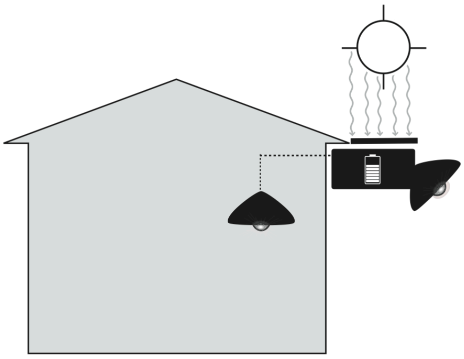


Figure 2 – Fixed outdoor components with an indoor light point – Example

Portable components are further classified by the presence or absence of an integrated solar module:

c) Portable separate components are portable, with a battery and load permanently or temporarily joined. If the component is intended to be connected to a fixed outdoor or portable integrated component or a PV module, the cable connecting the two components shall be sufficiently long to place the outdoor component outdoors in an appropriate location while the indoor component remains indoors; otherwise, the portable integrated category shall apply. See Figure 3 for an example.

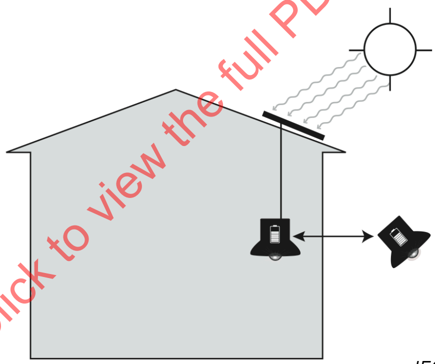


Figure 3 – Portable separate components – Example

d) Portable integrated components are portable and are charged with a solar module that is integrated in the casing or is otherwise designed so that the whole component is left outdoors to charge via the solar module. This includes portable components that are intended to be connected to fixed outdoor or portable integrated components, or a PV module, by a cable that is too short to allow the component in question to be placed indoors. Portable integrated components may contain PV modules; however, PV modules without additional components form their own category. See Figure 4 for an example.

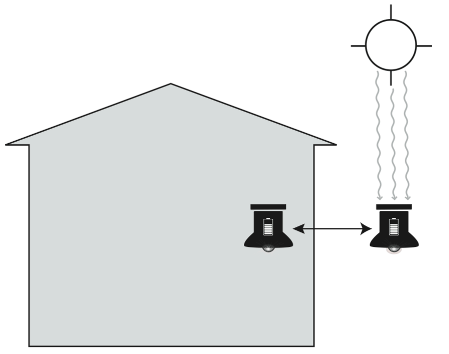


Figure 4 – Portable integrated components – Example

PV modules may be subjected to different standards for durability (including physical and water ingress protection), and are therefore considered a separate category:

e) PV modules include one or more PV cells surrounded by encapsulating or laminating materials with a transparent glass or plastic covering, plus a junction box mounted on the back of the module for electrical connections. A PV module can be surrounded by a frame, typically of metal or plastic, and can include mounting brackets or other hardware. This category applies only to PV modules; assemblies containing one or more PV modules plus additional electrical or electronic components, such as circuit boards or batteries, shall be considered fixed outdoor components.

NOTE The requirement regarding assemblies containing PV modules is not intended to apply to PV modules with small circuit boards or discrete electronic components such as diodes installed in their junction boxes.

4.1.3 Lighting parts definitions

The portion of the product which provides lighting can also be divided into several subsystems, as defined below. The subsystems are nested beginning with the smallest subsystem and working down to complete product.

a) Light source(s): individual LED, CFL, or other light emitting components.

b) Array(s): single or grouped light sources that can be controlled independently from other arrays.

c) Light point(s) or lighting appliance(s): house one or more arrays and can be moved with respect to other light points, if there are more than one.

d) Lighting unit(s): stand-alone parts of the product, each with an independent battery that powers one or more light points.

NOTE It is appropriate to categorize each lighting unit (as described in 4.1.2) separately, since the arrangement of battery and light point(s) can be different in different light units.

e) Stand-alone renewable energy product: the overall package of integrated components, including one or several lighting units and potentially other loads or appliances.

Figure 5 below illustrates how a hypothetical product can be subdivided and categorized. The levels of division are labelled with letters, corresponding to the descriptions above. There are six light sources (A) in this product divided among four arrays (B). Two of the three light points (C) have one array; the third light point (in the middle – C2) has two arrays. Note that one of the arrays – the one with three light sources – is turned off and the other is on. There are two light units (D). The light unit on the left (D1) can be categorized as portable separate; the other light unit (D2) can be categorized as fixed indoors. Both units are included in a single product (E). Note that although only lights are illustrated below, other appliances are often included as part of the product.

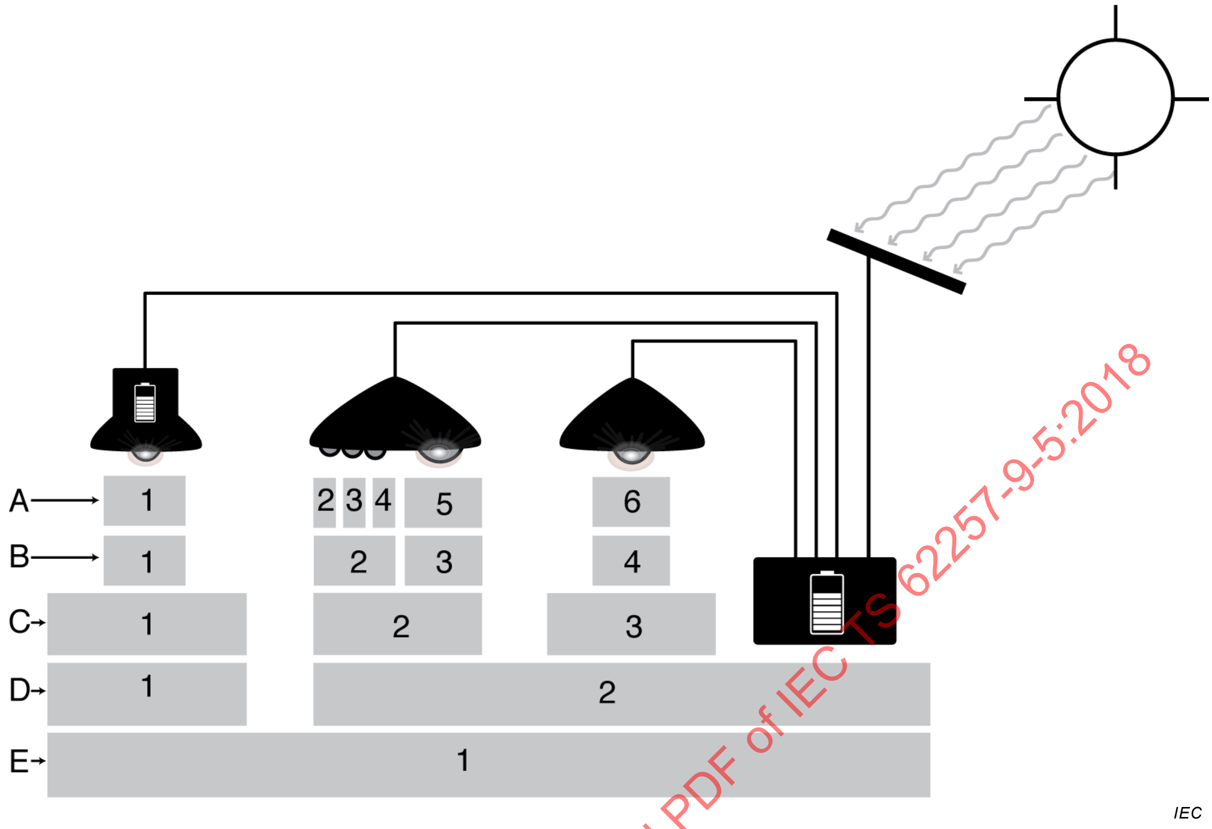


Figure 5 – Division of a product into subsystems – Illustrative example

4.1.4 Appliance definitions

Some products may include or advertise compatibility with one or more appliances, such as lights, radios, and mobile devices. Two categories of appliances are addressed in this document:

- Included appliances are packaged with and sold as part of the product, so their performance (e.g., power consumption) can be measured directly by the test laboratory.
- Advertised appliances are not included as part of the product but are mentioned in the accompanying advertising material, such as the product packaging or the manufacturer's website. This advertising can be a simple statement that the appliance can be used with the product or an estimate of the run time or service provided by the appliance with a full battery or after a day of solar charging. Methods are provided for evaluating these claims even though the appliances are not provided to the test laboratory.

In addition, appliances can be categorized by how they are connected to the other components of the product:

- Removable appliances can be powered or charged from the product by plugging a cable into a port, and can be disconnected when not in use.
- Built-in appliances are integrated into another component of the product so that they are not intended to be removed by the end user. These appliances include built-in radios and lights. The following are also considered built-in appliances for the purposes:
  - appliances (such as light points) connected to the product by a permanently attached cable that is not intended to be removed by the end user;
  - appliances (such as light points) that can be removed, but that depend on a circuit or assembly internal to another part of the product for their functionality. For example, a light point where some or all of the driver or ballast circuit is internal to the power control unit of the product is considered a built-in appliance. In some cases, such

appliances can be tested as removable appliances with some modifications to the test procedures; see EE.4.2.5.

In some cases, an appliance can be considered both "built-in" and "removable." For example, a product could have external lights that can be plugged into specially designated ports with brightness controls or into general-purpose appliance ports. These appliances may be tested as built-in appliances or removable appliances; the decision should be made based on how the appliance is likely to be used most often. It is not necessary to test such appliances using both sets of test methods (for built-in and removable appliances).

Removable appliances can be further divided into appliances with and without internal batteries. Different test methods for power consumption and voltage compatibility apply to these two categories. (The term "appliance with internal battery" in this document does not refer to built-in appliances.)

4.1.5 Additional system elements

In addition to technical elements, a system can also include:

- packaging with information about the product,
- user's manual(s),
- various advertising for the product across media: print, radio, television, internet, and others,
- warranty support from the manufacturer, and/or
- hardware for mounting the PV module and other components.

4.2 System measurements and observations

4.2.1 General

Subclause 4.2 describes aspects of an off-grid lighting product that can be measured and/or observed to ascertain its quality and performance. The aspects are grouped into categories, and each aspect begins with a description of its relevance. The description of each aspect concludes with a description of the result from the test procedure, the units, and an example result. In some cases, multiple pieces of information are grouped in a single aspect for clarity and concision.

4.2.2 Product design, manufacture, and marketing aspects

4.2.2.1 Arrangement of components

The arrangement of components is a critical aspect to observe because it determines the product category. Different arrangements will offer different utility to the end user.

a) Test procedure(s): Annex F: visual screening.
b) Result: qualitative description of each separate electronic enclosure and what is housed in or mounted on each.
c) Units: qualitative description.

EXAMPLE Enclosure A contains the battery and has a gooseneck light point protruding from the top. Enclosure B is a remote lighting point with ambient, omnidirectional LEDs mounted on the outside; it is connected to Enclosure A with a 5 m cable. A solar module with a 6 m cable powers Enclosure A.

4.2.2.2 Charging system information

This notes all the available options for charging the device. The key items to note are whether the device can be charged by "central" charging (e.g. via electric grid connection or at a central charging station), "independent" charging (e.g. via an included photovoltaic or electromechanical generator), or both. The available charging options can help determine the utility of the device for users based on the performance aspects (see 4.2.8).

a) Test procedure(s): Annex F: visual screening, Annex D: manufacturer self-reported information.

b) Result (for each charging option): charger type; central or independent.

c) Units: qualitative type.

EXAMPLE Two charging options: independent solar charging via the included module, and central grid charging via an auxiliary input designed for use with mobile phone chargers (not included).

4.2.2.3 Lighting system information

This describes the types of light sources used in the product and their arrangement. This is important for understanding the general product design.

a) Test procedure(s): Annex F: visual screening, Annex D: manufacturer self-reported information.

b) Result: qualitative description of the type, number, and arrangement of light sources.

c) Units: qualitative description.

EXAMPLE See 4.1.3.

4.2.2.4 Energy storage system information

This describes the type and number of energy storage systems included in the product.

a) Test procedure(s): Annex F: visual screening, Annex D: manufacturer self-reported information.

b) Result: the type and number of batteries in the system.

c) Units: qualitative description.

EXAMPLE Unit A has a 3,7 V lithium-ion battery with a rating of 2,0 Ah; Unit B has a 3,7 V lithium-ion battery with a rating of 1,0 Ah.

4.2.2.5 Battery easy replaceability

This is an assessment of whether a low-skill technician can easily replace the battery with only a screwdriver (i.e. no soldering). It is important for considering the relevance of battery replacement information.

a) Test procedure(s): Annex F: visual screening.

b) Result: a yes or no result on whether it is "easy" to replace the battery.

c) Units: yes/no.

4.2.2.6 Battery general aspects

These are the aspects of the battery(-ies) that are important for understanding selection of replacement batteries.

a) Test procedure(s): Annex F: visual screening, Annex D: manufacturer self-reported information or reference component rating.

b) Result (for each battery present): battery chemistry; nominal voltage; package type; package size; connection type.

c) Units: qualitative type.

EXAMPLE A sealed lead-acid 4 V prismatic package, 20 mm × 20 mm × 60 mm, wire lead connections.

4.2.2.7 Packaging and user’s manual information

Information about the packaging, user’s manual, and other consumer-facing information helps establish a baseline for comparing measured values in truth-in-advertising assessments. Certain programmes require particular information to be included in the manual, such as instructions for end-of-life disposal, particularly for batteries and other potentially hazardous components; thorough documentation of the packaging, user's manual, and other consumer-facing information allows compliance with these requirements to be assessed.

a) Test procedure(s): Annex F: visual screening.
b) Result: there are five types of result:
   1) photographic documentation of the packaging and manual (or digital copies of the original proofs);
   2) notes on the type of manual and which languages are included;
   3) description of the method or pathway for replacing components, including the battery;
   4) specifications of components that could require replacement (fuses, batteries, PV);
   5) instructions for PV and product installation and operation.
c) Units: qualitative type and photographs.

4.2.2.8 Warranty information

The terms and duration of warranty coverage provided to end users are important factors for engendering confidence in stand-alone off-grid lighting and trying to prevent early failure. In practice, servicing warranties is highly variable depending on the structure of supply and service chains.

a) Test procedure(s): Annex F: visual screening, Annex D: manufacturer self-reported information.
b) Result: detailed warranty terms and a "concise" version that highlights the key points of coverage and duration.
c) Units: qualitative description.

EXAMPLE Detailed warranty terms are documented in scanned attachments to test report. Coverage is against manufacturing defects or under normal use conditions. The product in general is covered for 24 months from the time of purchase; the PV module is warranted for 5 years.

4.2.2.9 Auxiliary outlets, ports and adapters information

This notes all the auxiliary outlets and ports present on the product. The inclusion of USB ports, outlets or mobile device adapters can be an important purchasing factor for a consumer.

a) Test procedure(s): Annex F: visual screening, Annex D: manufacturer self-reported information.
b) Result: list of included auxiliary outlets, ports and adapters, including receptacle type and nominal voltage.
c) Units: qualitative description.

EXAMPLE The product includes two 12 V ports with barrel jacks (5,5 mm outer diameter; 2,5 mm pin diameter) and three 5 V USB ports (type A receptacle).

4.2.2.10 Appliances information

This notes all the appliances included with the product and all appliances the product is advertised to support. Some products include appliances such as radios. Others include advertising stating that they support certain appliances or making claims as to how long they can power certain appliances.

a) Test procedure(s): Annex F: visual screening, Annex D: manufacturer self-reported information.
b) Result: list of included appliances and list of claims related to supporting appliances.
c) Units: qualitative description.

4.2.2.11 Other visual screening results

This incorporates various other important results obtained from visual screening (Annex F), including, but not limited to, component dimensions, component masses, the number of light output settings, and provided specifications.

a) Test procedure(s): Annex F: visual screening, Annex D: manufacturer self-reported information.

b) Result: various results including qualitative descriptions and quantitative measurements.

c) Units: qualitative descriptions and quantitative measurements.

4.2.3 Product durability and workmanship aspects

4.2.3.1 Water protection – enclosure

This provides a description of the product enclosure's ability to keep out water in terms of IP class. For components intended to be used and/or charged outside, water protection is important for product function as well as user safety.

a) Test procedure(s): Annex U: Physical and water ingress protection test according to IEC 60529 or the alternative methods if the alternative method results are unequivocal.

b) Result: pass or fail for IP class (second digit) and a description of degree of water protection provided by enclosure.

c) Units: pass or fail and qualitative description.

EXAMPLE The portable lamp included with the product passes IP x3. The lamp's enclosure contains tight fitting components, all of which have gaskets to prevent water intrusion. The battery, charge controller and TV are all fixed indoor components that do not require water ingress protection.

4.2.3.2 Water protection – circuit protection and drainage

This provides a description of any drainage means incorporated into a product and/or circuit board protection methods used in the product. The incorporation of drainage or circuit board protection is crucial for products intended to be portable or used outdoors that have enclosures providing little to no water intrusion protection.

a) Test procedure(s): Annex F: visual screening combined with Annex D: manufacturer self-reported information.

b) Result: qualitative description of drainage or circuit protection methods used.

c) Units: qualitative description.

EXAMPLE The product has a conformal coating on its circuit board as well as drainage holes in the base of the enclosure to allow drainage of collected water.

4.2.3.3 Water protection – overall

This combines the protection afforded by the enclosure, circuit protection, and consumer labelling to assess the overall protection from water exposure.

a) Test procedure(s): Annex V: level of water protection.

b) Result: descriptive assessment of exposure protection by enclosure only, technical means, and overall system. The assessment categories are "no protection," "occasional rain," "frequent rain, "permanent rooftop installation for PV modules," and "permanent outdoor exposure."

c) Units: qualitative type.

EXAMPLE Enclosure only: no protection. Technical means: occasional rain. Overall: occasional rain.

4.2.3.4 Water protection – solar module

This provides a description of an external solar module's ability to keep out water in terms of IP class. (If the solar module is integrated into the product enclosure, then 4.2.3.1 already covers the solar module.) Solar modules need to be left outside to collect solar energy; therefore, water protection is important for solar module function as well as user safety.

a) Test procedure(s): Annex U: Physical and water ingress protection test according to IEC 60529 or using the alternative methods (U.4.4) if the alternative method results are unequivocal.
b) Result: pass or fail for IP class (second digit) and a description of degree of water protection.
c) Units: pass or fail and qualitative description.

EXAMPLE The product's solar module passes IPx4; the solar module is well sealed, providing an adequate level of protection against water ingress.

4.2.3.5 Physical ingress protection

This provides a description of the degree of protection from the intrusion of foreign objects a component's enclosure provides in terms of IP class. Physical ingress protection is important for user safety as well as product functionality.

a) Test procedure(s): Annex U: Physical and water ingress protection test according to IEC 60529 or using the alternative methods (U.4.3) if the alternative method results are unequivocal.
b) Result: pass or fail for IP class (first digit) and description of degree of physical ingress protection.
c) Units: pass or fail and qualitative description.

EXAMPLE The product components pass IP 2x; the product enclosure's components fit together well, with vents smaller than 12,5 mm.

4.2.3.6 Physical ingress protection – solar module

This provides a description of an external solar module's ability to prevent the intrusion of foreign objects in terms of IP class (if the solar module is integrated into the product enclosure, then 4.2.3.5 already covers the solar module). Solar modules need to be left outside to collect solar energy; therefore, physical ingress protection is important for solar module function as well as user safety.

a) Test procedure(s): Annex U: Physical and water ingress protection test according to IEC 60529 or using the alternative methods (U.4.4) if the alternative method results are unequivocal.
b) Result: pass or fail for IP class (first digit) and description of degree of physical ingress protection.
c) Units: pass or fail and qualitative description.

EXAMPLE The product's solar module is estimated to pass IP 3x; the solar module is well sealed so that only small particles could intrude.

4.2.3.7 Drop resistance

This provides an evaluation of a product's robustness and ability to withstand being dropped. Drop resistance is important for product functionality and user safety and satisfaction in portable components.

a) Test procedure(s): Annex W: mechanical durability test.
b) Result: pass or fail for functionality, damage, and the presence of user safety hazards.
c) Units: a pass or fail result on whether the DUT functions, incurred damage, and presented a safety hazard to the user.

EXAMPLE When dropped, the product stopped working and its glass LED cover shattered, presenting a safety hazard to the user. Functional: fail. Damage: fail. Safety hazard: fail.

4.2.3.8 Gooseneck and moving part durability

This provides an evaluation of a product's gooseneck or other moving part's robustness and ability to withstand being torqued through its expected range of motion. Gooseneck and moving part durability is important for product functionality and user safety and satisfaction.

a) Test procedure(s): Annex W: mechanical durability test.

b) Result: a pass or fail for functionality, damage, and the presence of user safety hazards.

c) Units: a pass or fail result on whether the DUT functions, incurred damage, and presented a safety hazard to the user.

EXAMPLE After the gooseneck/moving part test, the LEDs worked properly but there was visible damage (a cracked housing) that did not pose a hazard. Functional: pass. Damage: fail. Safety: pass.

4.2.3.9 Connector durability

This provides an evaluation of a product's connectors' robustness and ability to withstand plug cycling. Connector durability is important for product functionality and user safety and satisfaction.

a) Test procedure(s): Annex W: mechanical durability test.

b) Result: a pass or fail for functionality, damage, and the presence of user safety hazards.

c) Units: a pass or fail result on whether the DUT functions, incurred damage, and presented a safety hazard to the user.

EXAMPLE After 400 cycles in the connector test, the PV module's barrel plug socket detached from the DUT enclosure, rendering the PV module connector unusable. Functional: fail. Damage: fail. Safety: pass.

4.2.3.10 Switch durability

This provides an evaluation of a product's switches' robustness and ability to withstand switch cycling. Switch durability is important for product functionality and user safety and satisfaction.

a) Test procedure(s): Annex W: mechanical durability test.

b) Result: a pass or fail for functionality, damage, and the presence of user safety hazards.

c) Units: a pass or fail result on whether the DUT functions, incurred damage, and presented a safety hazard to the user.

EXAMPLE After 600 cycles in the switch test, the light switch stopped turning on the DUT. Functional: fail. Damage: fail. Safety: pass.

4.2.3.11 Strain relief durability

This provides an evaluation of a product's strain reliefs' robustness and ability to withstand being pulled. Strain relief durability is important for product functionality and user safety and satisfaction.

a) Test procedure(s): Annex W: mechanical durability test.

b) Result: a pass or fail for functionality, damage, and the presence of user safety hazards.

c) Units: a pass or fail result on whether the DUT functions, incurred damage, and presented a safety hazard to the user.

EXAMPLE The strain reliefs all withstood the strain relief test without incurring any damage. Functional: pass. Damage: pass. Safety: pass.

4.2.3.12 Wiring quality

This provides a qualitative evaluation of a product's wiring quality, including (but not limited to) neatness and connection quality.

a) Test procedure(s): Annex F: visual screening.

b) Result: a qualitative description of wiring quality.

c) Units: qualitative description and number of failures with respect to key indicators.

EXAMPLE The product's wires are neatly arranged (i.e. not tangled or wrapped around one another) and the solder joints are of good quality. No bad joints, pinched wires, or other poor wiring indicators.

4.2.3.13 Battery protection strategy

This provides a quantitative evaluation of a product's battery discharge-recharge protection strategy / algorithm, which is important for battery longevity as well as user safety.

a) Test procedure(s): Annex S: charge controller behaviour test or Annex FF: appliance tests.
b) Result: deep discharge and overvoltage protection voltages.
c) Units: quantitative description.

4.2.4 Lighting durability aspects

4.2.4.1 500 h lumen maintenance

This is a measure of the amount of light degradation after 500 h of operation at a constant voltage, which can provide valuable insight into the quality of the LEDs and/or the product's circuitry.

a) Test procedure(s): Annex J: lumen maintenance test.
b) Result: percentage of lumen output maintained after 500 h of constant operation.
c) Units: percentage (%).

4.2.4.2 2 000 h lumen maintenance

This is a measure of the amount of light degradation after 1 000 h and 2 000 h of operation at a constant voltage, which can provide valuable insight into the quality of the LEDs and/or the product's circuitry.

a) Test procedure(s): Annex J: lumen maintenance test.
b) Result: percentage of lumen output maintained after 1 000 h and 2 000 h of constant operation.
c) Units: percentage (%).

4.2.4.3 Fluorescent light durability

These are additional checks of durability for fluorescent lights that account for their unique characteristics.

a) Test procedure(s): Cycling test of IEC TS 62257-12-1.
b) Result: a pass or fail for the cycling test of IEC TS 62257-12-1.
c) Units: pass or fail.

4.2.5 Battery performance aspects

4.2.5.1 Battery capacity

This is a measure of the quantity of electricity (electric charge), usually expressed in ampere-hours (Ah), which a fully charged battery can deliver under specified conditions, which affects the run time of products.

a) Test procedure(s): Annex K: battery test (all chemistries), Annex D: manufacturer self-reported information or reference component rating.
b) Result: capacity of the battery at a particular discharge rate.
c) Units: ampere-hours (Ah) at a discharge rate expressed in terms of I_t A (as defined in K.4.1).

EXAMPLE 3,5 Ah at 0,2 I_t A.

4.2.5.2 Battery round-trip energy efficiency

This is a measure of how efficient the battery is at storing energy to deliver for later use.

a) Test procedure(s): Annex K: battery test.
b) Result: storage efficiency of the battery pack.
c) Units: percentage (%).

4.2.5.3 Battery storage durability

This is a measure of battery capacity degradation from storage, which can indicate batteries that could degrade prematurely under typical use.

a) Test procedure(s): Annex BB: battery durability test.
b) Result: percent capacity loss from storage.
c) Units: percentage (%).

4.2.5.4 Battery nominal voltage

This is important for matching to the other components and determines, along with the battery ampere-hour capacity, the energy capacity of the battery. It depends on the battery chemistry (what materials are used to store energy) and the number of electrochemical cells that are in series.

a) Test procedure(s): Annex F: visual screening, Annex D: manufacturer self-reported information or reference component rating.
b) Result: nominal voltage of the battery pack.
c) Units: voltage (V).

4.2.6 Solar module aspects

4.2.6.1 Solar I-V curve parameters

These are the key parameters describing solar module performance at standard test conditions (STC: AM 1,5, 25 °C cell temperature, 1 000 W/m^2 irradiance) and typical module operating temperature (TMOT: AM 1,5, 50 °C cell temperature, 1 000 W/m^2 irradiance).

a) Test procedure(s): Annex Q: photovoltaic module I-V characteristics test, IEC 60904-1.
b) Result (for both STC and TMOT):
   1) Open circuit voltage (V_{oc}).
   2) Short circuit current (I_{sc}).
   3) Maximum power voltage (V_{mpp}).
   4) Maximum power current (I_{mpp}).
   5) Peak power (P_{mpp}).
   6) Voltage temperature coefficient (relative to the open-circuit voltage at STC).
c) Units: volts (V), amperes (A), watts (W), per degree Celsius (1/°C).

EXAMPLE STC values: V_{oc} = 7,5 V, I_{sc} = 0,55 A, V_{mpp} = 5,8 V, I_{mpp} = 0,50 A, and P_{mpp} = 2,9 W. The module's voltage temperature coefficient is -0,004 2/°C.

4.2.6.2 Cable length

The length of solar module cables and other cables connected to fixed outdoor components are important because it is one aspect that determines the product category; a minimum length is typically specified for products to "qualify" as having separate PV modules to ensure that a user can place the solar module, or other component, outdoors while the other components remain indoors. This has implications for the degree of water protection in quality standards.

a) Test procedure(s): Annex F: visual screening.

b) Result: There are two main outputs:

   1) the length of any cables that connect a portable component or fixed indoor component to a solar module; and

   2) the length of any cables that connect any fixed outdoor or portable integrated component to any other component (other than another fixed outdoor component).

c) Units: metres (m).

4.2.7 Electrical characteristics

4.2.7.1 Appliance voltage compatibility

This provides an assessment of whether an included appliance can safely and properly operate over the entire set of operating conditions of the DUT, including discharging with a deeply discharged battery and charging with a nearly full battery.

a) Test procedure(s): Annex EE: assessment of DC ports, or Annex FF: appliance tests.

b) Result: pass or fail for functionality, damage, and safety.

c) Units: pass/fail; qualitative description.

4.2.7.2 Power consumption

The power consumed by an appliance or lighting appliance in use is an important metric for off-grid applications in which the supply of energy is limited. The power consumption is measured in order to calculate the run time for systems with included appliances. Appliances with internal batteries will have a power consumption when in use, and a different power consumption when charging; the latter is measured in the appliance charging efficiency test.

a) Test procedure(s): Annex FF: appliance tests.

b) Result: DC power.

c) Units: watts (W).

4.2.7.3 Circuit and overload protection

This provides an assessment of the system's PV overvoltage protection, output overload protection, and safeguards against miswiring in systems that include ports or outlets.

a) Test procedure(s): Annex DD: protection tests, Annex D: manufacturer self-reported information.

b) Result: a pass or fail result on whether the unit had adequate protection, functioned, or showed damage, fault indications or safety hazards after tests. Tables with quantitative and qualitative results of the voltage range and miswiring protection tests.

c) Units: volts (V), pass or fail results on whether the unit had adequate protection, functioned, or showed damage, fault indications or safety hazards after test.

EXAMPLE The DUT uses appropriately sized fuses to provide adequate circuit protection. Spare fuses are included and the fuse size is noted on the product casing.

4.2.7.4 Battery-charging circuit efficiency

The battery-charging circuit efficiency, or generator-to-battery charging efficiency, is a measure of how efficient the DUT electronics are at feeding generated energy into the battery.

a) Test procedure(s): Annex R: solar charge test,

b) Result: battery-charging circuit efficiency.

c) Units: percentage (%).

4.2.7.5 DC ports

This provides an assessment of the system's DC ports.

a) Test procedure(s): Annex EE: assessment of DC ports.
b) Result: minimum and maximum port voltages, tables and plots of voltage, current, power and efficiency of each port.
c) Units: volts (V), amperes (A), watts (W), percentage (%).

4.2.7.6 Appliance charging efficiency

The charging efficiency and power consumed by an appliance during charging is an important metric for use in off-grid applications in which the supply of energy is limited. The charging efficiency is measured for appliances with internal batteries charging from the main unit. The power consumption during charging is measured in order to calculate the run time for systems with included appliances that have internal batteries.

a) Test procedure(s): Annex FF: appliance tests.
b) Result: appliance charging efficiency, DC power.
c) Units: percentage (%), watts (W).

4.2.8 Performance aspects

4.2.8.1 General

Energy availability, component run times and light output are key elements of performance for stand-alone renewable energy products. Some of the aspects listed below will be different for different light settings and appliance combinations.

4.2.8.2 Daily energy service

The daily energy service is the duration of service provided to end users after one day of solar charging and depends on the system-level performance for a particular setting. The standard solar charging day is defined as an incident solar resource of 5 kWh/m^2. This is an important metric because it is an estimate of the day-to-day services users can expect in ideal charging conditions. The daily energy service depends on the system-level performance for a particular light setting and combination of appliances.

a) Test procedure(s): Annex M: full-battery run time test, Annex R: solar charge test, Annex FF: appliance tests, Annex GG: energy service calculations.
b) Result: watt·hours per day of energy available after a battery is charged from empty for one standard solar day.
c) Units: watt·hours (Wh).

4.2.8.3 Solar-day lighting run time

The solar-day run time is the duration of service provided to end users from one day of solar charging and depends on the system-level performance for a particular setting. The standard solar charging day is defined as an incident solar resource of 5 kWh/m^2. This is an important metric because it is an estimate of the day-to-day services users can expect in ideal charging conditions. It is important to note that variations in available solar energy (due to climate, weather, or user behaviour) will result in commensurate differences in actual run time from solar charging.

a) Test procedure(s): Annex R: solar charge test; or Annex M: full-battery run time test, Annex R: solar charge test, and Annex GG: energy service calculations.
b) Result: hours of operation to 70 % of the initial brightness after the battery is charged for one standard solar day.
c) Units: hours (h).

4.2.8.4 Solar-day appliance run time

The solar-day run time is the duration of service provided to end users from one day of solar charging and depends on the system-level performance for a particular setting. The standard solar charging day is defined as an incident solar resource of 5 kWh/m^2. This is an important metric because it is an estimate of the day-to-day services users can expect in ideal charging conditions. It is important to note that variations in available solar energy (due to climate, weather, or user behaviour) will result in commensurate differences in actual run time from solar charging.

a) Test procedure(s): Annex R: solar charge test; or Annex M: full-battery run time test, Annex R: solar charge test, Annex FF: appliance tests, and Annex GG: energy service calculations.
b) Result: hours of operation after the battery is charged for one standard solar day.
c) Units: hours (h).

4.2.8.5 Solar charging time

The solar charging time is the duration of solar charging required for the product to receive a full charge. The standard solar charging day is defined as an incident solar resource of 5 kWh/m^2. This is an important metric because it is an estimate of the day-to-day services users can expect in ideal charging conditions. It is important to note that variations in available solar energy (due to climate, weather, or user behaviour) will result in commensurate differences in actual run time from solar charging.

a) Test procedure(s): Annex R: solar charge test; or Annex M: full-battery run time test, Annex R: solar charge test, Annex FF: appliance tests, and Annex GG: energy service calculations.
b) Result: hours of solar charging required for the product’s battery(-ies) to receive a full charge from empty to full.
c) Units: hours (h).

4.2.8.6 Main unit full-battery run time

The main unit full-battery run time is the duration of service provided to end users from a fully charged battery and depends on the system-level performance for a particular setting. This is an important metric because it is an estimate of the services that can be provided by the product’s main battery. If a product is submitted with no lighting appliances, other included or generic appliances may be used to determine the main unit’s full-battery run time.

a) Test procedure(s): Annex M: full-battery run time test, alone or in conjunction with Annex GG: energy service calculations.
b) Result: hours of operation to 70 % of the initial brightness when beginning with a fully charged battery; sometimes also known as "autonomous run time."
c) Units: hours (h).

4.2.8.7 Appliance full-battery run time

The appliance full-battery run time is the duration of service provided to end-users from a fully charged appliance battery, such as a lantern, radio, fan or TV with an internal battery. This is an important metric because it is an estimate of the services that can be provided by the appliance once it receives full charge from the main system.

a) Test procedure(s): Annex M: full-battery run time test or Annex FF: appliance tests (measurement according to Clause FF.9 or calculation according to FF.6.8.5).
b) Result: hours of operation to the run time endpoint after the battery is fully charged.
c) Units: hours (h)

4.2.8.8 Grid-charge energy

The grid-charge energy is the energy delivered to the battery in an 8 h period for DUTs that are centrally charged (i.e. with a central charging station or the grid). This is an important metric because it provides the expected run time after a full day of grid charging.

a) Test procedure(s): Annex O: grid charge test.

b) Result: energy delivered to the battery in 8 h.

c) Units: watt·hours (Wh).

4.2.8.9 Electromechanical charger power or energy output

The electromechanical charger power output is an important metric because it allows one to estimate the duration of user effort required each day for a given level of service for an electromechanically charged product (e.g. one with a hand crank or bicycle pedals). In some products, as detailed in Annex P, energy is a more appropriate metric than power.

a) Test procedure(s): Annex P: electromechanical charge test.

b) Result: power output of the electromechanical charger.

c) Units: watts (W) or watt·hours (Wh).

4.2.8.10 Standby loss

The standby loss measurement quantifies the current drawn by a DUT when not in use. If the standby loss is substantial, it can affect the use of the DUT.

a) Test procedure(s): Annex S: charge controller behaviour test.

b) Result: average current over 10 min period.

c) Units: amperes (A).

4.2.9 Light output aspects

4.2.9.1 Luminous flux output

Luminous flux output is the light output of a DUT when it is operated at the typical battery discharge voltage or when an individual lighting appliance is measured at the appliance operating voltage. This is a key metric that compares the overall light output of DUTs.

a) Test procedure(s): Annex I: light output test.

b) Result: average luminous flux.

c) Units: lumens (lm).

4.2.9.2 Full width half maximum (FWHM) angles

The full width half maximum angle is a metric used to understand the light distribution of a DUT and is the total included angle for which the illumination is greater than half the illumination at the brightest point in the plane.

a) Test procedure(s): Annex T: light distribution test.

b) Result: vertical and horizontal FWHM angles.

c) Units: degrees (°).

4.2.9.3 Average light distribution characteristics

A light distribution is the illuminance "map" of a DUT. This metric is useful for determining the utility with respect to task lighting. The test is done with the DUT operating at the average operating point from the full-battery run time test.

a) Test procedure(s): Annex T: light distribution test.

b) Result: constant-voltage usable area at a specified distance, and illuminance on a work surface of 0,3 m × 0,4 m.

NOTE The work surface dimensions were selected to correspond to two adjacent sheets of A4 paper.

c) Units: square metres (m^2) and lux (lx).

EXAMPLE The usable area at a distance of 0,75 m is 0,76 m^2 and the work surface illuminance is 40 lux.

4.2.9.4 Colour characteristics

The colour characteristics of light include the colour rendering index (CRI) and the correlated colour temperature (CCT).

a) Test procedure(s): Annex I: light output test.

b) Result: CRI value and colour temperature.

c) Units: CRI is unitless and the colour temperature is in kelvins (K).

4.2.10 Self-certification aspects

4.2.10.1 Product and manufacturer information

Manufacturer-reported product and manufacturer information is important for tracking purposes as well as for ensuring the test lab has up-to-date product information.

a) Test procedure(s): Annex D: manufacturer self-reported information.

b) Result: various qualitative and quantitative information.

c) Units: qualitative and quantitative.

4.2.10.2 Warranty coverage

Warranty coverage goes beyond the terms of a warranty and provides detail on coverage in a particular location. It is typically only provided in cases where it is necessary to verify coverage in a particular town or region.

a) Test procedure(s): Annex D: manufacturer self-reported information.

b) Result: qualitative description.

c) Units: qualitative description.

EXAMPLE The support in [region name] is provided by a small network of technicians who have been trained to repair products by [manufacturer or distributor name]. For repairs that are beyond the scope of their capabilities, replacement products are provided. The consumers in [region name] can access warranty service by dialling a phone number that is on a sticker placed on the original packaging.

4.2.10.3 Third-party marks and certifications

Third-party marks and certifications (e.g., UL or ISO) can be an important aspect in the eyes of consumers and investors, alike.

a) Test procedure(s): Annex D: manufacturer self-reported information.

b) Result: qualitative marks and certifications.

c) Units: qualitative description.

4.2.10.4 PAYG manufacturer declaration

In cases where products are pay-as-you-go (PAYG) or fee-for-service enabled, an additional declaration form shall be submitted that provides more information on the PAYG aspects of the product. The PAYG declaration form also serves as an affirmation from the manufacturer that their product meets specific standards (e.g., that the solar module will still charge the battery when the product is in a "locked" state).

a) Test procedure(s): Annex D: manufacturer self-reported information.

b) Result: qualitative marks and certifications.

c) Units: qualitative description.

4.3 Constructions not specifically covered

If it is evident from the design and construction of the stand-alone renewable energy product that a particular test is not applicable, the test is either not made or reasonable adjustments may be made to apply the test to the product. Any modifications shall provide a level of accuracy equivalent to the original method and shall be fit for the intended use. All modifications shall be documented in the test report. The need for additional detailed requirements to cope with new situations should be brought promptly to the attention of the appropriate committee.

5 Product specification

5.1 General

Quality standards and warranty requirements are used to interpret the measurements and observations made about a product. Together they form a product specification.

- Quality standards set a minimum level of durability and protect buyers and users from false advertising claims.
- Warranty requirements set a minimum level of user protection from early failure.

Each criterion in a specification refers to a particular aspect of the product, as listed in 4.2, and requires a minimum level of quality, service, or performance.

The standards and requirements should be appropriate for the goals of the organization or individual who is using them as a framework for quality assurance and should consider the following factors:

- availability of products on the market with the necessary quality and performance;
- ability of buyers to pay for the products;
- diversity of end user needs;
- tolerance for manufacturing variation.

Clause 5 describes the framework for standards and requirements in general and offers insights on the best practices for creating a product specification. It includes a template product specification followed by guidance on completing each section.

5.2 Applications

Product specifications that include some combination of quality standards and warranty requirements can support a broad range of quality assurance needs. Table 1 lists examples of how they are applied depending on the type of quality assurance framework.

Table 1 – Applications of product specifications

Type of QA framework	Example(s) of applying 4.3
General market support	Use quality standards and general warranty requirements to qualify for institutional market support. Use quality standards to qualify for "verified product" programs. Use quality standards and other requirements to qualify for investment or financing.
Manufacturing/ distribution	For manufacturers: incorporate quality standards from market support programmes or distributors in the design and production QC processes. For distributors: set minimum quality standards and warranty requirements for products to identify suppliers.
Bulk procurement	Set minimum quality standards and warranty requirements for products to qualify in a request for offers. If the project is in a specific location, the warranty requirements may also include specific levels of service in that particular area.
Trade regulation	Set minimum quality standards for tax exemption or customs.

5.3 Quality assurance principles

The framework for considering quality standards and warranty requirements presented in this document is designed to support broad types of programmes and institutions in the off-grid lighting market. The following key principles guide the framework.

- Balance quality and affordability for price-sensitive buyers – it does not matter how well products perform if the target users cannot afford them.
- Encourage innovation and technological diversity. Wherever possible, be open-ended in the technical approaches that are allowed.
- Empower buyers to choose the right product for their needs and budget by focusing product specifications and communication on outcomes for end users.
- Use low-cost, rigorous, targeted tests to match the general affordability requirements for the market and accommodate both incremental and innovative changes to product design. The tests should be feasible for use by a broad set of potential users.
- Focus quality standards on elements of a product that are difficult for typical buyers to assess themselves, like truth-in-advertising and durability.
- Focus warranty requirements on providing a baseline of support.

5.4 Product specification framework description

5.4.1 General

Subclause 5.4 describes a framework for creating product specification documents for off-grid lighting. First, a blank specification (5.4.2) is provided that lists all the pieces that may be specified. Next, 5.4.3 describes guidelines for setting tolerances in a product specification. Finally, the main sections in a specification are described in more detail with notes and guidance (5.4.4, 5.4.5).

An example product specification for general market support programmes is in Annex A.

A product specification has five parts:

a) Scope: defines the applicability and use of the quality standards.
b) Test requirements: defines requirements for test result validity.
c) Product category requirements: unambiguously defines the categories that may be referenced later.

d) Quality standards: lists quality-related aspects and minimum or required results for each aspect with a tolerance; may be subdivided by product category.

e) Warranty requirements: lists requirements for minimum levels of warranty support.

5.4.2 Product specification template

5.4.2.1 General

Subclause 5.4.2 is a blank, rough template for setting quality standards and warranty requirements to support the goals of a programme or institution. Note that in many applications certain criteria or entire categories of criteria do not apply and should be removed. Text in *italics* is intended for replacement and describes what should go in each space.

5.4.2.2 Scope

Describe the intended use of the product specification. Describe the contents in general, and provide guidance on how to use the document.

5.4.2.3 Test requirements

Specify the level of testing that is required. Typically this is quality test method (QTM) testing (see Clause 6).

Describe which tests and standards apply to each appliance type included with a product. Describe if any external test results (such as test results from other IEC standards) could be used in place of results from this document.

Describe any product sampling requirements for qualification testing.

Specify the number of light output settings required to be measured for products with multiple settings. Typically, at least one set of test results should fully characterize the performance on the highest light output setting.

5.4.2.4 Product category requirements

Describe which product categories (see 4.1.2) are covered/allowed.

Describe any other requirements or eligibility criteria for products that are categorical (e.g. shall be solar charged, shall be low-voltage).

Qualification as a "separate" PV module requires meeting the criteria listed in Table 2:

Table 2 – Qualification as separate PV module

Criterion	Aspect(s)	Required value
PV module cable length	4.2.6.2 Cable length	*Define the length in metres that is required for qualification as a separate PV module.*

5.4.2.5 Quality standards

The product shall meet each of the criteria listed in the truth-in-advertising (Table 3), safety and durability (Table 4), and end user support (Table 5) tables.

Table 3 – Truth-in-advertising tolerance

Truth-in-advertising criterion	Aspect(s) considered in assessment	Requirement
System performance tolerance – numeric ratings	4.2.8 Performance aspects 4.2.9 Light output aspects Others, if applicable	*Define the tolerance for deviation from ratings.*
System components tolerance – numeric ratings	4.2.5 Battery performance aspects 4.2.6 Solar module aspects 4.2.7.1 Appliance voltage compatibility 4.2.7.2 Power consumption 4.2.7.5 DC ports Others, if applicable	*Define the tolerance for deviation from ratings.*
Other numeric ratings tolerance	Multiple	*Define the tolerance for deviation from ratings.*
Overall truth–in-advertising statement	Multiple	*Include an overall description of the requirements for truth in advertising that are not covered by the requirements above.*

Table 4 – Safety and durability standards

Safety or durability criterion	Aspect(s) considered in assessment	Product category (form factor and/or technology)	Requirement
Level of water exposure protection (*overall, technical, or enclosure-only*)	4.2.3.1 Water protection – enclosure 4.2.3.2 Water protection – circuit protection and drainage 4.2.3.3 Water protection – overall 4.2.3.4 Water protection – solar module 4.2.10.1 Product and manufacturer information 4.2.2.7 Packaging and user's manual information	Category 1	*Define level of protection in terms of water protection integrated assessment:* *No protection, occasional rain, frequent rain, or permanent outdoor exposure.*
		Category 2, Category 3, etc.	*Define level of protection in terms of water protection integrated assessment.*
Physical ingress protection	4.2.3.5 Physical ingress protection 4.2.3.6 Physical ingress protection – solar module	Category 1	*Define level of protection in terms of IP class.*
		Category 2, Category 3, etc.	*Define level of protection in terms of IP class.*
Mechanical durability – drop test	4.2.3.7 Drop resistance	Category 1	*Define type of drop test (2 drops or 6 drops per sample). Define maximum number of failures out of the number that are tested for damage, functionality, and safety.*
		Category 2, Category 3, etc.	*Define type of drop test (2 drops or 6 drops per sample). Define maximum number of failures out of the number that are tested for damage, functionality, and safety.*
Mechanical durability – goosenecks and moving parts	4.2.3.8 Gooseneck and moving part durability	Products with goosenecks/moving parts	*Define maximum number of failures out of the number that are tested for damage, functionality, and safety.*
Mechanical durability – connectors	4.2.3.9 Connector durability	Products with connectors	*Define maximum number of failures out of the number that are tested for damage, functionality, and safety.*
Mechanical durability – switches	4.2.3.10 Switch durability	All products	*Define maximum number of failures out of the number that are tested for damage, functionality, and safety.*
Mechanical durability – strain relief	4.2.3.11 Strain relief durability	Products with connectors	*Define maximum number of failures out of the number that are tested for damage, functionality, and safety.*
Workmanship	4.2.3.12 Wiring quality	All products	*Define maximum number of samples with bad solder joints, poor wiring, etc., out of the number that are tested.*

Safety or durability criterion	Aspect(s) considered in assessment	Product category (form factor and/or technology)	Requirement
Battery durability	4.2.3.13 Battery protection strategy 4.2.5.3 Battery storage durability 4.2.10.1 Product and manufacturer information 4.2.10.3 Third-party marks and certifications	All products	*Define a minimum level of battery protection that will protect the product's battery and the user. Define maximum capacity loss following battery durability test.*
Lumen maintenance	4.2.4.2 2 000 h lumen maintenance	All products	*Define maximum number of samples that may fail specified lumen maintenance criteria out of the number that are tested.*
Fluorescent light durability	4.2.4.3 Fluorescent light durability	Products with fluorescent lights	*Define maximum number of failures out of the number that are tested.*
AC-DC charger safety	4.2.10.1 Product and manufacturer information 4.2.10.3 Third-party marks and certifications	Products with AC-DC chargers included	*Define acceptable safety approval marks and certifications for AC-DC chargers.*
Hazardous substances ban	4.2.2.4 Energy storage system information 4.2.2.6 Battery general aspects 4.2.10.1 Product and manufacturer information	All products	*Define allowable battery chemistries.*
Cable specifications	4.2.10.1 Product and manufacturer information 4.2.10.3 Third-party marks and certifications	All products	*Define acceptable approval marks and certifications for outdoor cables*
Circuit and overload protection, PV overvoltage protection, and miswiring protection	4.2.7.3 Circuit and overload protection	All products	*Define maximum number of failures and number of samples to be tested*

Table 5 – End user support standards

Truth-in-advertising criterion	Aspect(s) considered in assessment	Requirement
Information on product design, utilization, and care	4.2.2.7 Packaging and user's manual information	*Define if there are requirements for consumer-facing information on packaging or in a user's manual, such as end-of-life disposal instructions, specifications of replaceable components, and instructions for product installation and maintenance.*
Other	4.2.2.11 Other visual screening results	*Define other product requirements that support end users to maintain the quality of the product.*

5.4.2.6 Warranty requirements

The product shall meet each of the end user support requirements listed in Table 6.

Table 6 – End user support requirements

Support type	Aspect(s)	Requirement
Maintenance and warranty terms	4.2.2.8 Warranty information	*Define minimum warranty requirements (length, components covered, etc.)*
Service capabilities	4.2.10.2 Warranty coverage	*Define "on the ground" requirements for warranty service (typically only for projects in a specific location)*

5.4.3 Tolerances

Tolerances are an allowable deviation from the target value for a particular criterion in a product specification and are part of the product specification. In the case of truth in advertising, the target value is what is advertised. Durability tests and other pass/fail criteria also have a target – passing the test.

Tolerances should be set carefully, considering how the measured or observed values from a test (with a limited number of samples) characterize the true quality or performance aspects of every product in the market. The sample size, expected manufacturing tolerance, and testing uncertainty should each be considered.

There are trade-offs between protecting buyers/end users and suppliers from "false positive" and "false negative" results, respectively. Tighter tolerance tends to protect buyers/end users better from poor quality or performance products but will also result in a higher number of good quality or performance products being excluded based on non-representative sampling or test results. The dynamic is reversed for looser tolerances.

The type of tolerance depends on the aspect being specified:

a) Qualitative: aspects that are descriptive (e.g. type of light source) do not typically have a tolerance.

b) Numeric: aspects that are described with a measured value (e.g. battery capacity) should have a tolerance defined in terms of percent deviation of the average DUT measurement from a particular value. Often, it is allowable for the test result to deviate in one direction but not the other. For instance, it is allowable to over-perform on the run time but not underperform. There may also be a tolerance defined for variability between samples.

   In general, the percent deviation from a target value is calculated using the following formula:

$$D = 100\,\% \cdot \frac{x_{\text{target}} - x_{\text{meas}}}{x_{\text{target}}}$$

   where:

   D is the percent deviation in a numeric value;

   x_{target} is the target value;

   x_{meas} is a measured value or the average of the measured values for each sample.

c) Boolean: aspects that are described in terms of "pass/fail" (e.g. drop test) should have a tolerance defined in terms of the number of allowable failures out of a set number of trials or tests. The statistical power of Boolean results for predicting population pass/fail rates is not very high with small sample sizes. Therefore, it is not possible to accurately predict population failure rates for a particular aspect from a small sample size, and it is often appropriate to allow some small but reasonable failure rate to avoid false negative results.

5.4.4 Quality standards criteria

5.4.4.1 General

Subclause 5.4.4 describes the quality standards aspects and gives guidance on how to implement a quality standard.

There are several categories of quality criteria listed below. For each category, it is important for a set of quality standards to specify:

- which aspects are referenced by the criteria,
- what level of failure or minimum quality level is acceptable for each aspect, and
- which product categories are subject to each criterion if there are differences across categories.

5.4.4.2 Truth in advertising

The goal of a truth-in-advertising standard (see Table 7) is to protect buyers and end users from false advertising claims. It is particularly important to ensure that the description of advertised values corresponds with test results in cases where buyers (anywhere in the supply chain) will make product purchasing decisions based partly or solely on advertising and packaging or where users have expectations set by them.

Table 7 – Truth-in-advertising criteria for quality standards

Truth-in-advertising criterion	Aspect(s) considered in assessment	Standard specification	Remarks
System performance tolerance – numeric ratings	4.2.8 Performance aspects 4.2.9 Light output aspects Others, if applicable	The tolerance between the rated performance and measured performance.	These are key aspects for end user experiences with the product, but also tend to have test results with higher uncertainty due to a combination of intrinsic manufacturing variation and test uncertainty due to the system-level nature of the aspects.
System components tolerance – numeric ratings	4.2.5 Battery performance aspects 4.2.6 Solar module aspects 4.2.7.1 Appliance voltage compatibility 4.2.7.2 Power consumption 4.2.7.5 DC ports Others, if applicable	The tolerance between the rated performance and measured performance.	These aspects, while important, have less impact on the overall user experience in general. They are more important for identifying replacement parts.
Other numeric ratings tolerance	Multiple	The tolerance between the rated performance and measured performance.	n/a
Overall truth-in-advertising statement	Multiple	Describe the general policy for interpreting truth-in-advertising requirements. Suggested statement: "All advertised features shall be functional. Any description of the product that appears on the packaging, inside the package, and in any other medium (e.g. internet) should be truthful and accurate. No statements should mislead buyers or end users about the features or utility of the product. Any user interfaces (charge indicators, SOC estimates, etc.) shall be accurate."	It is important to lay out a broad expectation of truth in advertising and to interpret it on a case-by-case basis.

In practice it is ideal to check any advertised quality or performance statements against the test results, keeping in mind that often the framing or messaging for advertised statements is different from test conditions and that there is always inherent uncertainty in the test result. In cases where the advertised values will not be directly comparable to test results, care should be taken to avoid wrongly identifying false advertising while maintaining vigilance for buyers.

For aspects that are described with numeric information, a tolerance should be defined for truth in advertising. For aspects that are described with qualitative or Boolean information, judgement is required to discern if the test results match advertised values.

Table 8 includes notes with guidance on aspects that are often part of a truth-in-advertising check because they are commonly advertised.

Table 8 – Remarks on common truth-in-advertising aspects

Aspect(s)	Remarks
4.2.8.2 Daily energy service	Depends on the desired services/appliances.
4.2.8.6 Main unit full-battery run time	Depends on the setting.
4.2.8.3 Solar-day lighting run time	Depends on the setting and often depends on the assumptions about solar resource, which is location-dependent.
4.2.8.8 Grid-charge	Depends on the setting.
4.2.8.9 Electromechanical	Depends on the setting.
4.2.9.1 Luminous flux output	Normally listed as peak luminous flux instead, but other times as the average during discharge, which is more representative of typical service levels.
4.2.2.4 Energy storage system information 4.2.2.6 Battery general aspects 4.2.5 Battery performance aspects 4.2.2.5 Battery easy replaceability	Package type, nominal voltage, capacity are all important for understanding if spares will be available; the replaceability determines if it is easy to service.
4.2.5 Battery performance aspects 4.2.2.4 Energy storage system information 4.2.2.6 Battery general aspects	This information is useful for ensuring the correct replacement battery can be obtained.
4.2.6 Solar module aspects	Peak power capacity and type are often listed.
4.2.2.9 Auxiliary outlets, ports and adapters information 4.2.2.10 Appliances information	The presence of functional auxiliary features (e.g. a mobile phone charger or USB power source) and available appliances (e.g. fan, radio or television) can be very important to some end users.
4.2.3.1 Water protection – enclosure 4.2.3.2 Water protection – circuit protection and drainage	Ensure that there is no information that misleads consumers about the level of protection afforded them by the combination of the enclosure and other water protection systems.
4.2.4.2 2 000 h lumen maintenance	Lifetime is often given for much longer durations (e.g. 20 000 h). These may be compared to the 2 000 h lifetime to ensure the claim is possible.

5.4.4.3 Safety and durability

5.4.4.3.1 General

Safety and durability criteria protect the user from harm and the product from early failure during typical use. It is important to balance the safety and durability requirements with cost implications and reasonable expectations of consumer care, or the safety and durability criteria risk being over-prescribed. It is helpful to consider the expected minimum product lifetime when determining durability-related criteria.

For pass/fail tests, tolerances for failure rates should be specified (see Table 9).

Table 9 – Safety and durability criteria for quality standards

Safety or durability criterion	Aspect(s) considered in assessment	Standard specification	Notes
Level of water exposure protection (overall, technical, or enclosure-only)	4.2.3.1 Water protection – enclosure 4.2.3.2 Water protection – circuit protection and drainage 4.2.3.3 Water protection – overall 4.2.3.4 Water protection – solar module 4.2.10.1 Product and manufacturer information 4.2.2.7 Packaging and user's manual information	The required level of water protection (see list below) and which aspects may contribute to protection. Levels of water protection: No protection Occasional rain Frequent rain Permanent outdoor exposure Permanent exposure in context of rooftop installation for PV modules	The degree of protection should include consideration of product category and expected exposure. Specify the aspects that may contribute to the level of water exposure protection by choosing an overall, technical, or enclosure-only criterion.
Physical ingress protection	4.2.3.5 Physical ingress protection 4.2.3.6 Physical ingress protection – solar module	The required level of physical ingress protection in terms of the minimum IP class.	Degree of protection should include consideration of product category and expected exposure. Also, consider how connectors will be incorporated. Most external power connectors are not protected above IP2x.
Mechanical durability – drop test	4.2.3.7 Drop resistance	The required success rates in the drop test for functionality and safety (two success rates).	Failure allowance should consider Boolean nature of results and consider product category (e.g. fixed products are unlikely to be dropped compared to portable products, and appliances like television sets are often not expected to be dropped).
Mechanical durability – goosenecks and moving parts	4.2.3.8 Gooseneck and moving part durability	The required success rates in the gooseneck and moving part durability test for functionality and safety (two success rates).	Only applies to products with a gooseneck or moving parts.
Mechanical durability – connectors	4.2.3.9 Connector durability	The required success rates in the connector test for functionality and safety (two success rates).	Failure allowance should consider Boolean nature of results.
Mechanical durability – switches	4.2.3.10 Switch durability	The required success rates in the switch test for functionality and safety (two success rates).	Failure allowance should consider Boolean nature of results.
Mechanical durability – strain relief	4.2.3.11 Strain relief durability	The required success rates in the switch test for functionality and safety (two success rates).	Failure allowance should consider Boolean nature of results.
Workmanship	4.2.3.12 Wiring quality	The required success rate for each aspect of the wiring quality inspection.	Failure allowance should consider the prevalence of each fault type.
Battery durability	4.2.3.13 Battery protection strategy 4.2.5.3 Battery storage durability 4.2.10.1 Product and manufacturer information 4.2.10.3 Third-party marks and certifications	The guidelines for determining if batteries are well protected from early failure and if users are protected from potential harm due to battery failure.	Be careful not to over-prescribe the requirements, since there are a wide range of battery protection strategies that can provide satisfactory results – particularly for emerging chemistries.
Lumen maintenance	4.2.4.2 2 000 h lumen maintenance	The minimum average level of lumen maintenance after 2 000 h and the required success rate on a sample-to-sample basis.	Consider the expected rate of use and desired product lifetime.

Safety or durability criterion	Aspect(s) considered in assessment	Standard specification	Notes
Lumen maintenance	4.2.4.2 2 000 h lumen maintenance	The minimum average level of lumen maintenance after 2 000 h and the required success rate on a sample-to-sample basis.	Consider the expected rate of use and desired product lifetime.
Fluorescent light durability	4.2.4.3 Fluorescent light durability	The required success rate for each sample in additional tests for fluorescent light durability.	Failure allowance should consider Boolean nature of results.
AC-DC charger safety	4.2.10.1 Product and manufacturer information 4.2.10.3 Third-party marks and certifications	The guidelines for determining if AC-DC chargers have acceptable safety approval marks and certifications.	Self-certification marks are not necessarily meaningful if no market oversight exists.
Hazardous substances ban	4.2.2.4 Energy storage system information 4.2.2.6 Battery general aspects 4.2.10.1 Product and manufacturer information	The guidelines for determining allowable battery chemistries.	A hazardous substance ban could apply to product components beyond the battery, though monitoring and enforcement is difficult in most markets.
Cable specifications	4.2.10.1 Product and manufacturer information 4.2.10.3 Third-party marks and certifications	The guidelines for determining if outdoor cables have acceptable safety approval marks and certifications.	Self-certification marks are not necessarily meaningful if no market oversight exists.
Circuit and overload protection, PV overvoltage protection, and miswiring protection	4.2.7.3 Circuit and overload protection	The required success rate and number of samples required for each protection test.	Failure allowance should consider Boolean nature of results, while sample number should consider the fact that each test is destructive.

5.4.4.3.2 Water exposure protection considerations

The specifying organization should consider several factors when establishing water exposure protection requirements for solar lighting products. The product category (as outlined in 4.1.2) is primarily responsible for determining these requirements, as some products are more likely than others to be exposed to water based on the product design. Cost is also a consideration, as products designed to be resistant to higher levels of water exposure are often more expensive because of the additional manufacturing costs associated with sealing the enclosure or internal circuit elements.

Table 10 describes how various levels of water protection are determined based on a combination of laboratory test results, product design and manufacturing information, and consumer information. The levels of protection are:

- No protection
- Occasional rain
- Frequent rain
- Permanent outdoor exposure
- Permanent exposure in context of rooftop installation for PV modules

The results of an assessment will include several "types" of water protection level. A quality standard will need to specify which type is applicable. The types are:

- Overall protection: water protection by all the potential sources, including user behaviour
- Technical protection: protection from all product design and manufacturing aspects

- Enclosure-only protection: protection from the enclosure only

Table 10 – Recommended level of water protection by product category

Product category	Recommended level of water protection	Remarks
Fixed separate (indoor)	No protection	Products intended for indoor use are unlikely to be exposed to water and do not require water protection.
Portable separate	Occasional rain	Portable products can experience occasional water exposure in service and should have some degree of water protection.
Portable integrated	Frequent rain	Portable integrated products are likely to be exposed to water when left outside to solar charge and should have good water exposure protection.
Fixed integrated (outdoor)	Permanent outdoor exposure	Outdoor products are certain to be exposed to rain and should have a high degree of water exposure protection.
External PV module	Permanent rooftop installation for PV modules	External PV modules are certain to be exposed to rain, and any sensitive electronics should have a high degree of water exposure protection.

5.4.4.4 End user support

End user support criteria describe the information (labelling, instructions, and built-in indicators) that enables end users to maintain and fully realize the potential of a device (Table 11).

Table 11 – End user support criteria for quality standards

End user support criterion	Aspect(s) considered in assessment	Standard specification	Remarks
Information on product design, utilization, and care	4.2.2.7 Packaging and user's manual information	Requirements for end user information.	Define if there are requirements for consumer-facing information on packaging or in a user's manual. In some cases, a specific piece of information has implications for the required level of quality in another criterion (e.g. advising the user to protect the device from exposure to water on the packaging or in the user's manual may warrant a reduction in the requirements for water protection defined by 4.2.3.1 and 4.2.3.2).
Other	4.2.2.11 Other visual screening results	Requirements for particular aspects of the visual screening.	Define if there are requirements for other aspects of end user support (e.g. indicator lights). As with requirements for consumer-facing information, these requirements should be added with care to avoid over-prescribing.

5.4.5 Warranty requirements criteria

Warranty requirements are generally narrow in scope, focusing on the minimum duration and coverage for product warranties. In situations where there is a specific need for service in a particular location, service capabilities may be added to the warranty requirements. Table 12 lists criteria that are included in a warranty standard.

Table 12 – Criteria for warranty standards

End user support criterion	Aspect(s) considered in assessment	Standard specification	Notes
Maintenance and warranty terms	4.2.2.8 Warranty information	Minimum warranty duration and coverage.	Define the minimum warranty terms with consideration for the implications on availability of service and reasonable expectations for guaranteed lifetime.
Service capabilities	4.2.10.2 Warranty coverage	Minimum availability of service to end users in a particular location	These requirements are very specific to "local" projects typically.

6 Quality test method

6.1 General

The quality test method (QTM) is a rigorous set of tests with a relatively large sample size that uses randomly procured samples. It is the most stringent set of tests in this document and is appropriate for:

- qualification for market support programmes, and
- generating information for third-party verified specification sheets.

The QTM is appropriate for all products, though the sample size varies depending on the rated power of the product (peak PV power, or other input power for non-solar products). In this document, products with peak PV power smaller than or equal to 10 W are referred to as "size A," while products larger than 10 W are referred to as "size B," unless otherwise defined in the product specification.

The required testing also varies depending on the design of the product. For instance, products with ports, such as DC power outlets, sockets, jacks, receptacles and USB charging ports, are subject to tests that simpler lanterns are not.

6.2 Applications

QTM tests can support a broad range of quality assurance needs where rigorous, unbiased test results are required. Table 13 lists examples of how they are applied depending on the type of quality assurance framework.

Table 13 – Applications of QTM results

Type of QA framework	Example(s) of applying Clause 6
General market support	Require QTM results for qualifying for market support. Accept QTM results from any accredited laboratory. Use QTM results to produce standardized specification sheets.
Manufacturing/ distribution	Use QTM results to assess the full production/supply chain. Require QTM results for assessing potential business partners. Accept QTM results from any accredited laboratory.
Bulk procurement	Require QTM results for assessing potential suppliers. Accept QTM results from any accredited laboratory.
Trade regulation	Require QTM results for trade policies such as tax exemption or importation requirements. Accept QTM results from any accredited laboratory.

6.3 Sampling requirements

The product samples should be selected and shipped to the test lab according to the random sampling guidelines outlined in Annex E.

The recommended number of samples to procure for QTM testing for size A products is 18: six each for two parallel batches plus six spares.

The recommended number of samples to procure for QTM testing for size B is 12: four each for two parallel batches and four spares that can be used for potentially destructive tests. If batteries are required during the lumen maintenance test, an additional 4 batteries shall be provided or procured, but these batteries need not be randomly sampled.

To minimize the in-kind cost of products and shipping costs for larger products, an alternative to sampling 12 complete kits is to sample the following numbers of individual components, along with the packaging for the kit. Similar numbers can be determined for size A products if necessary, based on the same logic described below. The recommended numbers of samples of each individual component to procure for QTM testing are as follows:

- PV module: 9 (4 for general testing, 1 for IP testing and 4 spares. If modules meet all requirements of the IEC 61215 series, only 5 samples are required – 4 to test charging functionality and provide connectors for the solar charge test, and 1 spare. If modules referencing IEC 61215 data shall also undergo strain relief testing, an additional 4 samples should be collected.)
- PV mounting material, if applicable: 1 (for IP testing).
- Control box with battery: 12 (4 for general testing, 4 for lumen maintenance/battery durability and 4 spares). If batteries are required during the lumen maintenance test, an additional 4 batteries shall be obtained, but these batteries need not be randomly sampled.
- Included lighting appliances: 9 of each type, plus an additional four multiplied by the number of that light type that are included in the kit.

EXAMPLE If a product includes five light points, three of Type A and two of Type B, select 21 samples of Type A and 17 samples of Type B. If a product only includes one of each light type, select 13 samples of each type (4 for general testing, 4 for lumen maintenance, 1 for IP testing and 4 spares).

- Included non-lighting appliances (or lighting appliances that are not required to undergo the lighting tests): 9 of each type (4 for general testing, 1 for IP testing and 4 spares).
- Included lighting appliance with its own battery: 13 of each type (4 for general testing, 4 for lumen maintenance, 1 for IP testing and 4 spares).

These recommendations assume that 4 spares are sufficient to conduct the potentially destructive tests, such as the drop test, miswiring test, output overvoltage protection, PV overvoltage protection, and switches/connectors test. If additional samples are required, they may be procured during the testing process.

6.4 Laboratory requirements

The test laboratory should be properly trained to undertake the test methods described below and accredited by a recognized accrediting body (e.g. an ILAC MRA signatory, to ISO/IEC 17025). The measurement equipment should be calibrated against reference instruments annually, or as directed by the equipment manufacturer or laboratory accreditation organization.

6.5 Testing requirements

Table 14 lists the test procedures that should be conducted on each product, along with the sample size required and applicability to specific product types or components. As indicated in the table, sample sizes for most QTM tests of Size A products is 6, while sample sizes for most QTM tests of Size B products is 4. In Table 14, the designation "all products" indicates that the aspect should be measured for all types of products, including components or appliances, unless otherwise indicated. The product specification may define categories of components or appliances that need not be subjected to certain tests.

The table is organized in order of the aspects described in 4.2 and notes which aspects are measured by a given test. It is not necessary that each aspect be measured on each sample under test, but it is important to note in the test results which samples were the source of each result in an unambiguous way.

For products with multiple settings, at least one set of test results should fully characterize the performance on the highest light output setting. Additional settings may be measured at the discretion of the test laboratory to verify truth in advertising statements from the manufacturer when other light settings are advertised, or as required in the product specification.

NOTE Table 14 includes columns with requirements for the initial screening method (ISM) and market check method (MCM) primary check testing (PCT) and includes comments regarding accelerated verification method testing and renewal testing. These tests are described in Clauses 7, 8 and 9. An additional method is described in Clause 10 for testing pay-as-you-go (PAYG) products, but sample sizes and requirements are given in Table 19.

Table 14 – QTM testing requirements

Test	Aspect Reference(s)	Applicability	Sample size				Test method Annex	Comments
			QTM (Size A)	QTM (Size B)	PCT[a] (n=2)	ISM (n=1)		
Product design, manufacture, and marketing aspects	**4.2.2**							
Visual screening – Properties, features and information; Specifications	4.2.2.1, 4.2.2.2, 4.2.2.3, 4.2.2.4, 4.2.2.5, 4.2.2.6, 4.2.2.7, 4.2.2.8, 4.2.2.9, 4.2.2.10, 4.2.2.11	All products	1	1	1	1	Annex F	The visual screening should be done before any other tests and before the samples are altered to prepare them for other tests.
Product durability and workmanship aspects	**4.2.3**							
Water ingress protection test and level of water protection	4.2.3.1, 4.2.3.2 4.2.3.3, 4.2.3.4	All products	1	1	1	1	Annex U, Annex V	Physical and water ingress protection shall be assessed on samples that have the least amount of impact or adulteration from the testing process. Unused spares should be the preferred samples for this assessment. The assessment of a technical level of water protection – circuit protection and drainage is only conducted at the request of the testing client. It is best to save destructive testing to the end of the test programme to ensure sufficient samples are available in other tests. These tests may be performed on spare samples or samples that have finished all other testing.
Physical ingress protection test	4.2.3.5, 4.2.3.6	All products	1	1	1	1	Annex U	
Mechanical durability – Drop test	4.2.3.7	Portable components, excluding appliances such as TVs and other specified products or appliances that are not typically expected to meet durability standards	6	4	2	1	Annex W	In general, it is best to save destructive testing to the end of the test programme to ensure sufficient samples are available in other tests. These tests may be performed on spare samples or samples that have finished all other testing. It is preferable to do durability testing (switches, connectors, gooseneck/moving part, and drop test) on the "spare" samples that have not been altered for testing. However, it is often infeasible to accomplish this if the unadulterated spares are required for other tests and in the best case there will be five unadulterated spares out of the original 18 or 16. In this case, the "least modified" samples should be used. Note there are different drop test procedures for portable lighting products and non-lighting portable appliances (radios, razors, etc.).
Mechanical durability - Gooseneck and moving part test	4.2.3.8	Products with a gooseneck/ moving part	6	4	2	1	Annex W	See notes for drop test.

Test	Aspect Reference(s)	Applicability	Sample size				Test method Annex	Comments
			QTM (Size A)	QTM (Size B)	PCT[a] (n=2)	ISM (n=1)		
Mechanical durability - Connector test	4.2.3.9	All products	6	4	2	1	Annex W	See notes for drop test.
Mechanical durability - Switch test	4.2.3.10	All products	6	4	2	1	Annex W	See notes for drop test.
Mechanical durability - Strain relief test	4.2.3.11	All products	6	4	2	1	Annex W	See notes for drop test.
Visual screening – Functionality and internal inspection	4.2.3.12	All products	6	4	2	1	Annex F	The visual screening should be done before any other tests and before the samples are altered to prepare them for other tests. This portion of the visual screening is conducted on multiple samples.
Charge controller behaviour test	4.2.3.13	All products	6	4	2	1	Annex S	The deep-discharge protection charge controller measurement may be incorporated into the full-battery run time. The overcharge protection charge controller measurement requires independent testing, but is required to be conducted prior to the full-battery run time test for all battery chemistries except NiMH.
Lighting durability aspects	**4.2.4**							
Lumen maintenance test – 500 h	4.2.4.1	All products required to undergo lighting tests	-	-	2	1	Annex J	Samples shall not have undergone any other testing prior to lumen maintenance testing. This test is long-term and is carried out in parallel with general testing. The 500 h test is appropriate for Accelerated Verification Method – Verification Entry (AVM-VE), Initial Screening Method (ISM), and certain Market Check Method (MCM) tests, including those used to renew products' verification periods.
Lumen maintenance test – Alternate method using LM-80-08 data	4.2.4.2	All products required to undergo lighting tests	6	4	2	1	Annex J	Samples shall not have undergone any other testing prior to lumen maintenance testing. This test is long-term and is carried out in parallel with those tests undergoing general testing. The "alternate method using LM-80-08 data" is designed to shorten the time required to test a product prior to market entry and is offered as an alternative to the 2000 h test. There may be restrictions regarding which products are eligible to use this method.
Lumen maintenance test – 2 000 h	4.2.4.2	All products required to undergo lighting tests	6	4	-	-	Annex J	Samples shall not have undergone any other testing prior to lumen maintenance testing. This test is long-term and is carried out in parallel with those tests undergoing general testing. The 2 000 h test is used for Quality Test Method (QTM) tests, though may be waived if the "alternate method using LM-80-08 data" is conducted.

Test	Aspect Reference(s)	Applicability	Sample size				Test method Annex	Comments
			QTM (Size A)	QTM (Size B)	PCT[a] (n=2)	ISM (n=1)		
Fluorescent light durability	4.2.4.3	Products with fluorescent light required to undergo lighting tests	6	4	2	2	Cycling test of IEC TS 62257-12-1	If fluorescent lights are included with the product, these shall undergo additional checks of durability as described in IEC TS 62257-12-1.
Battery performance aspects	**4.2.5**							
Battery test – Battery capacity	4.2.5.1	All products	6	4	2	1	Annex K	The battery tests should be done before any system-level run time tests to ensure the batteries are "refreshed" from any time they spent in storage before testing. Recommended practices are presented in Annex L.
Battery test – Battery round-trip energy efficiency	4.2.5.2	All products	6	4	2	1	Annex K	See note for battery capacity.
Battery durability test	4.2.5.3	All products required to undergo lighting tests	6	4	2	1	Annex BB	While the lighting appliances of samples are connected to power supplies for the lumen maintenance test, the batteries of the same samples are tested for durability during storage. This test is long-term and is carried out in parallel with general testing.
Battery test – Battery nominal voltage	4.2.5.4	All products	6	4	2	1	Annex F	The nominal voltage is not a measured value. It is recorded in the visual screening.
Solar module aspects	**4.2.6**							
Photovoltaic module I-V characteristics test	4.2.6.1	All products	6	4	2	1	Annex Q	Since outdoor solar PV module testing is subject to the availability of a clear "solar window", this is often the most "opportunistic" test in the programme. Alternatives are described for using indoor test methods or results from an IEC 61215 test report. For amorphous solar modules, it is important to begin sun soaking the modules immediately after they are received, since at least 30 days of outdoor exposure are needed before the tests commence.
Visual screening – Cable length	4.2.6.2	All products	6	4	2	1	Annex F	Cable length is measured during the visual screening.
Electrical characteristics	**4.2.7**							
Appliance tests – Appliance operating voltage range test	4.2.7.1	All products with appliances	1	1	1	1	Annex FF, Annex EE	In general, it is best to save destructive testing to the end of the test programme to ensure sufficient samples are available in other tests. This test may be performed on spare samples or samples that have finished all other testing. The voltage range compatibility of included appliances is measured in either Annex FF or Annex EE at the discretion of the test lab.

Test	Aspect Reference(s)	Applicability	Sample size				Test method Annex	Comments
			QTM (Size A)	QTM (Size B)	PCT[a] (n=2)	ISM (n=1)		
Appliance tests – Power consumption test	4.2.7.2	All products with appliances	6	4	2	1	Annex FF, Annex EE, Annex M	The power consumption of included appliances is measured in Annex FF, while the power consumption of built-in appliances is measured in Annex EE. Built-in appliances or appliances with internal batteries that have undergone a full-battery run time test (Annex M) with no other appliance plugged in may waive the power consumption test and use the average power over the full-battery run time instead.
Protection tests – Output overload protection test	4.2.7.3	All products with ports; not required for appliances	1	1	1	1	Annex DD	This test assesses whether the DUT is protected against excessive load or short circuits applied to the appliance receptacles. The test is not dependent on any other tests, but is required to be conducted prior to the assessment of DC ports in Annex EE. The test is potentially destructive and should be conducted on either samples that have finished all other tests, or spare samples that are not required for any other tests.
Protection tests – PV overvoltage protection test	4.2.7.3	All products with ports; not required for appliances	1	1	1	1	Annex DD	This test assesses whether the DUT can withstand a PV overvoltage condition when the battery is disconnected. This test is conducted on only one sample and shall be conducted after performing the photovoltaic module I-V performance test (Annex Q). The test is potentially destructive and should be conducted either on samples that have finished all other tests, or on spare samples.
Protection tests – Miswiring protection test	4.2.7.3	All products with ports; not required for appliances	1	1	1	1	Annex DD	This test assesses whether the DUT is protected against improper wiring. The test is not dependent on any other tests, but is potentially destructive and should be conducted on either samples that have finished all other testing, or spare samples that are not required for any other tests.
Solar charge test	4.2.7.4	All products	6	4	2	1	Annex R	The battery-charging circuit efficiency and the solar charging efficiency is determined during the solar charge test. The solar charge test shall be commenced after the sample is fully discharged according to the full discharge preparation in Annex N.
Assessment of DC ports	4.2.7.5	All products with ports; not required for appliances	6	4	2	1	Annex EE	The ports test is dependent on the result of the output overload protection test described in Annex DD. The port efficiencies are inputs to the energy service calculations.
Appliance tests – Charging efficiency test	4.2.7.6	All appliances with internal batteries	6	4	2	1	Annex FF	This measures the efficiency that an appliance charges from the main unit.

Test	Aspect Reference(s)	Applicability	Sample size				Test method Annex	Comments
			QTM (Size A)	QTM (Size B)	PCT[a] (n=2)	ISM (n=1)		
Performance aspects	**4.2.8**							
Energy service calculations	4.2.8.2, 4.2.8.3, 4.2.8.4, 4.2.8.5	All products	6	4	2	1	Annex GG	The energy service calculations are used to estimate the system-level run time at a given utility level (e.g. lumens of light, or volume of radio play). The calculations use values from the battery test (Annex K), the solar charge test (Annex R), the assessment of DC ports (Annex EE), generic appliances (Annex HH), Appliance tests (Annex FF), and full-battery run time test (Annex M). All of these tests shall be conducted prior to finalizing the energy service calculations.
Full-battery run time test	4.2.8.6	All products	6	4	2	1	Annex M	Cycle the batteries (as is done in the battery capacity measurements) and fully charge them before this test. It is often convenient to do the full-battery run time test directly after the battery capacity measurements.
Appliance tests – Appliance full-battery run time	4.2.8.7	All appliances with internal batteries	6	4	2	1	Annex FF	See notes for full-battery run time test.
Grid-charge test	4.2.8.8	Grid charged products	6	4	2	1	Annex O	Grid charge testing shall be commenced after the sample is fully discharged according to the full discharge preparation in Annex N. The grid charge energy determined by the grid charge test is used to determine the grid run time in Annex GG.
Electromechanical charge test	4.2.8.9	Electro-mechanically charged products	6	4	2	1	Annex P	Electromechanical charge testing shall be commenced after the sample is fully discharged according to the full discharge preparation in Annex N. The electromechanical charge power or energy value determined by the electromechanical charge test is used to determine the electromechanical charging ratio in Annex GG.
Charge controller behaviour test – Standby loss measurement	4.2.8.10	All products	6	4	2	1	Annex S	The standby loss measurement may be conducted independently of other charge controller tests.
Light output aspects	**4.2.9**							
Light output test	4.2.9.1	All products required to undergo lighting tests	6	4	2	1	Annex I	The light output test is not strictly on components, but of a system including a driver, light source, and optical components. However, the system may be treated as a single component if it is separable from the other main components while maintaining the same electrical and thermal characteristics that are present when the product is fully assembled. The light output test procedure should be done after the full-battery run time test and is presented in Annex I.

Test	Aspect Reference(s)	Applicability	Sample size				Test method Annex	Comments
			QTM (Size A)	QTM (Size B)	PCT[a] (n=2)	ISM (n=1)		
Light distribution test – Full width half maximum (FWHM) angles	4.2.9.2	All products required to undergo lighting tests	1	1	1	1	Annex T	Like the light output test, the light distribution test is not strictly on components, but of a system including a driver, light source, and optical components. However, the system may be treated as a single component if it is separable from the other main components while maintaining the same electrical and thermal characteristics that are present when the product is fully assembled. The light distribution test procedure should be done after the full-battery run time test.
Light distribution test – Average light distribution characteristics	4.2.9.3	Only required at request of specification	-	-	-	-	Annex T	If this test is requested, it may be performed on a single sample, unless otherwise specified.
Light output test – Colour characteristics	4.2.9.4	All products required to undergo lighting tests	6	4	2	1	Annex I	The CCT and CRI are collected as part of the light output test.
Self-certification aspects	**4.2.10**							
Manufacturer self-reported information	4.2.10.1, 4.2.10.2, 4.2.10.3	All products	n/a	n/a	n/a	n/a	Annex D	If it has not already been done, the manufacturer (or their proxy) should be contacted to ask for self-certification information that is outlined in Annex D and to inform them the test samples were received.
Manufacturer self-reported information – PAYG manufacturer declaration	4.2.10.4	All products with PAYG functionality	n/a	n/a	n/a	n/a	Annex D	

[a] The MCM primary check test (PCT) is typically conducted with a sample size of two (n=2). A common use of the PCT is to renew QTM results at the end of the specified verification period using samples selected randomly from the manufacturer's warehouse according to the procedures in Annex EE. See Clause 7 for more details. The requirements of the PCT may also be used for the 2-sample version of the AVM-VE test, though the random sampling requirement is waived. See Clause 9 for more details.

6.6 Recommended tests programme

6.6.1 General

The following programme, illustrated in Figure 6, is one strategy to accomplish all the tests in a timely manner for products that do not have ports. Figure 7 illustrates a strategy to complete all the required tests for products with ports. If conducting the ports test and energy service calculations, the assessment of DC ports and appliance power consumption tests should be conducted after the charge controller behaviour tests and before the miswiring and PV overvoltage tests. The results from the tests in "Group A" will be used in the energy service calculations.

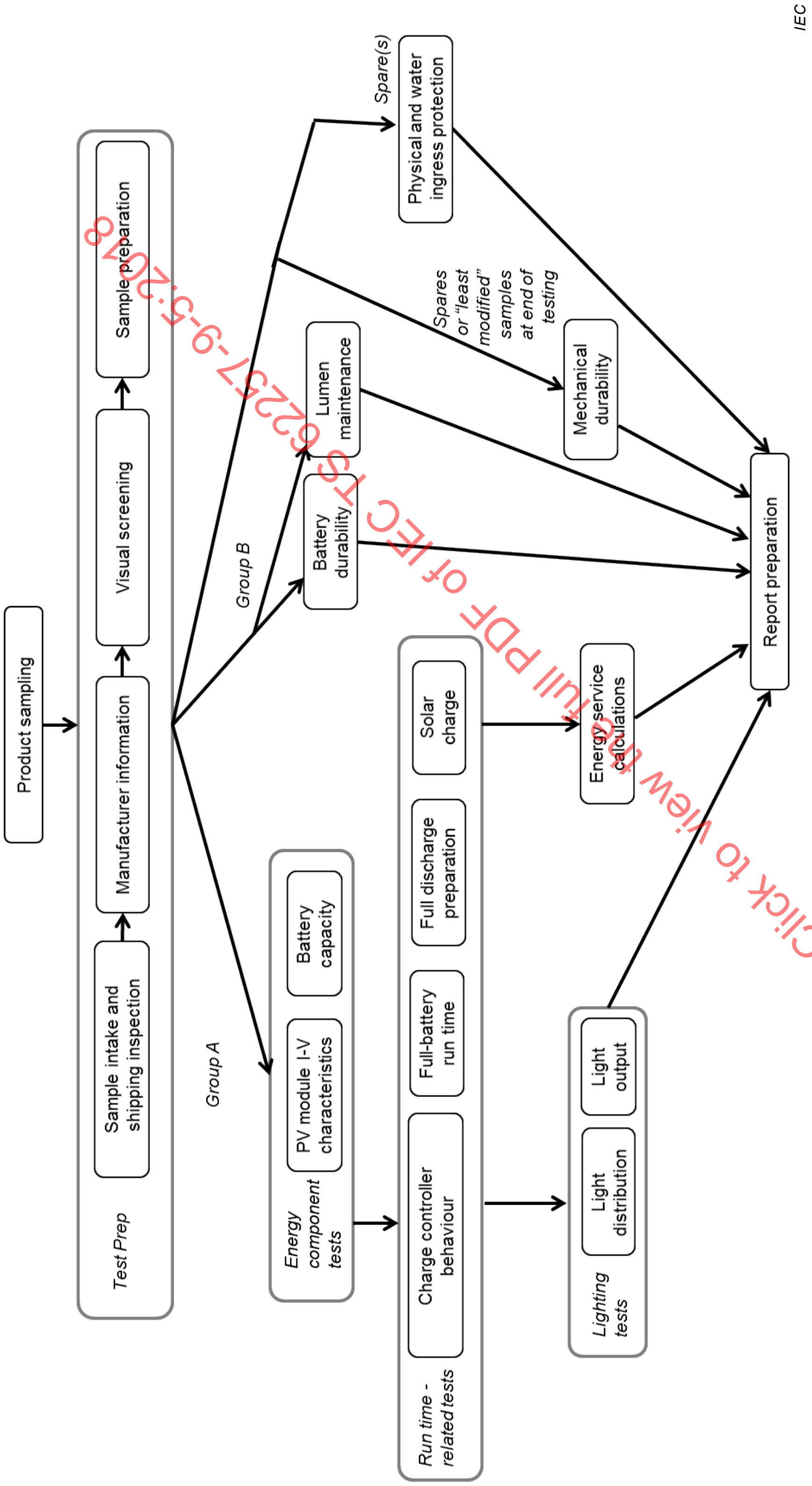


Figure 6 – Recommended sequence of testing for QTM for products without ports

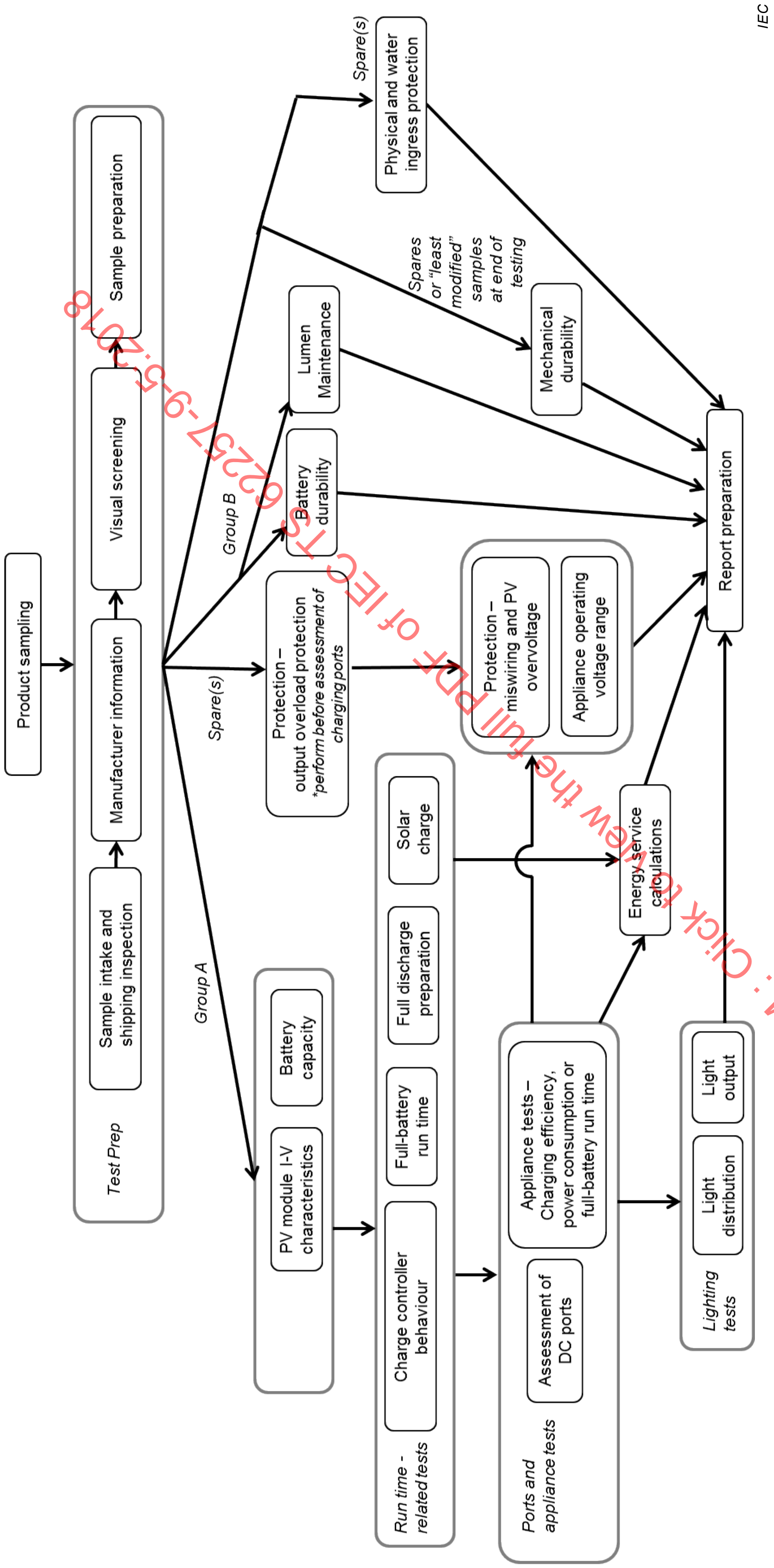


Figure 7 – Recommended sequence of testing for QTM for products with ports

6.6.2 Test preparation

The initial intake steps involve ensuring the samples are intact, preparing them for further tests, and requesting self-certification information from the manufacturer. As shown in Figure 6 and Figure 7, the tests included in a specific batch may differ from what is described below depending on the testing requirements. Initial steps required for all products include:

- Conduct test sample intake and shipping inspection: the samples should all be inspected for shipping damage, unambiguously labelled for identification during the testing process, and placed into batches.
- Solicit and record manufacturer self-reported information and self-certification aspects.
- Conduct the visual screening tests.
- Prepare samples for further testing. Many samples will require partial disassembly to provide easy access to various components. Sample preparation procedures are presented in Annex G. All samples, except for spares, shall be prepared.

6.6.3 Batch A tests

As shown in Figure 6 and Figure 7, it is recommended that tests be conducted in batches to minimize the time required for testing. Typically, Batch A undergoes the main set of tests in approximately the following order:

- Energy component tests:
  – Battery test
  – Photovoltaic module I-V characteristics test
- Run time tests:
  – Full-battery run time test(s)
  – Charge controller behaviour test
  – Full discharge preparation
  – Solar charge test, grid charge test, and/or electromechanical charge test
- Lighting tests:
  – Light output test
  – Light distribution test
- Energy service tests:
  – Ports test (if applicable)
  – Appliance power consumption test (if applicable)
  – Appliance charging efficiency tests (if applicable)
  – Appliance full-battery run time tests (if applicable)
  – Energy service calculations

6.6.4 Batch B tests

Batch B undergoes long-term lumen maintenance testing and the battery durability test in parallel with Batch A testing.

6.6.5 Batch C – potentially destructive tests

In general, it is best to save destructive testing to the end of the test programme to ensure sufficient samples are available in other tests. The only exception is the output overload protection test, which is performed before the ports test for products with ports. Potentially destructive tests may be performed on spare samples or batch A or B samples that have finished all other testing. Most potentially destructive tests are performed on only one sample, though the mechanical durability tests are performed on multiple samples. The following tests are to be performed:

- Physical and water ingress protection tests
- Mechanical durability tests (if applicable):
  - Switch and connector test
  - Gooseneck/moving part test
  - Strain relief test
  - Drop test
- Circuit protection tests (if applicable):
  - Output overload protection test
  - Miswiring protection test
  - PV overvoltage protection test
- Appliance voltage range test (if applicable)

6.6.6 Report preparation

After testing is complete and the results are validated, a report is generated and checked for accuracy before submission to the client.

6.7 Reporting

The report for QTM testing should support any activities that depend on the information from QTM testing.

At a minimum, the report should include the following elements.

a) Informative cover page.

b) Summary page(s).

c) Detailed test reports that include results for the aspects described in 6.5 that were measured at the primary test lab. Required results are listed at the end of each annex.

d) Detailed test reports for tests performed at other labs (e.g. ingress protection test results done at a specialty IP test lab).

e) Annexes that include supplementary images and/or other supporting information.

f) Annexes that indicate manufacturer-provided information and self-certification evidence (e.g. certificates of compliance).

7 Market check method

7.1 General

The market check method (MCM) is a flexible set of tests that is designed for market monitoring and enforcement. The MCM may comprise all the QTM tests, or a targeted subset of the QTM tests. The tests are designed for use in the following situations:

- when a program wants to monitor the on-going quality and performance of previously tested products;
- when there is suspicion that products on the market are substandard compared to those that were originally tested for programme qualification or the production of a standardized specification sheet;
- when a product is partially updated and an update is required for a standardized specification sheet.

MCM testing may be implemented as a two-stage process. In the first stage, which is referred to as a primary check test (PCT), the initial screening method (ISM) described in Clause 8 is used with a sample size between two to six, though products are randomly sampled as outlined in Annex E. A typical primary check test will use a sample size of two.

If results from these tests meet or exceed performance from prior QTM testing, no further action is required. However, if the results indicate possible deficiencies relative to the product specification and/or prior QTM test results, additional testing may be used to confirm the problem. This subsequent testing, which is referred to as secondary check testing, will focus only on the aspects of the product that appeared to have deficiencies according to the primary check testing results. The required sample size and allowable test classes for secondary check testing using the MCM should be the same as those required for QTM testing of the same aspect (see 6.5).

Alternatively, if a product is partially updated or only suspected to be substandard in particular aspects, a program may choose to forego the first stage of primary check testing and conduct targeted secondary check testing on only those aspects.

7.2 Applications

MCM tests may have a narrower focus than QTM tests – they may be targeted for determining if a deviation has occurred from previous QTM results for particular aspects. Table 15 lists examples of how MCM tests are applied depending on the type of quality assurance framework.

Table 15 – Applications of MCM results

Type of QA framework	Example(s) of applying MCM testing
General market support	Use MCM results for market monitoring and enforcement. Use MCM results to update standardized specification sheets. Use MCM results to renew QTM test results.
Manufacturing/distribution	Use MCM results for market monitoring.
Bulk procurement	n/a
Trade regulation	Use MCM results for market monitoring and enforcement.

7.3 Sampling requirements

The test samples should be randomly procured from retail outlets in the market according to procedures in Annex E. In select cases, such as renewal of QTM results, samples may be randomly selected from a manufacturer's warehouse according to procedures in Annex E.

Enough samples should be provided or selected so it is possible to complete the tests in a timely manner and account for unforeseen needs of additional samples.

The recommended number of samples for primary check testing is seven: two per batch plus three spares. Two additional samples are recommended if the product has ports. The recommended number of samples for secondary check testing will depend on the aspects under test, but may be up to 18: six per batch plus adequate spares.

To minimize the in-kind cost of products and shipping costs for larger products, an alternative to sampling complete kits is to sample the following numbers of individual components, along with the packaging for the kit. The recommended numbers of samples of each individual component to procure for MCM testing are as follows:

- PV module: 5 (2 for general testing, 1 for IP testing and 2 spares. If modules meet all requirements of IEC 61215 (all parts), only 3 samples are required – 2 to test charging functionality and provide connectors for the solar charge test, and 1 spare. If modules referencing IEC 61215 data shall also undergo strain relief testing, an additional 2 samples should be collected.)

- PV mounting material, if applicable: 1 (for IP testing).
- Control box with battery: 7 to 9 (2 for general testing, 2 for lumen maintenance/battery durability and 3 spares). Two additional samples are recommended if the product has ports. If batteries are required during the lumen maintenance test, an additional 2 batteries shall be provided or procured, but these batteries need not be randomly sampled.
- Included lighting appliances: 5 of each type, plus an additional two multiplied by the number of that light type that are included in the kit. For instance, if a product includes five light points, three of Type A and two of Type B, select 11 samples of Type A and 9 samples of Type B. If a product only includes one of each light type, select 7 samples of each type (2 for general testing, 2 for lumen maintenance, 1 for IP testing and 2 spares).
- Included non-lighting appliances (or lighting appliances that are not required to undergo the lighting tests): 5 of each type (2 for general testing, 1 for IP testing and 2 spares).
- Included lighting appliance with its own battery: 7 of each type (2 for general testing, 2 for lumen maintenance/battery durability, 1 for IP testing and 2 spares).

These recommendations assume that the spares are sufficient to conduct the potentially destructive tests, such as the drop test, miswiring test, output overvoltage protection, PV overvoltage protection, and switches/connectors test. If additional samples are required, they may be procured during the testing process.

7.4 Laboratory requirements

The test laboratory should be properly trained to undertake the test methods described below and accredited by a recognized accrediting body (e.g. an ILAC MRA signatory, to ISO/IEC 17025). The measurement equipment should be calibrated against reference instruments annually, or as directed by the equipment manufacturer or laboratory accreditation organization.

7.5 Testing requirements

Most of the specific test requirements for MCM tests will depend on the aspects that are being tested.

The particular test plan for MCM testing is case-dependent and up to the judgement of the organization or institution who initiates the testing. The following recommendations should be kept in mind when creating MCM test plans.

- Always include a visual screening test to uncover any unexpected changes to the product; be ready to augment the original test plan pending the visual screening results.
- Consider system-level impacts of component changes.

7.6 Recommended tests programme

See 6.6.

7.7 Report requirements

The report for MCM testing should support any activities that depend on the information from MCM testing. See 6.7 for minimum reporting requirements, though report should cover aspects described in 7.5.

8 Initial screening method

8.1 General

The initial screening method (ISM) is appropriate for preliminary testing and providing quick feedback on product design and performance in absolute terms.

8.2 Applications

ISM tests should be used for obtaining quick, preliminary results to help inform subsequent rounds of testing that confirm the preliminary results. Table 16 lists examples of how they are applied depending on the type of quality assurance framework.

Table 16 – Applications of ISM results

Type of QA framework	Example(s) of applying Clause 8
General market support	Use ISM results to filter potential organizations/products for targeted support, followed up by QTM testing for those with promise. Use ISM results to trigger MCM testing when there is suspicion of a change in the quality or performance or products in the market.
Manufacturing/distribution	Use ISM results for batch-to-batch monitoring of production runs of shipments.
Bulk procurement	Use ISM results for batch-to-batch monitoring shipments.
Trade regulation	Use ISM results to make preliminary decisions, followed up with QTM testing to confirm results.

8.3 Sampling requirements

The test samples may be provided directly by a manufacturer (or their proxy) or may be randomly procured from the market according to procedures in Annex E.

Enough samples should be provided or selected so it is possible to complete the tests in a timely manner and account for unforeseen needs of additional samples.

The recommended number of samples for ISM testing is three: one each for two parallel batches and one spare. An additional sample is recommended if the product has ports. It may be necessary to obtain additional spares if the product fails more than one of the potentially destructive tests.

To minimize the in-kind cost of products and shipping costs for larger products, an alternative to sampling complete kits is to sample the following numbers of individual components, along with the packaging for the kit. The recommended numbers of samples of each individual component to procure for ISM testing are as follows:

- PV module: 3 (1 for general testing, 1 for IP testing and 1 spare. If modules meet all requirements of IEC 61215 (all parts), only 2 samples are required – 1 to test charging functionality and provide connectors for the solar charge test, and 1 spare. If modules referencing IEC 61215 data shall also undergo strain relief testing, an additional sample should be collected.)
- PV mounting material, if applicable: 1 (1 for IP testing).
- Control box with battery: 3 (1 for general testing, 1 for lumen maintenance/battery durability testing and 1 spare). If batteries are required during the lumen maintenance test, an additional battery shall be provided or procured, but these batteries need not be randomly sampled.
- Included lighting appliances: 3 of each type, plus an additional one multiplied by the number of that light type that are included in the kit. For instance, if a product includes five light points, three of Type A and two of Type B, select 6 samples of Type A and 5 samples

of Type B. If a product only includes one of each light type, select 4 samples of each type (1 for general testing, 1 for lumen maintenance, 1 for IP testing and 1 spare).

- Included non-lighting appliances (or lighting appliances that are not required to undergo the lighting tests): 3 of each type (1 for general testing, 1 for IP testing and 1 spare).
- Included lighting appliance with its own battery: 4 of each type (1 for general testing, 1 for lumen maintenance, 1 for IP testing and 1 spare).

These recommendations assume that 1 spare is sufficient to conduct the potentially destructive tests, such as the drop test, miswiring test, output overvoltage protection, PV overvoltage protection, and switches/connectors test. If additional samples are required, they may be procured during the testing process.

8.4 Laboratory requirements

The test laboratory should be properly trained to undertake the test methods described below. The measurement equipment should be calibrated against reference instruments annually, or as directed by the equipment manufacturer.

8.5 Testing requirements

As indicated in Table 14, each of the aspects listed in the ISM column should be measured where they are applicable to a product. It is not necessary that each aspect be measured on each sample under test, but it is important to note in the test results which samples were the source of each result in an unambiguous way. A general description of the test method family for each aspect is listed for informative purposes only. In Table 14, the designation "all products" indicates that the aspect should be measured for all types of products, including components or appliances, unless otherwise indicated. The product specification may define categories of components or appliances that need not be subjected to certain tests.

For products with multiple settings, at least one set of test results should fully characterize the performance on the highest light output setting. Additional settings may be measured at the discretion of the test laboratory to verify advertising statements from the manufacturer when other light settings are advertised, or as required in the product specification.

8.6 Recommended tests programme

See 6.6.

8.7 Reporting

The report for ISM testing should support any activities that depend on the information from ISM testing. See 6.7 for minimum reporting requirements, though report should cover aspects described in 8.5.

9 Accelerated verification method

9.1 General

The accelerated verification method (AVM) is an optional pathway to enable expedited entry to markets or market support programmes. The AVM includes a 2-step process of a verification entry (AVM-VE) test and follow-up test. Results from AVM-VE testing may qualify a product for market support until the results are verified through a randomly sampled follow-up test. It is recommended that this pathway only be offered to manufacturers who meet specified eligibility criteria. The three elements of the AVM – eligibility criteria, verification entry testing, and follow-up testing – are described below:

- Eligibility based on a manufacturer’s experience and historical performance with the off-grid lighting market support programme. Recommended eligibility criteria should consider the number of products that a manufacturer has successfully tested with the programme, any recent instances in which the manufacturer's products were tested and did not meet the quality standards, as well as the manufacturer's conduct in the market and communication with the market support programme.

- AVM-VE testing can be equivalent to one of the following. When arranging for AVM-VE testing, the market support programme should include a mechanism to cover the cost of follow-up testing and associated administrative costs.
  - ISM test with a sample size of two (n=2) with product samples provided directly from the manufacturer;
  - QTM test with a sample size of six (n=6), with the random sampling requirement of QTM testing waived.
- Follow-up testing conducted shortly after AVM-VE testing is finished and the product is commercially available in markets. The sample size of the follow-up test is determined by the sample size of the AVM-VE test, as described in 9.3.3. Poor performance in follow-up tests may be accompanied by penalties enacted by the market support programme to incentivize compliance. Recommended penalties include loss of programme support, loss of eligibility to use the AVM pathway and monetary penalties.

9.2 Applications

The AVM pathway is only recommended for manufacturers who meet specified eligibility criteria and for products that are reasonably expected to meet the rigors of the QTM test. The AVM enables these select products to undergo initial, expedited testing with samples that are representative of the products the manufacturer plans to distribute, but are not necessarily from a full production run. Table 17 lists examples of how AVM tests are applied depending on the type of quality assurance framework.

Table 17 – Applications of AVM results

Type of QA framework	Example(s) of applying AVM testing
General market support	Require AVM-VE test results for qualifying for temporary market support. Use follow-up test results to continue market support. Accept AVM results from any accredited laboratory. Use AVM-VE test results to produce standardized specification sheets. Update these standardized specification sheets with results from the follow-up test.
Manufacturing/distribution	Use AVM-VE test and follow-up test results to assess the full production/supply chain. Require AVM-VE test and follow-up test for assessing potential business partners. Accept AVM results from any accredited laboratory.
Bulk procurement	Require AVM-VE test and follow-up tests for assessing potential suppliers. Accept AVM results from any accredited laboratory.
Trade regulation	Require AVM-VE test and follow-up test results for trade policies such as tax exemption or importation requirements. Accept AVM results from any accredited laboratory.

9.3 Sampling requirements

9.3.1 General

Testing for the AVM is segmented into two parts: AVM-VE testing and follow-up testing.

9.3.2 Verification entry testing

The test samples for AVM-VE testing may be provided directly by a manufacturer (or their proxy) or may be randomly procured from the market according to procedures in Annex E.

The manufacturer shall provide a declaration to accompany the products which states: "a) the samples provided for testing are an accurate representation of the final production model that they plan to distribute, and b) the product is expected to meet the quality standards of the off-grid lighting market support programme." The off-grid lighting market support programme may also require the manufacturer to submit documentation to assist with follow-up testing and routine market check testing. Documentation may include, but is not limited to:

- an annual report listing the main markets in which their quality-verified products are being sold, differentiated by product model name,
- the names and contact details of the principal distributors to whom they sell their products,
- annual shipment figures (for the previous year) of quality-verified products, and
- the intended markets and distributors that will be used for the product under test.

Enough samples should be provided or selected so it is possible to complete the tests in a timely manner and account for unforeseen needs of additional samples.

AVM-VE tests can either be equivalent to an ISM test with a sample size of two or equivalent to a QTM test with a sample size of six, with the random sampling requirement of QTM testing waived.

If a sample size of two is used, the recommended number of samples for the AVM-VE testing is seven: two each for two parallel batches and three spares. An additional sample is recommended if the product has ports. See 7.3 for recommendations regarding sampling options for individual components.

If a sample size of six is used, the recommended number of samples for AVM-VE testing is 18: six each for two parallel batches and six spares. See 6.3 for recommendations regarding sampling options for individual components.

9.3.3 Follow-up testing

The test samples for follow-up testing should either be randomly procured from retail outlets in the market or randomly sampled from a manufacturer's warehouse according to procedures in Annex E.

Enough samples should be provided or selected so it is possible to complete the tests in a timely manner and account for unforeseen needs of additional samples.

- If the AVM-VE test for a product was conducted with a sample size of two, the follow-up test shall use a sample size of six, equivalent to a QTM. See 6.3 for sampling requirements.
- If the AVM-VE test for a product was conducted with a sample size of six, the follow-up test should use a sample size of two, equivalent to a typical market check method (MCM) primary check test (PCT). See 7.3 for sampling requirements.

9.4 Laboratory requirements

The test laboratory should be properly trained to undertake the test methods described below and accredited by a recognized accrediting body (e.g. an ILAC MRA signatory, to ISO/IEC 17025). The measurement equipment should be calibrated against reference instruments annually, or as directed by the equipment manufacturer or laboratory accreditation organization.

9.5 Testing requirements

9.5.1 General

Testing requirements for the AVM are segmented into two parts: AVM-VE testing and follow-up testing.

9.5.2 Verification entry testing

If the AVM-VE test for a product is conducted with a sample size of two, each of the aspects listed in the PCT column of Table 14 should be measured where they are applicable to a product. The list of tests is equivalent to that of the ISM, but all tests, aside from some select visual screening and IP assessments, are conducted with a sample size of two.

If the AVM-VE test for a product is conducted with a sample size of six, each of the aspects listed in the QTM (Size A) column of Table 14 should be measured where they are applicable to a product.

It is not necessary that each aspect be measured on each sample under test, but it is important to note in the test results which samples were the source of each result in an unambiguous way. A general description of the test method family for each aspect is listed for informative purposes only. In Table 14, the designation "all products" indicates that the aspect should be measured for all types of products, including components or appliances, unless otherwise indicated. The product specification may define categories of components or appliances that need not be subjected to certain tests.

For products with multiple settings, at least one set of test results should fully characterize the performance on the highest light output setting. Additional settings may be measured at the discretion of the test laboratory to verify truth in advertising statements from the manufacturer when other light settings are advertised, or as required in the product specification.

9.5.3 Follow-up QTM testing

If the AVM-VE test for a product was conducted with a sample size of two, the follow-up test shall be conducted with a sample size of six as described in 6.5. Each of the aspects listed in the QTM (Size A) column of Table 14 should be measured where they are applicable to a product.

If the AVM-VE test for a product was conducted with a sample size of six, the follow-up test should be conducted with a sample size of two. Each of the aspects listed in the PCT column of Table 14 should be measured where they are applicable to a product.

It is not necessary that each aspect be measured on each sample under test, but it is important to note in the test results which samples were the source of each result in an unambiguous way. A general description of the test method family for each aspect is listed for informative purposes only. In Table 14, the designation "all products" indicates that the aspect should be measured for all types of products, including components or appliances, unless otherwise indicated. The product specification may define categories of components or appliances that need not be subjected to certain tests.

For products with multiple settings, at least one set of test results should fully characterize the performance on the highest light output setting. Additional settings may be measured at the discretion of the test laboratory to verify truth in advertising statements from the manufacturer when other light settings are advertised, or as required in the product specification.

9.6 Recommended tests programme

See 6.6.

9.7 Report requirements

The report for AVM testing should support any activities that depend on the information from AVM testing. See 6.7 for minimum reporting requirements, though report should cover aspects described in 9.5.

10 Pay-as-you-go (PAYG) method

10.1 General

The pay-as-you-go (PAYG) method provides a set of targeted tests to verify key parameters that may be affected by adding PAYG or fee-for-service technology to a product. In some cases a product is sold in both a pay-as-you-go (PAYG) enabled version and a non-PAYG version. The provider of PAYG technology may be the same organization that designs and sells the energy system, or may be a third-party "business to business" provider of PAYG. In either case, targeted testing may be appropriate rather than requiring that all aspects of the otherwise similar product be retested. Targeted testing is composed of:

- Visual inspection, including internal assessment.
- Durability testing on any aspects that may have been impacted by the addition of the PAYG option (e.g., new ports or changes to the existing casing).
- An estimate of the parasitic consumption or additional standby loss due to the addition of the PAYG option.
- Submission of manufacturer declaration indicating that the performance of the PAYG enabled version is equivalent to that of the previously tested non-PAYG product.

10.2 Applications

The pay-as-you-go (PAYG) method is appropriate for targeted testing of fee-for-service or PAYG-enabled versions of products that previously qualified for market entry or market support programmes through the process of QTM or AVM testing. Fee-for-service or PAYG-enabled products that are not versions of an otherwise identical product that already meets a programme’s quality standards should be fully tested according to the QTM or AVM to qualify for market support programmes and/or produce a standardized specification sheet. In cases where PAYG-enabled versions of products are similar, but not identical to the previously-tested non-PAYG version, those aspects which differ shall be tested. Table 18 lists examples of how PAYG tests are applied depending on the type of quality assurance framework.

Table 18 – Applications of PAYG method results

Type of QA framework	Example(s) of applying PAYG testing
General market support	Require PAYG test results for qualifying for market support in cases where a non-PAYG version of the product already qualifies for market support. Accept PAYG results from any accredited laboratory. Use PAYG results to update standardized specification sheets to include the PAYG-enabled version of a product.
Manufacturing/distribution	Require PAYG for assessing potential business partners in cases where a non-PAYG version of the product has already been tested. Accept PAYG results from any accredited laboratory.
Bulk procurement	Require PAYG test results for qualification screening on bidders in procurements that will include a PAYG element, accepting a combination of non-PAYG and targeted PAYG testing as appropriate. Accept PAYG results from any accredited laboratory.
Trade regulation	Require PAYG test results for qualification screening on products that are subject to trade regulation, accepting a combination of non-PAYG and targeted PAYG testing as appropriate. Accept PAYG results from any accredited laboratory.

10.3 Sampling requirements

The test samples may be provided directly by a manufacturer (or their proxy) or may be randomly procured from the market according to procedures in Annex E.

Enough samples should be provided or selected so it is possible to complete the tests in a timely manner and account for unforeseen needs of additional samples.

The recommended number of samples for PAYG testing is four: two each for two parallel tests.

In cases where PAYG-enabled versions of products are similar, but not identical to the previously-tested non-PAYG version, those aspects which differ will require testing using samples that are procured according to the sampling requirements of the QTM or AVM.

10.4 Laboratory requirements

The test laboratory should be properly trained to undertake the test methods described below. The measurement equipment should be calibrated against reference instruments annually, or as directed by the equipment manufacturer.

10.5 Testing requirements

Each of the aspects listed in Table 19 should be measured where they are applicable to a product. It is not necessary that each aspect be measured on each sample under test, but it is important to note in the test results which samples were the source of each result in an unambiguous way. A general description of the test method family for each aspect is listed for informative purposes only. In Table 19, the designation "all products" indicates that the aspect should be measured for all types of products, including components or appliances, unless otherwise indicated.

In cases where PAYG-enabled versions of products are similar, but not identical to the previously-tested non-PAYG version, those aspects which differ shall be tested. For example, if a PAYG-version of a product includes an updated LED, the lighting and run time tests would need to be conducted with sample sizes appropriate for the QTM or AVM.

Table 19 – PAYG testing requirements

Test	Aspect Reference(s)	Applicability	Sample size	Test method Annex
Product design, manufacture, and marketing aspects	**4.2.2**			
Visual screening – Properties, features and information; Specifications	4.2.2.1, 4.2.2.2, 4.2.2.3, 4.2.2.4, 4.2.2.5, 4.2.2.6, 4.2.2.7, 4.2.2.8, 4.2.2.9, 4.2.2.10, 4.2.2.11	All products	1	Annex F
Product durability and workmanship aspects	**4.2.3**			
Water ingress protection test and level of water protection	4.2.3.1, 4.2.3.2 4.2.3.3, 4.2.3.4	All products if enclosure differs from originally tested product	2	Annex U, Annex V
Physical ingress protection – enclosure(s) and PV module	4.2.3.5, 4.2.3.6	All products if enclosure differs from originally tested product	2	Annex U
Mechanical durability – Drop test	4.2.3.7	Portable components, excluding TVs or other specified products or appliances that are not typically expected to meet durability standards if enclosure differs from originally tested product	2	Annex W
Mechanical durability -Gooseneck and moving part test	4.2.3.8	Products with a gooseneck/moving part if moving parts differ from originally tested product	2	Annex W
Mechanical durability -Connector test	4.2.3.9	All products if connectors differ from originally tested product	2	Annex W
Mechanical durability -Switch test	4.2.3.10	All products if switches differ from originally tested product	2	Annex W
Mechanical durability -Strain relief test	4.2.3.11	All products if cables differ from originally tested product	2	Annex W
Visual screening –Functionality and Internal Inspection	4.2.3.12	All products	2	Annex F
Performance aspects	**4.2.8**			
Charge controller behaviour test – Standby loss measurement	4.2.8.10	All products	2	Annex S
Self-certification aspects	**4.2.10**			
Manufacturer self-reported information	4.2.10.1,4.2.10.2, 4.2.10.3	All products	n/a	Annex D
PAYG manufacturer declaration	4.2.10.4	All products	n/a	Annex D

10.6 Recommended tests programme

See 6.6, though only applicable tests are required as described in 10.5.

10.7 Reporting

The report for PAYG testing should support any activities that depend on the information from PAYG testing. See 6.7 for minimum reporting requirements, though report should cover aspects described in 10.5.

Annex A
(informative)

Reserved

Annex A is reserved as a placeholder.

Annex B
(informative)

Reserved

Annex B is reserved as a placeholder.

Annex C
(informative)

Reserved

Annex C is reserved as a placeholder.

Annex D
(normative)

Manufacturer self-reported information

D.1 Background

Having proper manufacturer information is important for communication throughout the testing process as well as for understanding key product information and any certifications possessed by the manufacturer's facility or product. To this end, there are three categories of self-reported information: manufacturer information, product information, and manufacturer self-certification regarding either the manufacturing facility or the product. Additional information may be needed for products with pay-as-you-go or fee-for-service features.

D.2 Outcomes

The manufacturer self-reported information outcomes are listed in Table D.1.

Table D.1 – Manufacturer self-reported information outcomes

Metric	Reporting units	Related aspects	Notes
Manufacturer information	Varied	4.2.10.1 Product and manufacturer information	Record all provided manufacturer information
Product information	Varied	4.2.10.1 Product and manufacturer information	Record all provided product information
Self-certification information	Varied	4.2.10.3 Third-party marks and certifications	Record all manufacturer or product certifications

D.3 Solicited information

D.3.1 General

At a minimum, the information contained in D.3.2 and D.3.3 should be solicited from the manufacturer. At a minimum, report all items marked with an asterisk (*).

D.3.2 Confidential information (not released publicly)

D.3.2.1 Manufacturer information

The following confidential manufacturer information should be solicited:

a) manufacturer company name*;

b) contact person name*;

c) contact person position at company (i.e. job title)*;

d) manufacturer company physical address*;

e) contact telephone number(s)*;

f) contact e-mail address*.

If separate people manage contracting issues and technical testing questions, request contact information for both parties.

D.3.2.2 Product information

The following confidential product information should be solicited:

a) markets in which the product is for sale (e.g., Kenya, India, China);

b) free on board (FOB) product price for at least 1 000 units ($);

c) typical product shipping point of origin;

d) product driver type (e.g., resistor, pulse-width modulation);

e) if the driver uses PWM, request the PWM frequency and a description of when it operates;

f) PV charge control methods (series regulator, shunt regulator, PWM, MPPT, etc.)*;

g) if the charge controller uses PWM, request the PWM frequency and a description of when it operates;

h) list of battery protection and charge control methods (i.e., deep discharge protection and/or overcharge protection);

i) description of deep discharge charge control, including the low voltage disconnect threshold and individual cell protection for lithium-ion or lithium iron phosphate batteries with multiple cells (or parallel cellblocks) in series;

j) description of overcharge protection charge control, including the overcharge protection disconnect voltage and individual cell protection for lithium-ion or lithium iron phosphate batteries with multiple cells (or parallel cellblocks) in series;

k) battery information sheet from battery manufacturer, preferably showing acceptable deep discharge protection and overcharge protection cutoffs at a minimum;

l) whether the battery contains internal protection circuitry*;

m) whether the battery or product includes circuitry to monitor the voltage of or balance the individual battery cells, and if so, what type of circuitry is used and where it is located;

n) description of any special procedures necessary for the test lab to access the battery;

o) current limit used for overcurrent protection for the system*;

p) type of current protection used*;

q) list of other current protection limits if different overcurrent protection limits are used for individual outlets, inputs or appliances*;

r) USB charging modes supported*;

s) description of how USB charging modes are implemented;

t) whether the product or any of the included appliances are considered portable separate, and if so, how the manufacturer intends to meet water ingress protection requirements;

u) whether the product or any of the included appliances are considered portable integrated, and if so, how the manufacturer intends to meet water ingress protection requirements;

v) statement of how the manufacturer intends to meet requirements regarding outdoor cables (only required for Size B products as defined in 6.1);

w) whether the manufacturer prefers that the lumen maintenance be measured using the expedited method described in Clause J.6;

x) description of special testing considerations, such as any characteristics that would impede the testing process. Characteristics include: an auto-off function that turns the lights or appliances off after a specific number of hours of operation; the product disables if the enclosure is opened; the product connects to a wireless network; the product is tamperproof; the product enters a low-power (standby or sleep) mode after a delay longer than 5 min; the product would not be able to be disconnected from its battery and powered by a laboratory power supply for over 500 h;

y) expected/rated performance, including:

   1) name, light output, full battery run time, and solar run time for each setting for all appliances included with or advertised for use with the product*;

2) brightness setting specifications, if publicly advertised or provided to the laboratory by the manufacturer*;
3) rated power of any appliances included with the product*;
4) estimated battery capacity, battery type, full battery run time, solar run time, percentage of a full charged received from the power control unit when the power control unit is fully charged and when the power control unit has been charged for a standard solar day, for any appliances with their own batteries*;

z) the names of the settings the manufacturer would wish to be tested.

D.3.3 Public information (may be released publicly)

D.3.3.1 Manufacturer information

The following public manufacturer information should be solicited:

a) official customer facing/brand name*;
b) public manufacturer contact information if different from that collected in D.3.2.1*.

D.3.3.2 Product information

The following public product information should be solicited:

a) product name*;
b) product model number*;
c) all product lighting technologies used (e.g. fluorescent tube, LED). If the product uses LEDs, are the LEDs high-power or low-power?
d) battery chemistry (VRLA, NiMH, etc.)*;
e) battery package type*;
f) battery nominal voltage (V)*;
g) battery capacity (Ah)*;
h) charge/discharge rate at which the battery capacity is specified*;
i) all product charging system types (e.g. solar module, AC power, dynamo)*:
   1) if the product has AC power charging, whether an adapter is included;
   2) if the product has solar charging, the active PV material (e.g., mono-Si, poly-Si, CIS);
   3) if the product has solar charging, the peak power rating of the PV module(s) at STC;
j) all included product features (e.g. mobile device charging, radio)*;
k) if the product has mobile device charging, are adapters included?*
l) all optional product features (e.g. mobile device charging, radio)*;
m) description of any advertised capabilities to charge specific devices or provide specific USB charging modes*;
n) description of product warranty terms, including duration*;high resolution product photograph on a white or transparent background.

D.3.3.3 Manufacturer certifications

These certifications should be accompanied with supporting documentation, such as copies of the original certifications, letters from an appropriate organization, or self-certification.

a) all manufacturer company certifications and markings (e.g. ISO 9000, UL, CE);
b) all product certifications and markings (e.g. UV-resistant plastic, UV-free LEDs, high-temperature batteries);
c) all component-level certifications and markings (e.g. IEC 62133 for battery safety);

d) documentation of UN 38.3 testing and a description of individual cell protection measures for all Li-ion batteries included with the system;

e) manufacturer declaration regarding the adequate sizing of current carrying conductors used in the product (only required for Size B products as defined in 6.1);

f) manufacturer declaration that all cables intended to be used outdoors, such as cables connecting the PV module, are appropriately protected against UV radiation and water ingress (only required for Size B products as defined in 6.1);

g) confirmation of AC-DC charger approval from a recognized consumer electronics safety regulator, such as UL (if product includes an AC-DC charger)*;

h) if the expedited method described in Clause J.6 is requested, IESNA LM-80-08 data (minimum 6 000 h) from the LED manufacturer and a picture that shows where the temperature should be measured on the LED array.

D.3.3.4 Additional information for pay-as-you-go (PAYG) products

Testing products that include pay-as-you-go (PAYG) or fee-for-service features may require gathering additional information. The following information should be solicited:

a) quantities that are measured with the PAYG system (e.g. kWh, h);

b) quantities that are billed with the PAYG system (e.g. $/kWh, $/day);

c) the most common unit of sale (e.g. kWh, h);

d) internal software rules for enforcement mechanism (i.e. how does the product decide to restrict access to services in the case of non-payment?);

e) estimate of accuracy, precision and drift for enforcement mechanism;

f) statement regarding whether the PV module stays connected so that the product can still receive a charge if the enforcement mechanism is activated*;

g) statement regarding whether the charge control algorithm operates as normal if the enforcement mechanism is activated*;

h) description of the battery charged control and protection when the enforcement mechanism is activated*;

i) description of the payment transaction method;

j) description of the communication method for verifying payments;

k) statement whether the product is restricted to use on mobile phone networks and description of any restrictions;

l) description of software or hardware measures used to prevent tampering with or replacing the battery;

m) description of how these tamper-prevention features can be disabled for testing;

n) description of any additional items or actions needed to test the product in a lab in either Europe, the USA or China that is not otherwise described;

o) desired information to be displayed on a standardized specification sheet for the PAYG feature;

p) if the product is a PAYG version of a previously tested product, collect the following:

   1) product name and information for the previously tested product*;

   2) description of any performance differences, aside from the PAYG feature, between the two products (e.g. decreased run time, increased standby loss, etc.)*;

   3) description of any physical differences between the two products (e.g. additional port, keypad, etc.).*

D.4 Reporting

Report all items in Clause D.3 that are marked with an asterisk (*).

Annex E
(normative)

Product sampling

E.1 Background

Proper product sampling is the first step in the testing process, and it is critical to maintaining the test method's fairness and credibility.

E.2 Test outcomes

The product sampling outcomes are listed in Table E.1.

Table E.1 – Product sampling outcomes

Metric	Reporting units	Related aspects	Remarks
Sample type	Retail/warehouse	n/a	--
Sample procurement agency	Agency name	n/a	The third-party agency that procures the samples
Sample procurement agent	Name	n/a	The name of the person who procures the samples
Sample procurement date	Date	n/a	--
Sample procurement address(es)	Address(es)	n/a	--
Sample shipping date	Date	n/a	The date the samples are shipped to the test lab(s) from the third-party sampling agency
Test lab(s)	Test lab name(s)	n/a	--
Test lab address(es)	Address(es)	n/a	--
Sample delivery date(s)	Date(s)	n/a	The date the samples are received by the test lab(s)

E.3 Related tests

Testing is predicated upon the product samples already being procured, shipped, and received at the test lab(s).

E.4 Procedure

E.4.1 Retail sampling

E.4.1.1 General

For retail sampling, third-party agents will procure product samples from a variety of retail outlets in the market.

E.4.1.2 Equipment requirements

No equipment is required for retail sampling.

E.4.1.3 Test prerequisites

Samples shall be procured from a geographically diverse set of retail outlets. Retail outlets include both vendors or retail shops where end users may directly purchase products, and local or regional distributors.

E.4.1.4 Apparatus

No apparatus is required for retail sampling.

E.4.1.5 Procedure

The following steps shall be followed.

a) The third party sampling agency identifies a specified number of retail outlets in the market from various geographic locations.
b) The sampling agency selects a subset of the retail outlets to procure samples from, ensuring that the subset of retail outlets is geographically diverse (e.g. each retail outlet is in a different city and/or country than the rest of the subset).
c) The sampling agency procures the product samples from the various retail outlets, ensuring that no more than 40 % of the overall number of procured samples comes from any single retail outlet.
d) The date, locations, sampling agent, and number of samples procured from each location should be documented by the sampling agency.
e) The sampling agency ships the products to one or more test labs and reports the shipment tracking number(s), when available.
f) Once received at the test lab(s), the date(s) of reception, test lab name(s), and test lab location(s) should be documented.

E.4.1.6 Calculations

There are no calculations for retail sampling.

E.4.2 Warehouse sampling

E.4.2.1 General

For warehouse sampling, third-party agents will procure samples from a warehouse, distributorship, factory, or other bulk storage location.

E.4.2.2 Equipment requirements

No equipment is required for warehouse sampling.

E.4.2.3 Test prerequisites

The sampling location should be the main bulk storage location in the region.

For size A products, as defined in 6.1, there shall be enough products available that the procured samples account for no more than 3,5 % of the total product stock. In cases where size A products are being sampled according to the alternative sampling requirements for individual components, if the minimum stock requirement for any one component exceeds 1 500, the minimum stock requirement may be reduced to 1 500 units.

For size B products, as defined in 6.1, there shall be enough products available that the procured samples account for no more than 8 % of the total product stock. In cases where size B products are being sampled according to the alternative sampling requirements for individual components, if the minimum stock requirement for any one component exceeds 500, the minimum stock requirement may be reduced to 500 units.

The sampling agent shall be able to sample from the bulk storage location's entire stock.

E.4.2.4 Apparatus

No apparatus is required for warehouse sampling.

E.4.2.5 Procedure

The following steps shall be followed.

a) At least 24 h before the sampling takes place, the sampling agency shall make contact (via email or telephone) with representatives at the sampling location to provide proper notice and ensure that the number of samples procured will not exceed the percentage of the sampling location's total product stock specified in E.4.2.3 (either 3,5 % or 8 % depending on the product size).

b) The sampling agency randomly procures the product samples from the bulk storage location's entire stock (i.e. the entire product stock shall be available to sample from).

c) The date, location, sampling agent, and number of samples procured should be documented by the sampling agency.

d) The sampling agency ships the products to one or more test labs and reports the shipment tracking number(s), when available.

e) Once received at the test lab(s), the date(s) of reception, test lab name(s), and test lab location(s) should be documented.

E.4.2.6 Calculations

There are no calculations for warehouse sampling.

E.5 Reporting

Report the following in the product sampling test report.

- Metadata:
  - report name;
  - procedure(s) used;
  - product manufacturer;
  - product name;
  - product model number;
  - name of test laboratory;
  - approving person;
  - date of report approval.
- Sampling instructions
- Sampling and shipping information:
  - name of sampling agency;
  - name(s) of sampling agent(s);
  - sampling location name(s), address(es), and description(s);

- number of samples procured (at each location);
- name of shipping agency;
- shipment tracking number(s);
- date samples are shipped to test lab(s);
- date samples are received at test lab(s).

Annex F
(normative)

Visual screening

F.1 Background

The visual screening process covers DUT specifications, properties (such as external DUT measurements), functionality, observations, and internal/external construction quality.

The DUT's components, materials, and utilities are categorized and, in some cases, evaluated. The visual screening test provides a thorough qualitative and quantitative assessment of the DUT as received from the manufacturer and assigns a unique identifier to each sample. The DUT's operation out of the packaging is documented before any modifications are made for subsequent tests.

F.2 Test outcomes

The test outcomes of the visual screening process are listed in Table F.1.

Table F.1 – Visual screening test outcomes

Metric	Reporting units	Related aspects	Remarks
DUT specifications	Varied	4.2.2 Product design, manufacture, and marketing aspects	Record all provided specifications
DUT information	Varied	4.2.2 Product design, manufacture, and marketing aspects 4.2.10.1 Product and manufacturer information	Record dimensions and qualitative descriptors
Internal DUT inspection	Varied	4.2.3 Product durability and workmanship aspects	Describe/document wiring and electronics fixtures
Internal DUT inspection	Number of defects	4.2.3 Product durability and workmanship aspects	Record the number of soldering and/or electronics quality defects

F.3 Related tests

Annex F is not related to any of the other annexes.

F.4 Procedure

F.4.1 Properties, features, and information

F.4.1.1 General

Relevant DUT information, such as external DUT measurements and observations, are recorded to capture the DUT's characteristics. Sufficient comments should be provided to thoroughly describe the DUT's characteristics. This part of the procedure may be completed on a single sample.

F.4.1.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Callipers and/or ruler.
- Balance (scale).
- Bright task light with good colour rendering.
- Camera.

F.4.1.3 Test prerequisites

The DUT should be new, unaltered, and in its original packaging. Read the packaging box and documentation for instructions on using the product. Consult the manufacturer for missing information pertaining to the required observations.

F.4.1.4 Apparatus

The DUT may be positioned under a bright task light in the examination, if necessary.

F.4.1.5 Procedure

All photographs or scans of packaging, documents (e.g., user's manual and warranty card), and labels shall be in colour and of sufficient quality that all text is legible (unless illegible in the original document) and all diagrams, icons, and other images are clearly reproduced. All photographs of DUT components shall be in colour and of sufficient quality that all relevant text is legible (unless illegible on the item being photographed) and all relevant icons and images are clearly reproduced. These steps shall be followed.

a) Provide the following.

   1) Note the date that the samples were received.
   2) Note the method of sample procurement.
   3) Note any identification code for the inspected sample(s) for properties, features, and information.
   4) Note all available manufacturer contact information (e.g. name, address, phone number, email, website, etc.).
   5) Note all available designer contact information (e.g., name, address, phone number, e-mail address, and website).
   6) Photograph or scan all sides of the product's retail box and describe the box's quality, if available.
   7) Note if a user's manual is included with the DUT. If so, report the type of manual it is (e.g. booklet, sheet, etc.), report the language(s) in which it is written, and photograph or scan each page.
   8) Note and describe any labelling of hazards (e.g., related to inverters or high DC output).
   9) If a warranty is available, record the warranty duration, in months, describe the terms and conditions, and photograph or scan the warranty material. Note if there are separate warranty durations for the battery or included appliances.
   10) Photograph or scan any other documents included with the DUT.
   11) Note and describe any instructions for proper disposal of the battery and/or product.
   12) Note and describe any instructions for replacement of the battery.
   13) Note and describe any instructions for obtaining service or replacement parts in case of a problem with the product.
   14) Note and describe any instructions for ensuring the PV module is not shaded.

15) Note and describe any instructions on how to connect the PV module to the product's power control unit for charging.

16) Note and describe any instructions on facing the PV module surface towards the sun.

17) Note and describe any required pre-use instructions during installation (e.g. charging the battery fully, inserting a supplied fuse).

18) Note and describe any instructions on how to make required permanent connections, including instructions for wire termination or connection, if applicable, during installation.

19) Note and describe any instructions on how to connect advertised appliances.

20) Note and describe any instructions on how to install the product securely.

21) Note and describe any instructions on the battery's state of charge.

22) Note and describe any specifications for product components that could require replacement (e.g. fuses, lights, PV module, batteries).

23) Note and describe any instructions on keeping the PV module surface clean.

24) Note and describe any instructions to not ding the PV module from the back.

25) Note and describe any instructions to not carry the PV module by its cable.

26) Note and describe any instructions on preventing the PV module from cracking during handling.

27) Note and describe any instructions to keep the product away from fire.

28) Note and describe any instructions on the product's graphical display, if a display is included.

29) Note and describe any instructions to not drop the product.

30) Note and describe any instructions to not cut or heat the product's cables.

31) Note and describe any instructions to avoid keeping the battery at a low state-of-charge for long periods of time.

32) Note and describe any instructions on replacing product components that could require replacement (e.g. fuses, lights, PV, batteries).

33) Note and describe any instructions to fully charge the batteries before long-term storage of the product.

34) Note if the installation instructions recommend that the DUT be installed by the company that sells the DUT and/or trained technicians.

35) Note any instructions provided regarding wire or cable connections, e.g. warnings to prevent shorting connections, directions on stripping the wires, and instructions to securely screw down the wires.

36) If the DUT is recommended to be installed by a company or trained technicians, i.e. not the customer, note if technician training documentation or other detailed installation documentation has been provided. Describe any additional installation instructions included in this documentation that were not already noted above.

b) Provide the following (in the specified units) without disassembling the DUT.

1) List each individual component group along with a description and a list of the items included in each group. Do not include the photovoltaic module in this section. If, as identified in F.4.1.5 a) 19), the user manual or other consumer-facing information indicates that multiple appliances without internal batteries that provide the same type of service, e.g. lighting, should be connected to a single port (e.g. by daisy-chaining or with a splitter cable), these appliances may be treated as a single appliance component group or as individual appliance component groups. Treatment of the appliances should be consistent throughout the test methods; for instance, if the appliances are treated as a single appliance in the full-battery run time test, they should also be treated as a single appliance in the light output test, appliance tests, and energy service calculations. The product specification may provide further guidance on treatment of these appliances.

2) Measure the DUT’s mass, in grams (g), as it would typically be used in a lighting application (not including any external solar modules or mobile device charging connectors) and indicate the specific components included in mass measurement.

3) Measure any included appliances’ mass, in grams (g).

4) Measure the length, width, and height, in centimetres (cm), of the DUT, lamp unit(s) and any additional included appliances, components or interconnected parts, separately. Do not include dimensions of an external PV module or any mobile device charging accessories.

c) Observe the following (consult the documentation for any explanations; see 4.1.3 for details on the terminology used in the following steps).

1) Measure and describe the length, in metres (m), of any cables connecting the control box to the batteries, the control box to the lamp units, or the control box to any included appliances.

2) Note if any cables will be predominantly used outdoors. Note if certification documentation has been provided for these cables indicating they are suitable for outdoor use.

3) Note if the DUT has any screw terminal connections or if all connections are plug-and-play.

4) Note the total number of unique lighting units, indicate the technology used in each (LED, fluorescent, incandescent, etc.), and provide a description and photographs of each.

5) Note the number of light points in each lighting unit.

6) Note the number of arrays contained in each light point (e.g. a group of LEDs that function as a single unit is an array). For example: If a lamp unit contains 10 LEDs, and 5 LEDs illuminate for one setting, and all 10 LEDs illuminate for the only other setting, this lamp unit contains two arrays (5-LED and 10-LED).

7) Note the number of independent light sources (i.e. the total number of LEDs or other bulb types) in each array.

8) Determine the number of DUT light output settings. Use the setting descriptions provided by the included literature. If no setting descriptions are provided, use appropriate descriptions (e.g. high, medium, low, 1 high-power LED, 3 low-power LEDs, etc.).

9) Describe the configuration of the main lighting unit, defined as the power control unit with lighting appliances (if applicable) or the brightest lighting unit (if no power control unit is included).

10) Note any built-in appliances, as defined in 4.1.4, including lights with some or all of their driver or ballast circuits internal to another component of the product. Lights with any of the following properties should be examined to determine whether they should be treated as a built-in appliance:

– The light has multiple brightness settings that are selected using a control on the main unit;

– The light is to be connected to a port which cannot be used for any other appliance (according to labels and/or user documentation);

– Internal inspection of the light point (F.4.3) reveals no electronic components on the PCB except the light sources (e.g., LEDs) themselves.

– The behaviour of the port (e.g., as observed in the assessment of DC ports, Annex EE), is consistent with the output of an LED driver circuit (e.g., a constant-current power supply).

Ports or appliances with security features, and appliances connected to ports with pulse width modulation (PWM), may be tested as built-in or removable appliances; see EE.4.2.5.

11) Describe and photograph the arrangement of lamp units, included appliances, battery(-ies), and energy source(s) in terms of housing/cases.

EXAMPLE There are two housings. In the main housing, there is a battery with a gooseneck lamp protruding from the housing. The other housing is a remote lamp unit with no battery; it is connected to the main housing with a 4 m cable that has an inline switch. The PV module is external and connects to the main housing with a cable.

12) Describe the materials that compose the lamp units, battery housing, charge controller housing, included appliances, and/or any other housings (e.g. plastic, metal, glass, or other).

13) Note if the DUT and included appliances have any indicators (e.g. charge indicators) and, if so, include descriptions of indication meanings and photographs of the indicators.

14) Note and photograph any other features present on or included with the DUT and included appliances (e.g. handles, mounting brackets, stands).

15) Note if the DUT has a radio or mobile device charging capabilities. If so, photograph the connectors.

16) Describe and photograph any other included appliances, accessories or connectors not yet documented (excluding DC ports and connectors associated with the PV module).

17) Indicate if the DUT provides central (e.g. grid, central station) or independent (e.g. electromechanical, solar PV) charging and the specific charging means and describe the robustness of each included charging mechanism.

18) If a grid charger is included, note if it carries any recognized safety marks, such as the CE mark. Note the source and nature of the safety marks and be sure to photograph any labels provided on the grid charger.

19) Note each component's primary form factor (fixed indoor, fixed outdoor, portable separate, portable integrated, or other) and also note any secondary form factors.

20) Note the product's expected use(s) (e.g., ambient, torch, task, etc.).

21) Provide any general comments regarding the product's properties, features, and/or information.

d) Measure and observe the following (in the provided units) for the PV module.

1) Measure the mass (g) of the PV module.

2) Measure the PV module's overall length and width, in centimetres (cm), including the frame.

3) Measure the active solar material's overall area, in square centimetres (cm^2).

4) Note if the PV module is external or integrated into the product's housing.

5) Measure the PV module's cable length, in metres (m), in the case of external PV modules.

6) Note the PV module's solar material (e.g. poly-Si, mono-Si, CIS, amorphous).

7) Note the PV module's encasing (e.g. lamination, glass, epoxy).

8) Carefully inspect each PV module under an illumination of not less than 1 000 lux and note any of the following visual defect conditions:

   – cracked, bent, misaligned or torn external surfaces;
   – broken cells;
   – cracked cells;
   – faulty interconnections or joints;
   – cells touching one another or the frame;
   – failure of adhesive bonds;
   – bubbles or delaminations forming a continuous path between a cell and the edge of the module;
   – tacky surfaces of plastic materials;
   – faulty terminations, exposed live electrical parts;
   – any other conditions which could affect performance;

– (for thin film PV modules) voids in, and visible corrosion of any of the thin film layers of the active circuit.

9) Make note of and photograph the nature and position of any visual defects, cracks, bubbles or delaminations, etc. which could worsen and adversely affect the module performance.

10) Photograph the PV module, including the back side that does not have PV material.

11) Note whether any appliances (including built-in appliances) without internal batteries can turn on while the main unit is charging from its PV module.

12) Note whether any appliances with internal batteries can turn on while charging from the power control unit.

13) Describe the robustness of the PV module.

14) Describe the quality of workmanship in the PV module's junction box, if present.

15) Note any additional information about the PV module (e.g. number of individual cells).

e) Provide the following information regarding the product's DC ports.

1) Number of distinct port types.

2) For each port type:

i) brief description of the port (e.g. "USB port 1");

ii) receptacle type (e.g. USB 2 type A, barrel jack, cigarette lighter jack);

iii) number of identical ports of this type;

iv) nominal port voltage, determined from any of the following sources:

– manufacturer-supplied information;

– user documentation and labelling;

– if the port is a standardized or conventional connector, the applicable standards and/or conventions;

– measurement of the open-circuit voltage and the voltage under load.

v) rated maximum port current, if any, determined from any of the following sources:

– measurement of the open-circuit voltage and the voltage under load;

– manufacturer-supplied information;

– user documentation and labelling;

– markings on any DUT components, such as a fuse or circuit breaker, if it can be determined that the component limits the current for the port.

vi) whether the port is intended or expected to be used for charging mobile devices (e.g. based on labelling, documentation, or provided adapters);

vii) photograph of the port.

F.4.2 Specifications

F.4.2.1 General

All relevant DUT specifications are recorded for later comparison in testing results. This part of the procedure may be completed on a single sample.

F.4.2.2 Equipment requirements

No equipment is required for this part of the visual screening procedure.

F.4.2.3 Test prerequisites

The DUT should be new, unaltered, and in its original packaging. Read the packaging box and documentation for instructions on using the product. Consult the manufacturer for missing information pertaining to the required observations.

F.4.2.4 Apparatus

No apparatus is required for this part of the visual screening procedure.

F.4.2.5 Procedure

Examine the DUT's packaging, user's manual, product website, and components for battery, lamp, charge controller, included appliances and PV module specifications. While obtaining the specifications, the DUT should not be opened or otherwise tampered with in any way. The internal inspection of F.4.3 can reveal more product specifications, which should be included with the specifications from F.4.2 and noted accordingly.

a) When provided, note the following specifications (in the specified units), indicate and photograph the source(s) of each, and comment on any specification discrepancies. Indicate if the specification is not provided but can be ascertained by observation (e.g. battery chemistry and battery nominal voltage).
   1) Battery chemistry (VRLA, NiMH, Li-Ion, LiFePO4, or specify other).
   2) Rated battery capacity, in ampere hours (Ah).
   3) Battery nominal voltage, in volts (V).
   4) Battery package type (AA Cell, 18650, 26650, or specify other).
   5) Lamp type (LED, compact fluorescent, linear fluorescent, incandescent, or specify other).
   6) Lamp driver (constant voltage source, constant current source, pulse width modulation, resistor, or specify other).
   7) Charge controller present (yes/no).
   8) Charge controller deep discharge protection voltage, in volts (V).
   9) Charge controller overcharge protection voltage, in volts (V).
   10) PV module maximum power point power (P_{mpp}), in watts (W).
   11) PV module open circuit voltage (V_{oc}), in volts (V).
   12) PV module short circuit current (I_{sc}), in amperes (A).
   13) PV module maximum power point voltage (V_{mpp}), in volts (V).
   14) PV module maximum power point current (I_{mpp}), in amperes (A).
   15) Daily energy service, in watt·hours (Wh).
   16) Included appliances (specify what is included).
   17) Appliance input voltage range (V).
   18) Appliance maximum power usage (W).
   19) Appliance average power usage (W).
   20) Appliance standby power usage (W).
   21) Where available, note basic television specifications – the screen size (inch), TV technology (LCD, LED, Plasma or CRT), antenna type, built-in DVD player, AC power adapter included and built-in FM tuner/radio capabilities.
   22) Where available, basic fan specifications – the fan diameter in millimetres (mm), speed settings, type of stand and ceiling mounting.
   23) Where available, note for any included radio specifications – the radio bands, built-in MP3 player, battery chemistry, battery capacity in ampere hours (Ah), nominal battery voltage in volts (V) and battery run time specified.
   24) Where available, note for any included portable video player specifications – the screen size (inch), DVD player, AC power adapter included, USB inputs, memory card slots, built-in FM tuner/radio capabilities, built-in MP3 player, battery chemistry, battery capacity in ampere hours (Ah), nominal battery voltage in volts (V) and battery run time specified.

25) Where available, note for any included refrigerator specifications – the refrigerator capacity in litres (l), the freezer capacity in litres (l), the energy use per day in watt·hours per day (Wh/day) and the temperature the energy use is specified for in degrees Celsius (°C).

26) Where available, note for any other included appliances any relevant specifications on their use.

b) For each advertised or included appliance, provide the following information:

1) The advertised name of the appliance.

2) Whether it is included with the product (yes/no).

3) Whether or not it is a lighting appliance (yes/no).

4) The name of each setting, a description of each setting, and the total number of settings.

5) Appliance input voltage range (V).

6) Appliance maximum power usage (W).

7) Appliance average power usage (W).

8) Appliance standby power usage (W).

9) Where available, note basic television specifications – the screen size (inch), TV technology (LCD, LED, plasma or CRT), antenna type, built-in DVD player, AC power adapter included and built-in FM tuner/radio capabilities.

10) Where available, basic fan specifications – the fan diameter in millimetres (mm), speed settings, type of stand and ceiling mounting.

11) Where available, note for any included radio specifications – the radio bands, built-in MP3 player, battery chemistry, battery capacity in ampere hours (Ah), nominal battery voltage in volts (V) and battery runtime specified.

12) Where available, note for any included portable video player specifications – the screen size (inch), DVD player, AC power adapter included, USB inputs, memory card slots, built-in FM tuner/radio capabilities, built-in MP3 player, battery chemistry, battery capacity in ampere hours (Ah), nominal battery voltage in volts (V) and battery run time specified.

13) Where available, note for any other included appliances any relevant specifications on their use.

c) When provided, record the following run time specifications, in hours (h), indicate and photograph the source(s) of each, and comment on any discrepancies. Be aware that any run time claims reported on the packaging or other consumer-facing information shall be considered to be the solar run time on the brightest (or highest power) setting, unless otherwise specified in the claim.

1) Note the number of hours of operation on a full battery charge for all appliance settings (full-battery run time) and all appliance uses specified.

2) Note the number of hours of operation on a battery charge from a day of solar charging for all appliance settings (daily solar run time) and all appliance uses specified.

3) Note the number of hours of operation after a specified electromechanical charge period for all appliance settings (electromechanical run time ratio).

4) Note the number of hours of operation after a specified AC/DC adapter charge period for all appliance settings (grid run time).

5) Note and describe any specified run times that do not fit into the previous four categories.

6) Note any additional claims regarding charging of mobile phones or other devices, including the number of devices, types of devices, energy availability or hours of charging, etc.

d) When provided, record the following charging time specifications, in hours (h), indicate and photograph the source(s) of each, and comment on any discrepancies:

1) Note the charging time required to fully charge the battery, including appliances as applicable.
2) Note the daily charging time required to achieve any advertised solar run times, including appliances as applicable.
3) Note the duration of charging or amount of effort required for any specified electromechanical run time, including appliances as applicable.
4) Note the duration of charging required to achieve any specified grid run time, including appliances as applicable.
5) Note and describe any specified charging times that do not fit into the previous four categories.
6) Note any additional claims regarding charging time.

e) Where available, note any light output specifications, in lumens (lm), indicate and photograph the source(s) of each, the corresponding lamp setting(s), and comment on any discrepancies.
f) Note any general comments related to specifications and discrepancies in specifications, if any.

F.4.3 Functionality and internal inspection

F.4.3.1 General

An internal inspection is performed to assess the electronics and soldering workmanship. The DUT and included appliances fail the inspection if poor internal workmanship inhibits the DUT and included appliances from properly functioning. This part of the procedure should be completed for every sample being tested.

F.4.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Bright task light with good colour rendering.
- Miscellaneous hand tools (screwdrivers, wrenches, etc.) to disassemble DUT.
- Camera to document DUT characteristics with particular attention to potential points of failure (e.g. cold solder joints).
- DC voltmeter or multimeter for conducting basic electronic integrity and functionality tests
- Optional: DC current clamp meter.

F.4.3.3 Test prerequisites

The DUT and included appliances should be new, unaltered, and in original packaging. Read the retail box and documentation for instructions on using the DUT and included appliances. Consult the manufacturer for missing information pertaining to the required observations. If the DUT or appliance instructions require them to be fully charged prior to operation, do so prior to conducting this test.

F.4.3.4 Apparatus

The DUT and included appliances should be positioned under a bright task light for examination.

F.4.3.5 Procedure

All photographs of DUT components shall be in colour and of sufficient quality that all relevant text is legible (unless illegible on the item being photographed) and all relevant icons and images are clearly reproduced. The following steps shall be followed.

a) Check the functionality of the DUT and included appliances before disassembling. If a proper charging cable and/or appliances is not included with the product, the proper charging cable and/or appropriate appliance shall be obtained by the test laboratory to check for functionality.

   1) Do the DUT and included appliances work as described with provided documentation?

   2) Do the DUT and included appliances charge as described with provided documentation? Be sure that any included grid charger properly functions. To ensure that the DUT is receiving a charge, the current at the battery should be measured with a DC current clamp meter. The product’s charging indicator, if any, should not be used for this assessment as it can turn on even when the battery current is negligible.

   3) For functions that require additional components for testing that are not included with the product (e.g. mobile device charging), obtain the appropriate appliance and/or charging cable. Do the functions work as described with provided documentation?

   4) Do all of the switches and connectors on all components of the DUT, including appliances, function as they should?

   5) Comment on any notable characteristics of the DUT’s light output (e.g. glare, colour, inconsistency between samples).

   6) Comment on any notable characteristics of the functionality of the included appliances.

   7) Comment on the proper functioning of the indicator lights (such as a charging indicator) and/or informative displays (such as a display showing the battery’s state of charge), if applicable.

   8) Comment on any faulty operation and provide photographs, if necessary.

   9) A DUT is considered to no longer function if any of the following functions fail to work at any point during testing under normal use with the battery at the appropriate state of charge:

      – one or more included appliance will not turn on;

      – any of the light sources, arrays and light points will not turn on;

      – the product will not charge via solar, and/or grid, and/or mechanical, as applicable;

      – battery is unsafe (leaked fluid, inflated, etc.).

b) Inspect the DUT and included appliances for potential hazards or safety issues, such as:

   – bare conductors;

   – sharp points and edges that can cut someone (including exposed screws and fasteners with sharp points and edges);

   – plugs that could exceed ampacity ratings if improperly used;

   – electrical situations that could lead to a fire;

   Make note of and photograph any potential hazards or safety issues identified.

c) Disassemble the DUT and included appliances so the following internal observations can be made.

   1) Inspect the internal electronics for potential hazards or safety issues such as: a potential for shorting the product's battery if two bare wires near each other and could touch or inflated/leaking batteries. If lithium batteries are inflated or fluid is present, these batteries are dangerous and shall not be used for any additional tests. Dispose of the batteries properly.

      Make note of and photograph any potential hazards or safety issues identified.

   2) Inspect the electronic components’ quality and workmanship. Document the workmanship with comments and photographs. Record the number of observations of each deficiency listed below for each sample examined:

- soldering: note any poor solder joints, such as cold joints or joints with insufficient or excess solder;
- wiring: note any poor wiring, such as a badly pinched wire;
- fixture: note any poor securing of internal components, such as poor gluing that is likely to fail;
- battery: note any battery-related deficiency that does not constitute a safety issue, such as corrosion of battery terminals or if the battery is not adequately fastened, such as with loose connectors;
- minor functionality: functional deficiencies include an indicator light or display failing to work, a non-functional accessory (such as extension cable), and an extra port not functioning. Functional deficiencies are not severe enough to result in the product no longer functioning according to F.4.3.5 a) 9), above.

Determine the product's total deficiencies score. Sum the number of deficiencies observed between the examined samples for soldering, wiring, fixture, and battery. Sum and triple the number of deficiencies observed between the examined samples for minor functionality. Add these two sums together and divide by the number of samples examined – this is the total deficiencies score.

3) Indicate whether the DUT and included appliances use cable strain reliefs and, if so, which cables have strain reliefs. Document with photographs.

4) Indicate methods used to secure parts inside the DUT and included appliances (e.g. screws, glue, tape, clamps/straps, or other) and document with photographs.

5) Indicate methods used for securing wire and cable connections (e.g. solder, pin-and-socket connector, screw terminal) and document with photographs.

6) Note if the DUT and included appliances have an easily replaceable battery and/or printed circuit board (PCB). The battery and PCB are easily replaceable if they can be interchanged without any tools other than screwdriver(s) (i.e. no soldering or splicing) that are used only for the removal and replacement of screws (i.e. no prying). If the battery and/or PCB can be replaced in this manner, it is considered "field replaceable." Note if any instructions are included for replacing the battery and/or PCB.

7) Some batteries utilize safety and/or cell balancing circuitry on the power control unit PCB (external to the battery pack). Note if the DUT's battery utilizes a safety/cell balancing circuit external to the battery pack. This arrangement can be observed as additional wire connections between the battery and the PCB. Document with photographs. Consult the manufacturer if uncertain.

8) Examine the internal components, especially the batteries, and note any specifications that were not apparent in F.4.2.5.

9) Note if the batteries contain any internal circuitry. This type of circuitry typically consists of a small PCB located beneath a plastic jacket encasing the battery. Document with photographs.

NOTE Additional wire connections between the battery and the PCB can have other functions as well; for example temperature sensing. Voltage measurements of the additional wires can be helpful in assessing their function; voltages on wires added for cell monitoring and/or balancing will be multiples of the cell voltage.

10) For lithium-ion or lithium iron phosphate batteries with multiple cells (or parallel cellblocks) in series, note if the appearance of the battery pack and circuitry is generally consistent with the description provided by the manufacturer in D.3.2.2 i), D.3.2.2 j), and D.3.3.3 d) regarding individual cell protection.

11) Determine and note the workmanship quality using the following guidelines:
   - good: no deficiencies were observed with the samples examined, and all samples being tested continued to function throughout normal use during testing without any hazards or safety issues;
   - fair: deficiencies score greater than 0 but less than or equal to 1,25, and all of the initially functional samples being tested continued to function throughout normal

use during testing, without any hazards or safety issues. At most, one sample did not function as defined in F.4.3.5 a) 9) when initially evaluated;

– poor: deficiencies score greater than 1,25, or one or more initially functional samples being tested stopped functioning throughout normal use during testing or developed one or more hazards or safety issues, or two or more samples did not function when initially evaluated.

The workmanship quality may be reassessed upon completion of testing, as samples can stop functioning under normal use during a later test.

12) Provide any additional overall internal screening comments as necessary.

F.5 Reporting

Report the following in the visual screening test report.

- Metadata:
  – report name;
  – procedure(s) used;
  – DUT manufacturer;
  – DUT name;
  – DUT model number;
  – name of test laboratory;
  – approving person;
  – date of report approval.
- Manufacturer contact information (e.g. website, email address, phone number, etc.).
- Retail box description, if available.
- User’s manual information:
  – included with DUT (yes/no);
  – type (e.g. booklet, pamphlet, sheet);
  – language;
  – comments.
- Proper disposal instructions information, if available.
- Battery replacement instructions, if available.
- Hazard labelling, if available.
- Warranty information, if available:
  – duration (months);
  – description of terms and conditions.
- Complete DUT information (e.g. battery unit, lamp units, control unit, appliances):
  – mass (g);
  – list of components included in mass measurement.
- DUT cable information:
  – length of all cables except those used to connect PV modules (m);
  – cable to be used outdoors (yes/no);
  – certification documents provided for cables to be used outdoors (yes/no);
  – description of all cables except those used to connect PV modules.
- DUT component information:
  – length of each component (cm);

- width of each component (cm);
- height of each component (cm);
- number of each component included with DUT;
- description of each component.

• DUT lamp unit technology information:
  - type of each unique lamp unit variety (e.g. LED, CFL, incandescent.);
  - number of light points in each unique lamp unit variety;
  - number of arrays in each unique lamp unit variety;
  - description of each unique lamp unit variety's technology use.
• Description of DUT arrangement in expected typical use.
• DUT setting information:
  - name of all individual light output settings;
  - description of each individual light output setting.
• DUT and included appliances materials information:
  - list of all materials used to construct each DUT component (e.g. glass, balsa wood, plastic);
  - description of all DUT components construction materials.
• DUT included appliances indicators information:
  - list of all indicators present on each DUT component (e.g. battery charge indicators);
  - description of all DUT component indicators.
• DUT included appliances features information:
  - list of all features present on each DUT component (e.g. handles, mounting brackets, stand);
  - description of all DUT component features.
• DUT accessories included appliances information:
  - radio included (yes/no);
  - mobile device charging capability (yes/no);
  - descriptions of included appliances;
  - descriptions of other included DUT accessories and connectors.
• DUT charging mechanism information:
  - grid charging supported (yes/no);
  - electromechanical charging supported (yes/no);
  - solar charging supported (yes/no);
  - description of each included charging mechanism.
• DUT DC ports information:
  - number of distinct port types;
  - description of each port type;
  - receptacle type for each port type;
  - number of identical ports of each type;
  - nominal port voltage for each port type and source of information;
  - rated maximum port current for each port type and source of information;
  - whether each port type is intended or expected to be used for charging mobile devices.
• DUT PV module information:

  - length of each PV module (cm);
  - width of each PV module (cm);
  - active area of each PV module (cm^2);
  - form of each PV module (external or integrated);
  - cable length of each PV module (m);
  - active solar material of each PV module (e.g. mono-Si, amorphous, CIS);
  - encasing of each PV module (e.g. lamination, glass);
  - description of any PV module visual defect conditions;
  - description of the robustness of each PV module;
  - description of PV module junction box workmanship;
  - other PV module information.
- DUT form factor and use information:
  - DUT's primary form factor (e.g. fixed indoor, fixed outdoor);
  - DUT's secondary form factor(s);
  - DUT's expected use(s) (e.g. ambient, torch, task).
- Overall comments based on the visual inspection.
- Provided DUT specification information, if available:
  - battery chemistry and source of information;
  - rated battery capacity (mAh) and source of information;
  - battery nominal voltage (V) and source of information;
  - lamp type(s) and source of information;
  - lamp driver and source of information;
  - presence of charge controller (yes/no) and source of information;
  - charge controller deep discharge protection voltage (V) and source of information;
  - charge controller overcharge protection voltage (V) and source of information;
  - PV module P_{mpp} (W) and source of information;
  - PV module V_{oc} (V) and source of information;
  - PV module I_{sc} (A) and source of information;
  - PV module V_{mpp} (V) and source of information;
  - PV module I_{mpp} (A) and source of information.
- Description of any provided DUT specification discrepancies.
- Provided appliance specification information, if available.
- Description of any provided appliance specification discrepancies.
- Provided DUT run time information, if available:
  - full-battery run time (h) for each setting and source of information;
  - daily solar run time (h) for each setting and source of information;
  - electromechanical run time for each setting and source of information;
  - grid run time (h) for each setting and source of information;
  - claims regarding mobile phone or other device charging abilities;
  - other run time (h) for each setting and source of information.
- Provided DUT charging time information, if available:
  - full-battery charging time (h) and source of information;
  - daily solar charging time (h) and source of information;

- electromechanical charging time (h) and source of information;
- grid run time (h) for each setting and source of information;
- claims regarding mobile phone or other device charging times;
- other charging time (h) and source of information.

- Description of any provided run time discrepancies.
- Provided light output (lm) for each setting and source of information.
- Description of any light output discrepancies.
- DUT and appliances function out of box (yes/no).
- All switches and connectors function for each DUT sample and appliances with comments as necessary (yes/no).
- Description of any potential hazards or safety issues.
- Description of cable strain relief methods used and for which connections, if applicable.
- Number of poor solder joints and workmanship deficiencies for each DUT sample and appliances with comments as necessary.
- Total deficiencies score.
- Workmanship quality (good/fair/poor).
- Means (e.g. screws, glue, tape) used to secure parts in each DUT component (e.g. lamp unit(s), charge controller, PV module(s),appliances).
- General fixture of parts comments.
- Means (e.g., solder, pin-and-socket connectors, screw terminals, etc.) of securing wire and cable in each DUT component (e.g., lamp unit(s), charge controller, PV module(s), appliance, etc.).
- Comments on overall layout and securing of wires and cables.
- Easily replaceable battery and PCB for the DUT and appliances (yes/no).
- Comments on ease of battery and/or PCB replacement.
- Type of battery connectors.
- Presence of battery replacement guide (yes/no).
- Sufficient information for proper disposal of batteries (yes/no).
- Presence of lithium-ion battery cell balancing or individual cell monitoring (yes/no).
- Overall description of internal workmanship.
- Figures:
  - properties, features, and information photographs;
  - specifications photographs;
  - functionality and internal inspection photographs.

Annex G
(normative)

Sample preparation

G.1 Background

The product sample shall be prepared before starting the tests. The preparation includes configuring the product to allow connection with a laboratory power supply, as well as taking measurements. For DUTs with multi-cell lithium battery packs, the preparation also includes charging the product.

G.2 Test outcomes

There are no sample preparation outcomes.

G.3 Related tests

The sample preparation procedures shall be performed on all DUTs prior to conducting the light output test (Annex I), lumen maintenance test (Annex J), battery test (Annex K), full-battery run time test (Annex M), grid charge test (Annex O), electromechanical charge test (Annex P), solar charge test (Annex R), charge controller behaviour test (Annex S), light distribution test (Annex T), battery durability test (Annex BB), protection tests (Annex DD), assessment of DC ports (Annex EE), and appliance tests (Annex FF).

G.4 Procedure

G.4.1 General

The DUT is configured in order to make measurements of current and voltage during selected tests, charge the battery via a battery analyser, and simulate a specified battery voltage during selected tests with a laboratory power supply. In some cases, this will mean selecting and attaching the correct plug and receptacle components. In other cases, the DUT will need to be modified, by cutting wires and/or drilling holes, to allow electrical connections. When possible, the testing laboratory shall use all cables and connectors that are provided with the DUT and shall configure the system according to product instructions and in way consistent with the normal use of the product. Any modifications shall be kept to a minimum. Additional configuration information can also be found in Annex H; see in particular Figure H.1.

G.4.2 Equipment requirements

The following equipment and supplies, or their equivalent, are required. Equipment and supplies shall meet the requirements in Table CC.2.

- Plugs and receptacles (e.g. pin-and-socket connectors) that connect to the DUT electrical ports to allow the use of a laboratory power supply and battery analyser with the DUT appliances.
- Insulated stranded copper wire. The conductor size shall be 0,75 mm^2 or thicker; for many products, it is necessary to use thicker wire to avoid introducing excessive voltage drop. The required conductor size depends on the wire length, the maximum current, and the sensitivity of the product to voltage drop; in all cases, the wire size shall be sufficient to avoid significantly affecting the behaviour of the DUT. Recommended minimum wire sizes are given in Table G.1. It is recommended to use four different colours.
- Wire cutters.
- Wire strippers.

- Soldering iron and solder.
- Heat-shrink tubing and heat gun.
- Screwdrivers and/or other appropriate tools for opening the DUT.
- Optional for DUTs with multi-cell lithium battery packs: DC power supply.
- Optional: DC current clamp meter.
- In some cases: a power drill with an appropriately sized drill bit to make a hole in the enclosure to fit four extension wires.

Table G.1 – Recommended minimum conductor sizes for copper wire

Expected maximum current A	**Minimum wire thickness** mm^2	**Minimum wire thickness (American wire gauge)**
≤ 2,0	0,75	--
≤ 2,2	0,82	18
≤ 3,5	1,31	16
≤ 4,0	1,50	--
≤ 5,5	2,08	14
≤ 6,7	2,50	--
≤ 8,8	3,31	12
≤ 10,7	4,00	--
≤ 14,0	5,26	10

G.4.3 Test prerequisites

The visual screening shall be completed prior to performing the sample preparation procedures.

G.4.4 Procedure

The following steps shall be followed.

a) For DUTs with multi-cell lithium battery packs, fully charge the product using the product's charging circuitry to ensure the DUT has been given the opportunity to balance the cells of its battery pack. (The battery pack and charge controller need not be from the same sample.) Use one of the two following options.

   - With the DUT configured for charging (e.g. solar module connected to power control unit), face the solar module towards the sun until the DUT reaches a full charge. Be sure to protect the DUT from water ingress.
   - Charge the DUT using a power supply. Set the power supply to the DUT's rated maximum power-point voltage and current. For DUTs with external solar modules, use a severed PV connector to deliver the power to the DUT's PV socket. For DUTs with integrated solar modules, open the DUT to access and sever the leads between the solar module and electronics to deliver the power through the DUT's electronics. If the maximum power-point voltage and current values are not rated, contact the manufacturer to obtain the values. (This option is less realistic but more convenient for laboratories without access to a secure location with frequent full sun exposure.)

   To determine when the DUT is fully charged, the lab may use the included instructions or check that current no longer enters the battery pack with a current clamp meter when the solar module is exposed to sun or power supply is providing power.

b) Identify the DUT's system components and appliances and determine the method of electrical connections between system components.

c) Modify the DUT to electrically isolate the battery from the electronics. This will allow the battery to be tested and will also allow the electronics and ports to be powered from a laboratory power supply. If the product has a cell balancing or monitoring circuit that is external to the battery, refer to H.5.6 e) when preparing the product.

   1) With wire cutters, cut the positive and negative wires individually where the battery connects with the rest of the DUT circuit. To avoid a short circuit, which could result in personal injury, fire, or explosion, do not cut the wires simultaneously. In some cases, additional wires are attached between the battery and circuit for battery temperature monitoring and/or cell balancing – do not cut these wires. Some batteries have two wires connected to each battery terminal – keep the wires attached to each terminal together and treat them as one wire end for the remainder of the procedure. Occasionally, multiple batteries or battery cells are connected through the PCB (or other electronics external to the battery). When isolating these batteries, ensure that the cells are connected in an equivalent manner to how they were originally connected through the PCB.

   2) Extend the four wire ends (two connected to the battery terminals, two connected to the DUT's PCB or other electronics) by soldering on additional wires. Make the wire extensions long enough to be extended approximately 6 cm outside the enclosure, but no longer than necessary. To avoid electric shock, keep the battery positive and negative extensions separated. Cover the wire connections with heat-shrink tubing once soldered. To minimize voltage drop, the conductor size of the extension wires added in this step shall be ≥ 0,75 mm^2 (see recommendations in Table G.1) and equal to or larger than the existing DUT battery leads. Wire extensions shall be kept as short as possible. The laboratory shall monitor the behaviour of the DUT to ensure that modifications do not significantly change the DUT's performance. Changes in performance can include changes to the DUT's power consumption, output, or any other function that is substantially different than the function of the unaltered sample.

      NOTE In the American wire gauge (AWG) system, 18 AWG (0,823 mm^2) is the smallest conductor size meeting this requirement.

   3) Close the DUT such that the wires can extend outside the enclosure without being pinched.

      Some products are designed with openings in their enclosures such that the wires can fit through these openings without physically changing the enclosure.

      Some products do not have openings for wire extensions to fit through, in which case a hole shall be drilled into the side of the DUT's enclosure. A drill bit with a diameter slightly greater than the combined diameter of all four extension wires should be used. Choose a location on the enclosure to minimize the extension wire length and minimize changes to the enclosure. Be sure that the extension wires do not interfere with the DUT's light output.

   4) Optionally, attach connectors (e.g. pin-and-socket connectors) to the ends of the extension wires for easy use during testing. Attach one connector to the battery positive and negative extension wires and the mating connector to the DUT power supply lead wires. If no connectors are used, be sure to keep the battery positive and negative extensions separate when bare to avoid short-circuiting the battery. Covering the ends of the wires with electrical tape is one method to keep the extensions separate.

      The charge controller behaviour test (Annex S), full-battery run time test (Annex M), and solar charge test (Annex R) impose limits on the total series resistance of the measurement apparatus. To meet these requirements, the use of connectors, soldered connections, or screw terminals is recommended. Alligator clips or similar spring-loaded removable connectors can introduce significant resistance and should not be used.

   5) To ensure the DUT still works after it has been rewired, connect the wire pairs (with connectors or electrical tape) so the original, unaltered circuit is replicated and turn the DUT on. If the DUT does not turn on, check that the wires are connected correctly and

that the solder joints connecting wires are good. Some products require having their PV modules attached with light shining on the PV module to get the product to turn on; afterwards, the PV module can be removed and the product will continue working until its circuit is broken again.

d) (optional) In some situations, it is acceptable for a test lab to supply a regulated voltage from a power supply directly to an appliance plug or wire end instead of supplying power to the DUT power control unit. This method shall be used only if the appliance is normally supplied power by a voltage-regulated port (constant voltage). Built-in appliances as defined by EE.4.2.6 f) cannot be tested by this procedure. If the test lab is uncertain about the voltage regulation of the port, this procedure shall not be used; instead, the lab shall use b) above.

   1) Identify the positive and negative terminals or leads on the DUT's plug and receptacle connectors. This can be done by checking DUT instructions or by measuring the voltage polarities on the connector terminals with the DUT turned ON.

   2) Configure plug and receptacle components to mate with the DUT system components and allow the use of a laboratory power supply (to power the appliances) and a battery analyser (to test the battery(-ies)). In cases where suitable plug and receptacles cannot be found, the DUT may be modified by cutting off connectors and/or opening DUT enclosures and proceeding with the DUT modifications outlined above. When possible, use the cables and connector components that are provided with the DUT and intended for normal operation.

e) Some products that use coulomb counting or similar methods for estimating state of charge will not correctly detect the battery state of charge when a discharge is started immediately after the battery is disconnected and reconnected. This can result in the DUT turning off or reducing brightness prematurely during the full-battery run time test. To avoid these problems, a "secondary" set of wires may be attached to the battery and PCB or other electronics, to allow the DUT to be removed from one test apparatus and transferred to another without breaking the circuit between the PCB and battery. Figure G.1 shows how the secondary set of wires can be incorporated. Instead of mating connectors, a switch may be used on these leads.

   When transferring a DUT prepared in this manner from one test apparatus to another, use the following procedure:

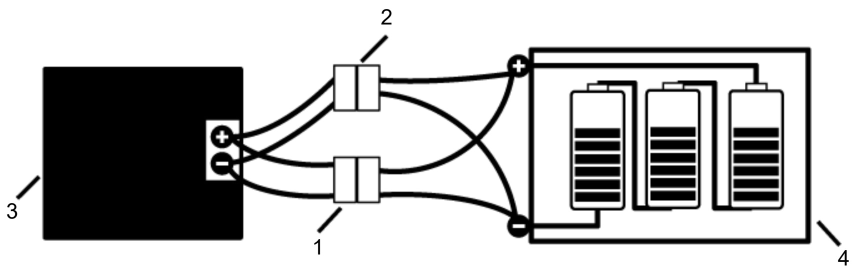
   1) Connect the secondary wires from the PCB to the secondary wires from the battery (or, if using a switch, turn the switch on).

   2) Disconnect the battery and PCB wires from the first test apparatus.

   3) Connect the battery and PCB wires to the second test apparatus. If the apparatus includes a relay or switch, ensure that it is closed before proceeding.

   4) Disconnect the secondary battery and PCB wires (or, if using a switch, turn the switch off).

   If it is necessary to start the test (e.g. turn on the DUT or start data collection) in step 3), perform step 4) as quickly as possible to avoid missing current measurements.



Key

1 Primary wire connection

2 Secondary wire connection (or switch)

3 DUT electronics

4 Battery

Figure G.1 – Connections with secondary set of wires to avoid battery disconnection

G.4.5 Calculations

No calculations are required with the sample preparation procedures.

G.5 Reporting

No reporting is required with the sample preparation procedures.

Annex H
(normative)

Power supply setup procedure

H.1 Background

Several of the photometric test procedures replace the battery with an external laboratory (bench) power supply to provide electrical power to the DUT for the duration of the test. Annex H specifies the power supply equipment requirements and setup procedure for these tests.

In order to correctly simulate the battery and provide the DUT accurate direct current (DC) power, the power supply shall be configured properly to eliminate errors that can occur from:

- voltage drops from the resistance of the lead wires, and
- electronic noise in the lead wires from either the DUT or the test environment.

These errors can (in most cases) be eliminated with a 4-wire test configuration and input filter capacitors.

H.2 Test outcomes

The test outcome of the power supply setup procedure is listed in Table H.1.

Table H.1 – Power supply setup test outcome

Metric	Reporting units	Related aspects	Remarks
Standard operating voltage	Volts (V)	n/a	Used when a typical battery voltage during discharge is needed, in tests (such as the lumen maintenance test) where it is impractical to use the typical battery discharge voltage from the full-battery run time test.

H.3 Related tests

Annex H is related to the light output test (Annex I), the lumen maintenance test (Annex J), the solar charge test (Annex R), the charge controller behaviour test (Annex S), and the light distribution test (Annex T), the protection tests (Annex DD), the assessment of DC ports (Annex EE), and appliance tests (Annex FF). It is necessary to perform the full-battery run time test (Annex M) to determine the typical battery discharge voltage in H.5.2. In some unusual cases (battery types other than lead-acid, NiMH, lithium iron phosphate, or other lithium-ion), it is also necessary to perform the full-battery run time test (Annex M) or battery test (Annex K) in order to determine the standard operating voltage in H.5.2.

H.4 Equipment requirements

The DC power supply shall be capable of delivering a stable, accurate DC input to the DUT. The power supply should have a voltage readout resolution of no more than 0,01 V and a current readout resolution of no more than 0,001 A. The voltage applied to the DUT should be regulated to within ± 0,2 % during photometric measurements, charge controller tests, and solar charging tests and ± 3 % for the duration of lumen maintenance tests. Equipment shall meet the requirements in Table CC.2.

Some test configurations may use power supplies without voltage and current readouts capable of measuring voltage and current values with the required accuracy. For example, a single power supply may be used to run concurrent lifetime tests on multiple DUTs (the DUTs are run in parallel from a single DC voltage rail). For these configurations, voltage measurements may be made at each DUT input using a voltmeter or multimeter and current measurements may be made using a voltage drop measurement on a series shunt resistor using Ohm's law.

H.5 Setup procedure for photometric measurements and lumen maintenance tests

H.5.1 Test setup

The following steps shall be followed.

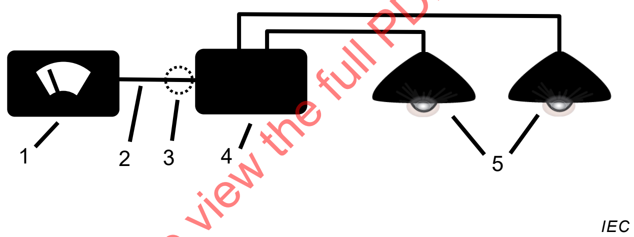
a) The power supply and DUT are configured according to Figure H.1 or Figure H.2. Input filter capacitors shall be placed at the device input according to H.5.5.

b) The voltage level is set according to H.5.2 and measured according to H.5.4.

c) The DUT is powered on and allowed to stabilize for ≥ 20 min according to H.5.3.

d) Tests are performed on the DUT.

e) During testing, monitor the DUT for erratic behaviour that could indicate a problem with the test setup, including light output flickering, voltage and current instability, and difficulty in device start-up.



Key

1 DC power supply

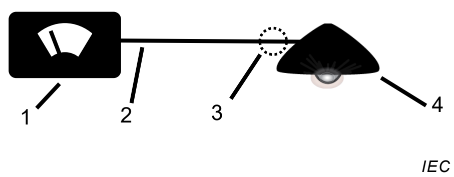
2 DC power supply lead wires (+ voltage sense wires for light output test)

3 Input filter capacitor attachment location

4 DUT power control unit (battery is removed or disconnected from DUT electronics; see G.4.4.)

5 DUT appliances

Figure H.1 – Power supply setup for powering a power control unit



Key

1 DC power supply

2 DC power supply lead wires (+ voltage sense wires for light output test)

3 Input filter capacitor attachment location

4 DUT appliance (appliance battery (when present) is electrically isolated from DUT electronics; see G.4.4.)

Figure H.2 – Power supply setup for directly powering an appliance

H.5.2 DC voltage and current levels

The constant DC voltage level for testing a product sample is based on the test requirements and battery characteristics.

When supplying power with a laboratory power supply to the DUT power control unit (Figure H.1), either the typical battery discharge voltage (corresponding to the voltage at the average power operating point found during the full-battery run time test, Annex M) or the standard operating voltage (Table H.2) is used. This simulates the DUT's battery voltage. The typical battery discharge voltage is more representative of the typical operating point than the standard operating voltage because it is based on measurements. The typical battery discharge voltage is therefore used in the light output test (Annex I), light distribution test (Annex T), assessment of DC ports (Annex EE), and appliance tests (Annex FF). The standard operating voltage is used for the lumen maintenance test (Annex J), in which it is often impractical for laboratories to drive multiple samples at different voltages and it is desirable to begin testing as soon as possible after receipt of samples. The standard operating voltage is also used for the protection tests (Annex DD) because these tests are conducted on a single sample that might not have undergone the full-battery run time test and the results are less sensitive to the operating voltage. The standard operating voltage is also used for the appliance tests because the typical battery discharge voltage is not always available for the appliance battery.

The standard operating voltage shall not be used in place of the typical battery discharge voltage. If it is necessary to determine a typical battery discharge voltage for a sample that will not undergo the full-battery run time test, the average value for all the samples tested may be used. When supplying power with a laboratory power supply directly to a light point (and not using the DUT's power control unit) (Figure H.2), the appliance operating voltage as determined in Clause FF.5 is used. This simulates the DUT's port voltage for that appliance.

The standard operating voltage depends on the type, configuration, and number of cells of the battery pack. These characteristics are typically provided by the manufacturer but may be determined by testing the discharge profile (Annex K) and inspecting the battery.

The standard operating voltages for several battery chemistries are listed in Table H.2. For unknown or new types of batteries, the typical battery discharge voltage may be used in place of the standard operating voltage, or a typical discharge voltage may be determined from manufacturer-provided battery specifications or from the battery test (Annex K), for example by using the average voltage during the final discharge cycle in the battery capacity test.

Table H.2 – Standard operating voltage for several common battery types

Battery type	Standard operating voltage V/cell
Lead-acid	2,05
NiMH	1,25
Lithium iron phosphate	3,25
Other lithium ion	3,7
Other battery chemistry	Use the typical battery discharge voltage (Annex M), or use a typical discharge voltage as determined from manufacturer-provided battery specifications or the battery test (Annex K).

During testing, some DUTs do not start up at the desired voltage and require an input slightly greater than the desired battery voltage. In this case, incrementally increase the power supply voltage by 0,05 V until the DUT is operational at the desired light setting. After start up, reduce the voltage back to the desired battery voltage and allow the DUT to stabilize. If the

DUT will not remain on when the voltage is reduced, repeat this step and run the DUT as close to the desired battery voltage as possible, making note of the issue.

The current drawn by a DUT powered with an external power supply at the typical battery discharge voltage is generally at or near the current measured in the full-battery run time test for the same setting at the typical battery discharge voltage. Similarly, the current drawn by an appliance powered at the appliance operating voltage should be close to the value measured during the determination of the appliance operating voltage. Variations greater than 5 % can indicate a problem with the power supply setup and should be noted in the test report.

H.5.3 Stabilization period

A DUT shall be allowed to stabilize (warm up) before light output measurements are made. There are two approved stabilization procedures:

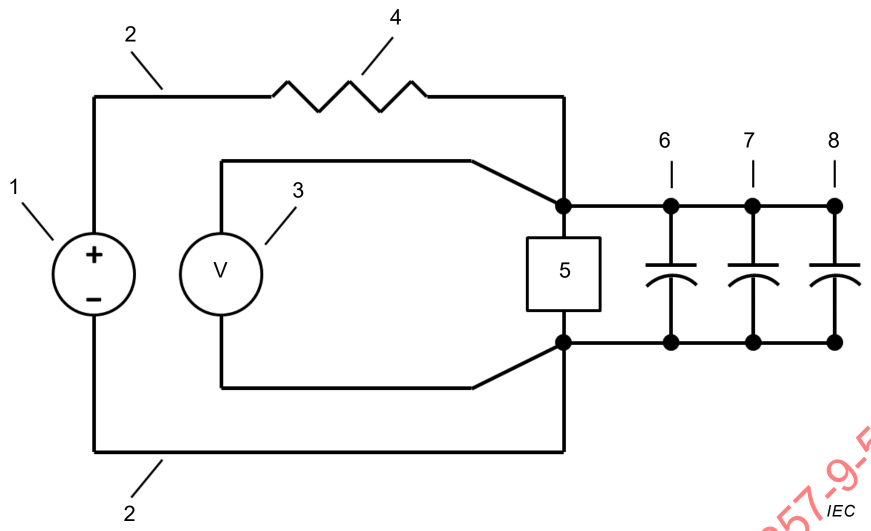
a) the DUT is powered on and allowed to stabilize for 20 min, or

b) the DUT is powered on and is considered stable when three consecutive output measurements, taken 15 min apart, have a variation of ≤ 0,5 % (IES LM-79-08).

In order to facilitate testing of multiple samples, 20 min is specified as the minimum stabilization time and is adequate for most products. Longer times can be necessary for DUTs with large heat sinks or high-powered LEDs. Voltage, current, and light output for a DUT should be monitored to determine if 20 min is an adequate stabilization time. If a longer stabilization time is necessary, the IES LM-79-08 procedure may be used to determine the stabilization time for a single DUT sample, and this time may then be used to test additional DUT samples of the same type.

H.5.4 4-wire power supply measurements

Current carrying lead wires used to provide power to the DUT should be appropriately sized and as short as possible, and shall be separate from the wires used to measure the device voltage (Figure H.3). This is typically referred to as a 4-wire test measurement, and eliminates the voltage drop associated with the resistance of the test leads because very little electric current is carried in the voltage sensing wires. Many power supplies are equipped to handle this measurement automatically (also known as remote sensing), although test personnel may make corrections by adjusting the sense voltage manually.



Key

1 DC power supply

2 Lead wire

3 Voltage sense

4 Series shunt resistor (optional)

5 DUT

6 1 µF capacitor

7 10 µF capacitor

8 100 µF capacitor

Figure H.3 – 4-wire test configuration with input filter capacitors

H.5.5 Filtering electronic noise

Electromagnetic interference (EMI) generated by the DUT or the test environment can interfere with voltage and current measurements. This can occur from switching power supplies found in some electronic devices and is exacerbated by using long lead wires from the power supply to the DUT. Problems with EMI will typically cause input voltage and current instability, and often can result in light output variation in the DUT.

Input capacitors shall be placed at the DUT input connections, between supply positive and negative leads, as close to the device as possible (Figure H.3). Wires connecting the capacitor filter to the DUT should be at least 0,75 mm^2 or larger if required by Annex G. The capacitors shall be ceramic or tantalum types and have 1 µF, 10 µF, and 100 µF values. These three capacitor values, used in parallel, will effectively mitigate most EMI problems.

H.5.6 Troubleshooting

If the DUT will not turn on after replacing its battery with a power supply, try the following steps, in order. If the DUT turns off or drops to a lower light output setting after a period of time, try the following steps starting with step b). If possible, consult the product manufacturer to ensure that any troubleshooting steps taken will not damage the product.

a) Some solar products require power to be applied to the PV module in order to turn on after the battery has been disconnected. Use the following steps:

   1) Follow the guidelines in H.5.1 for replacing the DUT's battery with a power supply.

   2) If the product does not have an integrated PV module, plug the DUT's solar module into its charging socket.

3) Shine a bright light very close to the solar module. A 100 W incandescent bulb placed as close as possible to the module while illuminating the entire surface is often effective. Alternatively, expose the module to direct sunlight.

4) If the DUT does not turn on, try cycling its on/off switch. After the DUT turns on, the solar module can usually be removed.

5) If these steps are unsuccessful, repeat the procedure, but while the light is being applied to the PV module, increase the power supply voltage to the overcharge protection voltage. If this voltage is not known, use the recommended value from Table L.2. If this is successful, try to reduce the voltage to the correct value once the product has turned on.

b) If the solar module is not available or it is not possible to expose it to sufficiently bright light, a power supply may be used to simulate the solar module.

1) Follow the guidelines in H.5.1 for replacing the DUT's battery with a power supply.

2) For products with external solar modules, connect an additional power supply to the solar module socket. For products with integrated PV modules, cut the leads connecting the PV module to the PCB and connect the power supply to these leads. Be sure to apply the power supply with the correct polarity; otherwise, the DUT can be damaged.

3) Set the additional power supply to the solar module's maximum power point voltage (V_{mpp}) and maximum power point current (I_{mpp}). Use the rated values if the photovoltaic module I-V characteristics test (Annex Q) has not yet been performed. (In some cases, it is necessary to obtain the appropriate voltage and current values from the product manufacturer.)

4) Follow steps a) 4) and a) 5), above. If necessary, leave the PV socket input connected.

Option b) can sometimes be used if it is necessary to supply the PV input to the DUT for the entire duration of the test, for example if the product has a timer function that turns off the product or changes the setting after a fixed duration regardless of the battery state of charge, or if the product uses coulomb counting to estimate the battery state of charge. However, it is more likely that c) will be successful.

c) Instead of replacing the DUT's battery with a power supply, leave the battery connected within the DUT. Supply power to the PV socket as in b). Provide a means to measure the battery voltage and current.

When this method is used, the battery voltage cannot be regulated; the battery will charge until the product's charge controller stops the charge cycle. Therefore, the use of this method is subject to the following cautions:

– For products with NiMH batteries, care should be taken to avoid overcharging the batteries during prolonged tests. A battery current of up to 0,05 I_t A is generally safe for extended testing. For shorter durations, higher currents (typically up to 0,2 I_t A or as specified by the battery manufacturer) can be used without damaging the battery. At rates greater than 0,05 I_t A, avoid applying a total quantity of charge greater than 1,6 times the nominal battery capacity (starting with a fully discharged battery).

– If the product's light output varies with input voltage, manufacturer approval should be obtained before using this method for the lumen maintenance test. For most products, holding the battery at 100 % state of charge is not representative of typical use and can result in faster light output degradation. (However, if it is possible to regulate the PV socket current so that the battery is held at a constant voltage, this caution does not apply. This regulation could be performed using a special-purpose electronic circuit or, in some cases, through manual monitoring and adjustment of the supply current.)

– If it is not known whether the DUT has appropriate overcharge protection, to ensure safety, the battery voltage should be monitored until it stabilizes.

d) Follow the instructions in c), but use a battery simulator instead of the DUT's battery. This will allow regulation of the simulated battery voltage and avoids the safety issues in c). Therefore, this method may be used in the lumen maintenance test even if the product's light output varies with battery voltage.

e) If the product has a cell balancing or monitoring circuit that is external to the battery (i.e. on a PCB external to the battery; see F.4.3.5), it is usually necessary to apply appropriate voltages to the cell balancing inputs. The laboratory should develop a solution in consultation with the manufacturer. The following options have been used successfully.

   1) Connect resistors between the cell voltage inputs in place of the battery cells. The resistor values shall be closely matched so that the balancing function does not operate. Ensure that the current drawn by the resistors does not result in an error of more than 1 % in any current measurement.

      This option is simpler than 2) and is often effective, but is unlikely to succeed if the balancing function continues to operate. Most cell balancers place a low resistance in parallel with the cell, and this will affect the voltages supplied to the inputs unless very low resistor values are used.

   2) In some cases, more complex circuitry is necessary to supply stable voltages to the DUT under all operating conditions. One method that has been used successfully is to connect an adjustable shunt voltage regulator in place of each cell. The power supply is then set to constant-current mode, with a current value greater than the current drawn by the DUT, and the shunt regulators determine the voltage. Alternatively, a bipolar power supply or power amplifier capable of either sinking or sourcing current may be used to supply a stable voltage to each cell input.

   It is sometimes necessary to use option e) in combination with one of options a) through d) to turn the DUT on.

Options b) through d) are not recommended for use with the following test procedures if it is necessary to supply power continuously through the PV input, unless the PV current can be reduced to a negligible value and it is possible to regulate the battery voltage for the duration of the test:

- Light output test (Annex I)

NOTE If the light output is independent of voltage, the light output test can be conducted. For products without a DC-DC converter, the PV socket and battery current can be summed to estimate the total current at the battery terminals during use. The voltage at the battery terminals can then be multiplied by the total current to calculate power and luminous efficacy. This calculation is not valid for products with DC-DC converters.

- Output overload protection test (DD.4.2)
- Assessment of DC ports (Annex EE)

H.6 Reporting

The voltage and current for tests using an external power supply shall be reported according to Table H.3.

Table H.3 – Voltage and current reporting requirements

	Notes
Standard operating voltage	Determined from Table H.2 (required if standard operating voltage is used during testing)
DC voltage	Regulated to within ± 0,2 % during photometric measurements and ± 3 % for the duration of lifetime tests
DC current	Measured using the power supply readout or series shunt resistor. Readout resolution should be ≥ 0,001 mA

Annex I
(normative)

Light output test

I.1 Background

The light output of a solar LED light is a key parameter as products that do not provide a sufficient amount of light have limited value.

Light output measurements (total luminous flux or lumen output) typically require the use of an integrating sphere or goniophotometer. An additional luminous flux measurement technique, referred to as the multi-plane method, involves conducting illuminance measurements on six planes that define a "box" around a test product and uses these measurements to calculate luminous flux. The multi-plane method is unique to IEC 62257 and is described in I.4.4.

Laboratories may measure total luminous flux using an integrating sphere, goniophotometer, or the multi-plane method.

The light output of all lighting appliances to be tested shall be measured individually. If more than one identical lighting appliance is included with the product, more than one of each type of identical lighting appliances need not be measured. The product specification may define categories of lighting appliances that need not be subjected to the light output test.

I.2 Test outcomes

The test outcomes of the light output test are listed in Table I.1.

Table I.1 – Light output test outcomes

Metric	Reporting units	Related aspects	Notes
Luminous flux	Lumens (lm)	4.2.9.1 Luminous flux output	Measured using a DC power supply, light sensor, and integrating sphere or goniophotometer (or using a multi-plane measurement).
Correlated colour temperature (CCT)	Kelvin (K)	4.2.9.4 Colour characteristics	Measured using equipment capable of characterizing spectral distribution
Colour rendering index (CRI)	0-100 (unitless)	4.2.9.4 Colour characteristics	Measured using equipment capable of characterizing spectral distribution

I.3 Related tests

The light output test is related to the full-battery run time test (Annex M) and the light distribution test (Annex T).

The light output test allows several alternatives for determining light output. The multi-plane method described in I.4.4 and a goniophotometer may be used to generate information on the distribution of the device (needed for Annex T) as well as information on light output. When these methods are utilized, data may also be used by Annex T to calculate illuminance on a plane, illuminance about an axis, and/or full width half maximum (FWHM) angles as described in T.5.3.6.

I.4 Luminous flux measurement techniques

I.4.1 General

The luminous flux of all of the lighting appliances supplied with the DUT shall be measured. If more than one identical appliance is included with the product, only one of each set of identical appliances should be tested.

These steps shall be followed:

a) Determine the method of supplying power to the lighting appliance(s). The appliance shall be connected either to a port on the DUT's power control unit or directly to a laboratory power supply. See Annex H for additional information on selecting an appropriate method to power the lighting appliance.

b) Prepare the test sample for lighting evaluation as described in Annex G. Set up a power supply to drive the DUT as described in Annex H. Measurements shall be taken in a conditioned space such that the air temperature is 22 °C ± 5 °C.

c) When connecting a lighting appliance to a port on the DUT's power control unit, use the typical battery discharge voltage (Annex M) to supply power from a laboratory power supply to the power control unit. All of the lighting appliances in the product shall be connected, powered on, and set at their highest output setting, unless otherwise specified in the product specification or requested by the client. Additional settings may be tested at the laboratory's discretion.

   When a DUT has multiple lights, these lighting appliances should be tested individually (for example, one lighting appliance is placed inside an integrating sphere and the others are powered on but left outside the sphere during the test). Though all lighting appliances are connected and powered on during the test, for DUTs with multiple identical lighting appliances, it is only necessary to measure one of each type of identical lighting appliances.

   EXAMPLE The DUT includes three different types of lighting appliances (e.g. a tube light, four ambient light points, and two more focused light points). In this case, three of the seven lighting appliances would be measured during testing – one of each lighting appliance type.

   In cases where multiple lighting appliances can be connected to a single port, as identified in F.4.1.5 a) 19) and F.4.1.5 b) 1), these appliances may be treated as a single appliance or as individual appliances. If treated as a single appliance, all lighting appliances in the chain should be tested together.

d) When connecting a lighting appliance directly to a laboratory power supply, use the appliance operating voltage (Clause FF.5). The DUT shall be powered on and set to the highest output setting. It is only necessary to measure one of each type of identical lighting appliance.

   All DUT luminous flux measurements will be performed with the DUT(s) set to the highest output setting. All DUT luminous flux measurements shall be performed with the DUT(s) set to the highest output setting, unless otherwise specified in the product specification or requested by the client. Additional settings may be tested at the laboratory's discretion.

e) Allow the DUT to stabilize according to H.5.3.

f) Record the voltage and current drawn by the DUT at the DUT's input connector.

g) When powering DUT lighting appliances with a product's power control unit, record the voltage and current at the power control unit's battery input connector.

I.4.2 Calculation for lighting appliances tested according to IEC TS 62257-12-1

If a lighting appliance without an internal battery has been tested according to the light output test method of IEC TS 62257-12-1, the light output test need not be repeated provided that the appliance operating voltage as determined in FF.6.3 is within the range of voltages at which relative light output was measured during the input voltage range test of IEC TS 62257-12-1.

The relative light output and luminous flux measurements shall have been made at the setting for which light output is to be calculated. (For example, the relative light output measured at the high setting shall not be used to calculate the light output at the medium setting.) The CRI and CCT values measured in the light output test of IEC TS 62257-12-1 may be used without correction even if the drive voltage was not equal to the appliance operating voltage.

To calculate light output for such a lighting appliance, use the following procedure:

a) Calculate, using linear interpolation, the relative light output at the appliance operating voltage (Clause FF.5), using the relationship between voltage and relative light output measured in the input voltage range test of IEC TS 62257-12-1. (The relative light output at the standard operating voltage defined in IEC TS 62257-12-1 is always 100 %.)

NOTE The standard operating voltage from IEC TS 62257-12-1 is not necessarily the same as the standard operating voltage defined in H.5.2.

b) Multiply the relative light output value calculated in a) by the luminous flux value measured in the light output test of IEC TS 62257-12-1.

I.4.3 Luminous flux measurements with an integrating sphere or goniophotometer

Refer to the following standard test methods for the measurement of luminous flux with an integrating sphere or goniophotometer:

- CIE 084;
- CIE 127;
- IESNA LM-78-07;
- IESNA LM-79-08.

I.4.4 Luminous flux measurements using the multi-plane method

I.4.4.1 General

1 lux is equal to 1 lumen per square metre. This relationship is used in this method to obtain total lumen output by determining the average illuminance (lux) on a 1 m^2 surface at six surfaces (left, right, front, back, top, and bottom) that completely encompass the DUT and summing up the zonal lumen output from each of these six surfaces. This method is similar conceptually to the method by which lumen output is calculated by summing zonal lumen output for goniophotometric measurements.

When connecting a lighting appliance to a port on the DUT's power control unit, use the typical battery discharge voltage (Annex M). All of the lighting appliances in the product shall be connected, powered on, and set at their highest output setting. Only one lighting appliance can be tested at a time with this procedure. Other lighting appliances shall be covered or otherwise arranged so that no light from these appliances reaches the measurement plane.

Though all lighting appliances are connected and powered on during the test, for DUTs with multiple identical lighting appliances, it is only necessary to measure one of each type of identical lighting appliance.

EXAMPLE The DUT includes three different types of lighting appliances (e.g. a tube light, four ambient light points, and two more focused light points). In this case, three of the seven lighting appliances would be measured during testing – one of each lighting appliance type.

In cases where, as identified in F.4.1.5 a) 19) and F.4.1.5 b) 1), multiple lighting appliances can be connected to a single port, these appliances may be treated as a single appliance or as individual appliances. If treated as a single appliance, all lighting appliances in the chain should be tested together.

If the lighting appliance is to be connected directly to a laboratory power supply as described in G.4.4 d), rather than to a port on the DUT's power control unit, use the appliance operating voltage (Annex FF.5). The DUT shall be powered on and set to the highest output setting. Additional settings may be measured at the discretion of the test laboratory to verify truth in advertising statements from the manufacturer when other light settings are advertised, or as required in the product specification. It is only necessary to measure one of each type of identical lighting appliance.

I.4.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Illuminance meter.
- Multi-plane test apparatus (described below).
- DC power supply.
- DC voltmeter or multimeter.
- DC ammeter.

I.4.4.3 Test prerequisites

See general procedure (I.4.1).

I.4.4.4 Apparatus

The test requires a lighting distribution grid surface that can hold an illuminance meter over a 1 m^2 surface with 0,1 m spacing – an 11 × 11 grid with 121 points (Figure I.1). The 81 interior points each represent 100 cm^2 of surface area, the 36 edge points each represent 50 cm^2 of surface area, and the four corner points represent 25 cm^2 of surface area. The light is fixed 0,5 m away from the centre of the grid surface (the 0,5 m is measured from the centre of the light source itself).

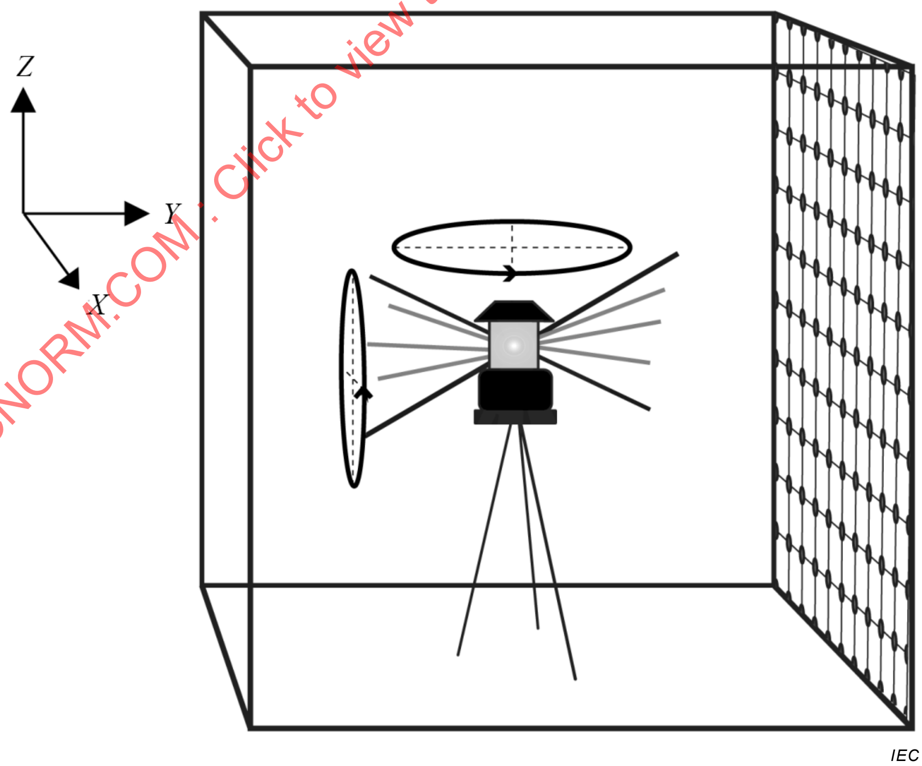


Figure I.1 – Conceptual schematic of the light output test setup, including the 11 × 11 grid, Cartesian coordinate axes for rotation reference, and the DUT

I.4.4.5 Procedure

In general, the light shall be situated so the first surface that is measured is the one that contains the peak of the overall light distribution. Subsequently, the light is carefully rotated to capture the other five surface measurements. Three of the remaining five positions are achieved by rotating the lamp exactly 90° about the vertical (Z) axis between each measurement. The remaining two positions are achieved by rotating the light about the horizontal (X) axis (see Figure I.1). After every rotation, the centre point of the light source should be exactly 0,5 m from the illuminance meter's sensor when it is placed in the centre of the measurement plane. The DUT shall be mounted using a turntable (rotating platform) or a clamping system.

Be sure no stray light hits the photometer and no reflections from other surfaces in the room interfere with the readings. Installing a black curtain around the test setup and having the test operator wear all black are recommended.

The following steps shall be followed.

a) Arrange the room and prepare the DUT, ensuring the stand can hold the DUT steadily and enables precise rotation.

b) Supply power to the DUT and allow the DUT to stabilize according to I.4.1.

c) Position the DUT such that the centre of its light source is 0,5 m away from the centre of the grid surface as shown in Figure I.1.

d) The centre of the grid surface shall read the highest light output provided by the DUT at a 0,5 m distance.

e) Measure illuminance levels at every 0,1 m distance on the grid surface, with the illuminance meter co-planar to the measurement grid (not normal to the light source).

f) Measure illuminance levels for the grid points that read a lux value greater than the resolution of the illuminance meter and greater than 0,2 % of the maximum lux reading from the first surface measured.

g) Rotate the DUT 90° clockwise, repositioning the DUT, if necessary, such that the centre point of the light source is exactly 0,5 m from the illuminance meter's sensor. It is also permissible to rotate the measurement grid about the DUT. Repeat steps d) through g) for the two remaining side faces until reaching the initial position.

h) Tilt the DUT 90° down (about the X axis) and reposition the DUT, if necessary, such that the centre point of the light source is exactly 0,5 m from the illuminance meter's sensor. It is also permissible to rotate the measurement grid about the DUT.

i) Measure illuminance levels for the grid points that read a lux value greater than the resolution of the illuminance meter and greater than 0,2 % of the maximum lux reading from the first surface measured.

j) Tilt the DUT 180° up (about the X axis) and reposition the DUT, if necessary, such that the centre point of the light source is exactly 0,5 m from the illuminance meter's sensor. It is also permissible to rotate the measurement grid about the DUT.

k) Measure illuminance levels for the grid points that read a lux value greater than the resolution of the illuminance meter and greater than 0,2 % of the maximum lux reading from the first surface measured.

I.4.4.6 Calculations

The illuminance data are used to estimate the DUT's luminous flux output. The six measured sides have virtually enclosed the light source within a box. All the illuminance values over the virtual surfaces will be integrated to calculate an estimate for luminous flux.

a) Estimate the luminous flux incident on the first measured surface: multiply the illuminance values by the appropriate area each one represents (0,01 m^2 for interior points, 0,005 m^2 for edge points, and 0,0025 m^2 for corner points) to obtain the luminous flux (lm) represented by each illuminance measurement.

b) Sum the luminous flux measurements over the entire surface.

c) Repeat step a) to calculate the luminous flux for the remaining five sides.

d) Total the luminous flux estimates over all six sides to obtain an estimated constant-voltage total luminous flux emitted from the DUT.

I.5 Correlated colour temperature (CCT) measurement

Measurement of correlated colour temperature shall be made in accordance with CIE 15:2004.

I.6 Colour rendering index (CRI) measurement

Measurement of colour rendering index (R_a) shall be made in accordance with CIE 13.3 and CIE 177.

I.7 Reporting

Report the following in the light output test report.

- Metadata:
  - report name;
  - procedure(s) used;
  - DUT manufacturer;
  - DUT name;
  - DUT model number;
  - DUT setting;
  - test room temperature (°C);
  - name of test laboratory;
  - approving person;
  - date of report approval.
- Results for tested DUT aspects for samples 1 through n:
  - drive current (A);
  - drive voltage (V);
  - stabilisation time (min);
  - total constant-voltage luminous flux (lm);
  - correlated colour temperature;
  - colour rendering index.
- Average of n sample results for each DUT aspect tested.
- Coefficient of variation of n sample results for each DUT aspect tested (%).
- DUT's rating for aspects tested, if available.
- Deviation of the average result from the DUT's rating for each aspect tested, if available (%).
- Comments:
  - individual comments, as necessary, for samples 1 through n;
  - overall comments, as necessary, for collective set of samples 1 through n.

Annex J
(normative)

Lumen maintenance test

J.1 Background

An important performance metric for LED lights is consistent luminous flux over the product's lifetime. The lifetime of LEDs is strongly influenced by electrical operating conditions and thermal management. Further criteria which can accelerate degradation include the quality of the phosphor used in white LEDs, component level chip design and LED packaging materials and processes, and the environmental stability of secondary optical components in the product housing. Assuming that an overall lifetime of 5 years and a daily burn time (DBT) of 4 h are achieved, this results in a total operation time of 7 300 h.

Examination of the lumen maintenance of LED light sources and products is performed in a long-term test of either the individual LED components or the entire LED product. LED components are sometimes tested by the LED manufacturer for a minimum of 6 000 h under IESNA LM-80-08. Because of time constraints, however, it is generally not practical to measure a complete LED lighting product over its entire expected lifespan. The test methods described in this module take two different approaches to estimating lumen maintenance.

The first approach monitors the DUT's light output over a fixed period of operation in order to identify and flag products that are found to suffer significant lumen depreciation. An initial screening method is described which monitors light output for 500 h (approximately 3 weeks) as well as a longer term evaluation in which light output is monitored for 2 000 h (approximately 12 weeks).

For the 2 000 h test, a $L_{90} \geq$ 2 000 h judgment may be made at 1 000 h if all tested product samples maintain ≥ 95 % lumen maintenance (L_{95}) for the entire 1 000 h. Testing has shown that these products are very likely to have L_{70} greater than 2 000 h.

Several of the tests used to evaluate solar LED products are relatively short-term, thus allowing a single test sample to be used on several different tests. Because the lumen maintenance test requires a sample to be dedicated for such a long period of time (up to 12 weeks), test samples should be dedicated to this test until the test is completed. In cases where the battery is not required to conduct the lumen maintenance test, the DUT's battery can be used for other testing (e.g. battery durability testing).

The second approach is an alternate method for estimating lumen maintenance that uses an IESNA LM-80-08 (LM-80) test report from the manufacturer of the LED component. The temperature of the LED(s) in the DUT are measured and compared to the LM-80 data for the component LED(s) and an estimate is reported. The initial screening method monitoring light output for 500 h is still performed, but no further lumen maintenance tests are required. This method therefore represents a faster assessment of a product's lumen maintenance performance.

J.2 Test outcomes

The lumen maintenance test outcomes are listed in Table J.1.

Table J.1 – Lumen maintenance test outcomes

Metric	Reporting units	Related aspects	Notes
Lumen maintenance at 2 000 h	%	4.2.4.2 2 000 h lumen maintenance	The percentage of initial light output (time = 0 h) that the product generates at the end of the test (time = 2 000 h).
Lumen maintenance at 1 000 h	%	4.2.4.2 2 000 h lumen maintenance	The percentage of initial light output (time = 0 h) that the product generates at the mid-point of the test (time = 1 000 h); this may be used as a provisional result at the discretion of stakeholders.
Lumen maintenance at 500 h	%	4.2.4.1 500 h lumen maintenance	The percentage of initial light output (time = 0 h, after the initial 60 min warm-up period) that the product generates at the end of the test (time = 500 h).

J.3 Related tests

Annex J is not related to any of the other annexes.

J.4 Procedure

J.4.1 General

Similar to the full-battery run time test (Annex M), the lumen maintenance test requires an accurate measurement of relative light output over time. Measurements shall be taken in a conditioned space such that the air temperature is 22 °C ± 5 °C. There are three approved methods for making these measurements:

- Fixed geometry method (J.4.4.1).
- Photometer box method (J.4.4.2).
- Integrating sphere method (J.4.4.3).

For DUTs with multiple identical lighting appliances, it is only necessary to measure one of each type of identical lighting appliance; therefore, it is not necessary for all the product's lighting appliances to be running during the duration of the test. The lighting appliances shall be measured individually (i.e. one lighting appliance is placed inside the test enclosure and the others are powered on but left outside the enclosure during the measurement).

EXAMPLE The DUT includes three different types of lighting appliances (e.g. a tube light, four ambient light points, and two more focused light points). In this case, three of the seven lighting appliances would be measured during testing – one of each lighting appliance type.

Interruptions (e.g. due to power outages) are permitted as long as the cumulative time used to establish the 2 000 h, 1 000 h, or 500 h lumen maintenance levels represents the actual run time (ON time) of the DUT. The OFF time during interruptions shall not count towards the 2 000 h, 1 000 h, or 500 h run time. When returning power to the DUT after an interruption, a 20 min warm-up period shall be observed before restarting the cumulative time.

Two tests are defined: a full lumen maintenance characterization in which DUTs are tested for 2 000 h and an initial screening test in which DUTs are tested for 500 h. The measurement schedule for the full screening test is given in Table J.2, and the schedule for the initial screening test is given in Table J.3. In the tables, values with no tolerances represent the maximum allowed intervals between measurements; more frequent measurements are acceptable. Measurements with tolerances shall be made at the time indicated.

Table J.2 – Measurement schedule for full screening test

Measurement number	Time interval h	Cumulative time h
1	1 h ± 5 min	0
2	24	24
3	48	72
4	48	120
5	48	168
6	48	216
7	168	384
8	168	552
9	168	720
10	168	888
11	112	$1\,000^{+24}_{0}$
12	224	1 224
13	168	1 392
14	168	1 560
15	168	1 728
16	168	1 896
17	104	$2\,000^{+24}_{0}$

Table J.3 – Measurement schedule for initial screening test

Measurement number	Time interval h	Cumulative time h
1	1 h ± 5 min	0
2	24	24
3	48	72
4	48	120
5	48	168
6	48	216
7	168	384
8	116	500^{+24}_{0}

J.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- DC power supply.
- DC voltmeter or multimeter.
- DC ammeter, or current shunt and voltmeter/multimeter.
- Illuminance meter (unless using an integrating sphere system).
- Fixed-geometry apparatus, photometer box, or integrating sphere system.

Since the current-sensing element is left in place for the duration of the test, it is generally most convenient to use a current-sensing resistor (current shunt) for each DUT. The voltage across the resistor can be measured with a multimeter when each measurement is taken.

J.4.3 Test prerequisites

The DUT shall have been prepared as described in Annex G.

J.4.4 Test methods

J.4.4.1 Fixed geometry method

J.4.4.1.1 Apparatus

The apparatus for the method is simply any dedicated space in which the DUT and the photometer are secured so they do not move relative to one another during testing and so no outside light is received. This could be a dedicated area in a "dark room" in which the photosensor and DUT are secured, or other similar setup.

J.4.4.1.2 Procedure

The following steps shall be followed.

a) Supply power to the lighting appliance according to I.4.1, except that the standard operating voltage (H.5.2) shall be used in place of the typical battery discharge voltage, and a fixed stabilization period of 60 min ± 5 min shall be used.

b) Place the DUT and the illuminance meter in fixed locations relative to one another for the duration of the test. Ensure that the DUT and the photometer are secured such that exactly the same alignment is maintained for each measurement and that no stray light (e.g. ambient light, light from other test samples, etc.) is able to reach the light sensor.

c) Refer to Table J.2 (full screening test) or Table J.3 (initial screening test) for the minimum frequency at which the relative illuminance of the DUT, ambient temperature, DUT voltage, and current are measured and recorded. The voltage measurement shall be made as close to the DUT as possible. A data logger or a lux meter with a data-logging function may be used to record the illuminance, or the measurements may be taken manually.

J.4.4.2 Photometer box method

J.4.4.2.1 Apparatus

The apparatus for the method is a photometer box, as described in the full-battery run time test (Annex M).

J.4.4.2.2 Procedure

The following steps shall be followed.

a) Supply power to the lighting appliance according to I.4.1, except that the standard operating voltage (H.5.2) shall be used in place of the typical battery discharge voltage, and a fixed stabilization period of 60 min ± 5 min shall be used.

b) The relative illuminance is measured using the photometer box.

c) The location of the DUT in the photometer box shall 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.

d) For the following measurements, the DUT shall be placed in the photometer box with exactly the same alignment and orientation.

e) Refer to Table J.2 (full screening test) or Table J.3 (initial screening test) for the minimum frequency at which the relative illuminance of the DUT, ambient temperature, DUT voltage, and current are measured and recorded. The voltage measurement shall be made as close to the DUT as possible. In the case that the DUT remains in the box throughout the duration of the test, a data logger or a lux meter with a data-logging function may be used to record the illuminance, or the measurements may be taken manually.

J.4.4.3 Integrating sphere method

The following steps shall be followed.

a) Supply power to the lighting appliance according to I.4.1, except that the standard operating voltage (H.5.2) shall be used in place of the typical battery discharge voltage, and a fixed stabilization period of 60 min ± 5 min shall be used.

b) The luminous flux is measured using an integrating sphere system.

c) Refer to Table J.2 (full screening test) or Table J.3 (initial screening test) for the minimum frequency at which the luminous flux of the DUT, ambient temperature, DUT voltage, and current are measured and recorded. The voltage measurement shall be made as close to the DUT as possible.

J.5 Calculations

Lumen maintenance is calculated by dividing the final light output reading by the initial light output reading and is expressed as a percentage. Lumen maintenance is always reported along with the test duration.

The lumen maintenance percentage may be calculated by linearly interpolating between the two measurements that bracket the target time (e.g. 2 000 h, 1 000 h, or 500 h), provided that the measurement schedule in Table J.2 or Table J.3 is followed. If the measurement is made within 8 h of the target time, the measured value may be reported without correction.

J.6 Alternate method for testing lumen maintenance using IESNA LM-80-08

J.6.1 Background

The lumen maintenance of an LED or LED array contained in a lighting product can be estimated by measuring the LED case temperature(s) (T_C). This measurement is compared to IESNA LM-80-08 data (minimum 6 000 h) from the LED manufacturer to estimate the DUT's lumen maintenance at 2 000 h.

The LED case temperature (T_C) measurement location, also sometimes referred to as the LED temperature measurement point (TMP), is established by the LED manufacturer. T_C is related to the temperature of the LED die and is measured by attaching a thermocouple as close to the LED component as possible on a printed circuit board pad adjacent to the LED. This measurement location may be one of the LED lead pads or may be a separate, electrically neutral pad on the printed circuit board configured as a heat sink for the LED. The LED manufacturer will have information on the correct TMP for the LED that was used during the LM-80-08 tests. The DUT manufacturer shall provide a TMP for the LEDs in the product that matches the T_C measurement location used for the LM-80 tests. This is often done by using the same printed circuit board pad configuration that was used for the LM-80 tests in the design of the DUT.

This LED temperature procedure tests the instantaneous LED temperature during normal operation to make an LED lumen maintenance assessment. It does not test longer duration operation of the LED or LED drive circuitry. To assess the ability of the DUT electronics to drive the LED(s) over a longer time period, a 500 h initial screening test shall also be performed as described in J.4.1.

J.6.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Thermocouple meter and thermocouple
- DC ammeter or multimeter
- DC power supply

NOTE For thermocouples, ammeter, and power supply, Table CC.2 includes requirements and recommendations specific to Clause J.6.

- DC voltmeter or multimeter
- Soldering apparatus or thermally conductive adhesive/epoxy
- White tape or heat-shrink tubing

Small gauge type T thermocouples (wire diameter ≤ 0,13 mm) are recommended and can be readily soldered to copper circuit board pads. Other thermocouples are acceptable but require the appropriate soldering flux and can be difficult to solder.

Equipment requirements for the 500 h test, performed in J.6.4 h), are given in J.4.2.

J.6.3 Test prerequisites

This test shall not be performed unless all of the following criteria are met.

- The DUT manufacturer has supplied the DUT LED component specification(s), including the complete component number and the LED specification document from the LED manufacturer.
- The DUT manufacturer has supplied IESNA LM-80-08 (LM-80) test data for the LED(s) used in the lighting product. LM-80 testing is typically done by the LED manufacturer. The laboratory performing the LM-80 test shall be accredited to do this type of testing.
- The DUT manufacturer has supplied an LED RMS drive current measurement at the product’s highest light setting.
- The LM-80 test data includes an LED case temperature (T_C) and LED drive current higher than the DUT’s LED case temperature and drive current.
- The DUT is designed in such a way as to allow temperature measurement of the LED T_C as specified by the LED manufacturer.
- The DUT manufacturer has provided instructions and diagrams showing the appropriate attachment point for thermocouples used during the test.

Additional requirements may be stated in the product specification.

J.6.4 Procedure

Perform the following procedure.

a) Review documentation supplied by the DUT manufacturer to confirm that the DUT qualifies for testing using this method.

b) Prepare the DUT for LED testing as outlined in J.6.5 below.

c) Attach thermocouples to one or more LED(s) as outlined in J.6.5 below.

d) Reassemble the product and orient in its normal operating position. The DUT shall be operated in a 22 °C ± 5 °C still air environment free from drafts, fans, and other air currents that could produce forced air convective currents and contribute to the cooling of the product.

e) Supply power to the lighting appliance according to I.4.1, except that the standard operating voltage (H.5.2) shall be used in place of the typical battery discharge voltage.

f) Allow the product to thermally stabilize for a minimum of 1 h. The LED case temperatures should be monitored to confirm thermal stabilization.

g) Record the LED case temperature (T_C).

h) Prepare the DUT for initial screening and perform a 500 h test as described in J.4.1. Only two measurements are required: one at the end of the stabilization period (60 min ± 5 min), and a final measurement at 500 $^{+24}_{0}$ h (not including the stabilization time).

J.6.5 DUT preparation and LED thermocouple attachment guidelines

The LED(s) in the DUT shall be accessed to allow the attachment of thermocouple wires. When opening the DUT optical housing to access the LED(s), the normal operating environment shall be preserved to the maximum degree possible. Holes drilled into compartments should be as small as possible and covered with tape to prevent additional air movement during operation. The T_C location of the LED(s) shall be accessible to allow thermocouple attachment without disturbing the normal operation of the array.

A thermocouple shall be attached to an LED's temperature measurement point by soldering or gluing using a thermally conductive adhesive/epoxy. The attachment method shall ensure adequate thermal contact between the thermocouple and the TMP. The thermocouple attachment, including any additional solder or epoxy, shall be as small as possible to prevent an additional heat conduction pathway that could artificially contribute to the heat sinking of the LED component. LED(s) with large thermal pads or heat sinks can require preheating to facilitate soldering the thermocouple to the TMP or T_C measurement location.

Thermocouple wire should be routed away from direct illumination by the LED(s) and/or should be shielded from direct light to prevent artificial heating of the wire. This can usually be accomplished with white tape or white heat-shrink tubing. Tape or tubing should not cover the LED in a way that could increase the self-heating of the LED component.

When testing a DUT with multiple LEDs in an LED array, the test lab shall attempt to identify the LED in the array that will experience the highest temperature in operation. In practice, this is often an LED located in the centre of the array. Measurements on multiple LEDs in an array may be warranted to adequately identify the T_C value used for an LM-80 assessment.

J.6.6 Calculations

The LM-80 test report for the DUT LED will contain lumen maintenance data for LED temperature measurements at 55 °C, 85 °C, and one additional temperature chosen by the LED manufacturer. These measurements are performed for a minimum duration of 6 000 h and will therefore contain test data at 2 000 h.

The test lab shall compare the LM-80 data and T_C to estimate the lumen maintenance of the product. The test lab shall use the nearest LM-80 data point above the duration (> 2 000 h), DUT T_C, and LED drive current.

EXAMPLE If the DUT T_C is measured at 65 °C, LM-80 data at 85 °C (or greater than 65 °C when available) would be used. If the DUT LED drive current is 65 mA, the LM-80 data would be at drive currents greater than 65 mA.

The test lab shall report the lumen maintenance of the DUT as the lumen maintenance measured by the nearest (higher conditions for T_C and drive current) LM-80 test data as specified above.

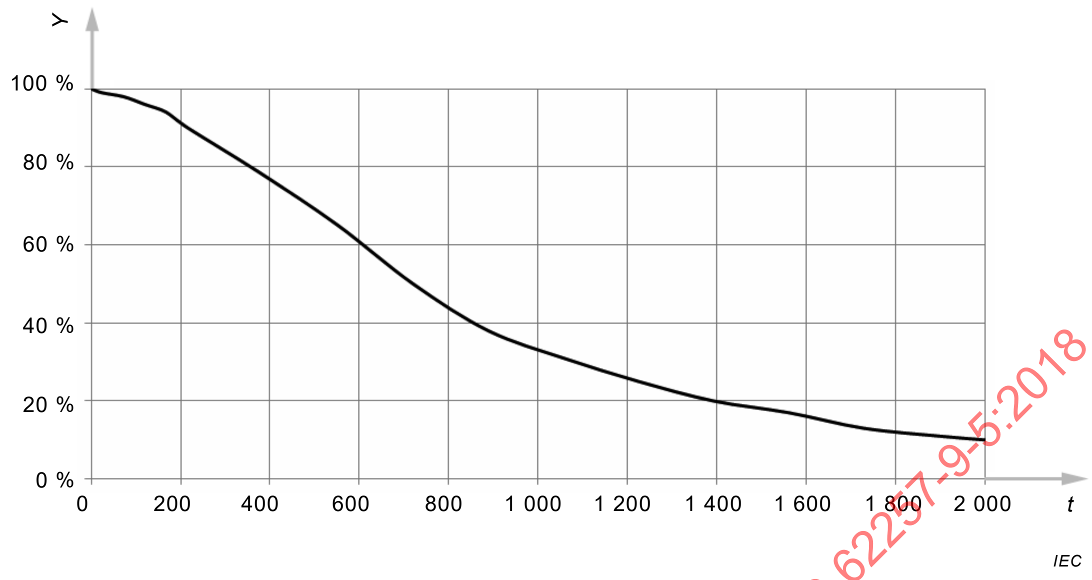
J.7 Reporting

Report the following in the lumen maintenance test report.

- Metadata:

- report name;
- procedure(s) used;
- DUT manufacturer;
- DUT name;
- DUT model number;
- DUT setting;
- test room temperature (°C);
- name of test laboratory;
- approving person;
- date of report approval.

- Results for tested DUT aspects for samples 1 through n:
  - drive current (A);
  - drive voltage (V);
  - stabilisation time (min);
  - lumen maintenance (note if at 500 h, 1 000 h, or 2 000 h) (%);
  - if applicable, LED case temperature (T_C).
- Average of n sample results for each lumen maintenance DUT aspect tested.
- Coefficient of variation of n sample results for each lumen maintenance DUT aspect tested (%).
- DUT's rating for lumen maintenance aspects tested, if available.
- Deviation of the average result from the DUT's rating for each lumen maintenance aspect tested, if available (%).
- Comments:
  - individual comments, as necessary, for samples 1 through n;
  - overall comments, as necessary, for collective set of samples 1 through n.
- Figures:
  - plot of lumen maintenance (see example in Figure J.1).
- Datasets:
  - table with all illuminance or flux, ambient temperature, DUT voltage, and current measurements.



Key

t Time (h)

Y Relative luminous flux

Figure J.1 – Example lumen maintenance plot

Annex K
(normative)

Battery test

K.1 Background

The battery test is used to determine the DUT's actual battery capacity and round-trip energy efficiency. This information is useful to determine if a battery is mislabelled or damaged. During the test, the battery is connected to a battery analyser, which performs charge-discharge cycles on the battery. The last charge-discharge cycle data from the battery test is analysed to determine the actual battery capacity and battery round-trip energy efficiency.

K.2 Test outcomes

The test outcomes of the battery test are listed in Table K.1.

Table K.1 – Battery test outcomes

Metric	Reporting units	Related aspects	Note
Battery capacity (C_b)	Ampere-hours (Ah) at a specific discharge current	4.2.5.1 Battery capacity	--
Battery round-trip energy efficiency (η_b)	Percentage (%)	4.2.5.2 Battery round-trip energy efficiency	At least two complete charge-discharge cycles are required for the calculation.

K.3 Related tests

The battery test results are inputs to the full-discharge preparation procedure (Annex N), the solar charge test (Annex R), the battery durability test (Annex BB), and the energy service calculations (Annex GG).

K.4 Procedure

K.4.1 General

Table K.2 contains battery testing information specific to the five common types (i.e., chemistries) of batteries. This information is pertinent to K.4.2.4, K.4.3.4, K.4.4.4, and K.4.5.4.

New or improved battery technologies could emerge for which Table K.2 does not contain information. The test lab should sufficiently research the new or improved battery technology to determine appropriate recommended battery practices for that new or improved battery technology. Communication directly with the supplier of the battery is recommended. For example, if the battery under test is a lithium battery but is not the lithium ion (3,7 V nominal voltage) or lithium iron phosphate chemistry, alternative charging and discharging rates and end-of-cycle voltage parameters should be obtained, preferably from the battery supplier.

In this document, I_t A is defined as the current obtained by dividing the nominal capacity of the battery in Ah by one hour; this definition is consistent with IEC 61960-3:2017 and IEC 61951-2:2017.

Table K.2 – Recommended battery testing parameters

Battery type	Charging				Discharging	
	Charge rate I_t A	Maximum charge voltage V/cell[a]	End-of-charge/ topping charge rate I_t A	End-of-charge time with constant voltage[b] h	Discharge rate I_t A	End-of-discharge voltage V/cell
Lead-acid	0,1	2,40	0,05	10	0,1	1,80
Lithium-ion	0,2	4,20	0,05	1	0,2	3,00
Lithium iron phosphate	0,2	3,60	0,01	1	0,2	2,50

Battery type	Charging			Discharging	
	Charge rate I_t A	Overcharge (charge factor)	Partial charge duration[c] h	Discharge rate I_t A	End-of-discharge voltage V/cell
Nickel-metal hydride	0,1	1,6	9	0,2	1,00

[a] For safety, never exceed the battery supplier's specified maximum allowable voltage.

[b] After a battery is charged to a specified voltage, it may be topped off using the recommended end-of-charge/ topping charge rate, or alternatively the battery may be topped off by supplying a constant voltage (the maximum charge voltage) over the recommended end-or-charge time.

[c] This value is used for measuring the battery efficiency only.

If cell balancing or individual cell monitoring circuitry is external to the battery, or a battery protection circuit other than the one incorporated into the DUT is used during the procedure, the usable capacity of the battery may differ when measured without the DUT’s circuitry included or with cell monitoring circuitry supplied by the laboratory. In cases where the test results are disputed for this reason, the battery capacity may also be evaluated by disassembling the battery pack and performing the test on a single cell (or parallel cellblock). The positions of the cells or cellblocks to test should be selected randomly in a way that maximizes coverage. The capacity of the entire pack may be assumed to be equal to the capacity of the selected cell or parallel cellblock. If the battery under test is to be used for further testing, all cells of the battery shall be returned to a balanced state of charge prior to further testing, e.g. by fully discharging or charging the cells under test to match the state of charge of the other cells in the pack.

K.4.2 Lead-acid battery test

K.4.2.1 General

The DUT’s valve-regulated or flooded lead-acid battery is cycled on a battery analyser, and the data from the final charge-discharge cycle is used to determine the actual battery capacity and round-trip energy efficiency.

If the DUT is a flooded lead-acid battery that was shipped dry, add acid according to the following directions:

a) Fill the battery with battery acid. The correct volume and density shall be determined from either the manufacturer-supplied information or the battery packaging. If the values from these two sources conflict, consult the manufacturer.

b) Measure the voltage and density immediately after filling the battery, and again 30 min after filling.

c) If after 30 min, the voltage is greater than 2,0 V/cell, continue with the battery test procedure (K.4.2.4).

d) If after 30 min the voltage is less than 2,0 V/cell, the density has dropped, and the battery temperature has increased, then the negative electrode (Pb) is likely oxidized. If the negative electrode is oxidized, remove the oxidation by overcharging using a 24 h IU charge (a constant current charge followed by a float charge held at a constant voltage with a total duration of 24 h). A charge rate of 0,1 I_t A (calculated using the battery's rated capacity) shall be used for the I phase (constant-current), and a voltage of 2,45 V shall be used for the U phase (float charge). The relatively high voltage and duration of this charge can cause the battery to produce hydrogen and oxygen, a combustible gas mixture. Conduct this procedure outdoors or in a well-ventilated room.

If, after 30 min, the battery voltage is less than 2,0 V/cell, but the density has not dropped or the temperature has not risen, the battery could have defects that cannot be addressed by overcharging. Attempt the overcharging procedure, but note that the battery conditions indicate possible defects.

K.4.2.2 Equipment requirements

A battery analyser meeting the requirements in Table CC.2 is required.

A DC power supply is needed in some cases, depending on the battery tested and the battery analyser in use.

K.4.2.3 Test prerequisites

The battery may be taken out of the DUT for this test, if desired. The DUT shall have been prepared as described in Annex G. The test shall be carried out at 22 °C ± 5 °C.

K.4.2.4 Procedure

Perform the capacity test from IEC 61427-1:2013, 8.1 (which references IEC 61056-1), with the following modifications.

- Perform a minimum of five charge-discharge cycles to ensure that the battery is sufficiently exercised prior to determining capacity and to ensure that enough data are available to calculate round-trip energy efficiency. Use the final charge-discharge cycle to calculate the battery's actual capacity and round-trip energy efficiency.
- Carry out the test at 22 °C ± 5 K.
- The battery shall be kept at open circuit for 1 h to 24 h after charging before starting each discharge. (It is not necessary to wait 5 h as required by IEC 60156-1.)
- Equipment need not meet the accuracy requirements of IEC 61427-1:2013 or IEC 61056-1, provided that it meets the requirements of Table CC.2.
- Record the current at an interval of 1 min or less.
- The capacity test from IEC 61056-1, as referenced by IEC 61427-1:2013, may be used for flooded lead-acid batteries; it is not necessary to use the test from IEC 60896-11.

If the battery contains internal circuitry (refer to F.4.3.5) and either the battery analyser will not start the test or the tester decides that the results from the test are unexpected or faulty in some way, the test may be repeated with the battery analyser connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so.

If the battery will be stored after undergoing this test, charge the battery using the charge information in Table K.2 and disconnect the battery from the DUT. Charge the battery every six months, or every three months if stored at a temperature greater than 30 °C.

If the battery analyser does not recognize the battery upon starting any of the above steps, the battery voltage could have dropped below the battery analyser's minimum threshold. If this is the case, a power supply shall be used to charge the battery in accordance with IEC 61427-1:2013 before the battery capacity is determined. Alternatively, the battery may be connected back into the DUT to receive a charge via solar or other means according to the product user's manual.

K.4.2.5 Calculations

Perform the following calculations.

a) Determine the total energy input into the battery during the final charge cycle (E_c) using the following formula:

$$E_c = \sum \left(V_c \cdot I_c \cdot \Delta t \right)$$

where

E_c is the energy entering the battery during the charge cycle, in watt·hours (Wh);

V_c is the voltage recorded during the charge cycle, in volts (V);

I_c is the current recorded during the charge cycle, in amperes (A);

Δt is the time interval between measurements, in hours (h).

b) Determine the total energy output from the battery during the final discharge cycle using the following formula:

$$E_d = \sum \left(V_d \cdot I_d \cdot \Delta t \right)$$

where

E_d is the battery's energy output during the discharge cycle, in watt·hours (Wh);

V_d is the voltage recorded during the discharge cycle, in volts (V);

I_d is the current recorded during the discharge cycle, in amperes (A);

Δt is the time interval between measurements, in hours (h).

c) Determine the battery capacity with data from the final discharge cycle using the following formula:

$$C = \sum \left(I_d \cdot \Delta t \right)$$

where

C is the measured battery capacity, in ampere-hours (Ah);

I_d is the current recorded during the discharge cycle, in amperes (A);

Δt is the time interval between measurements, in hours (h).

d) For lead-acid batteries only, correct the capacity to the reference temperature of 25 °C using the following formula (from IEC 60896-21), with λ set to 0,006 K^{-1}:

$$C_a = C \Big/ \left(1 + \lambda \left(T - 25\ °C \right) \right)$$

where

C_a is the actual battery capacity, in ampere-hours (Ah);

C is the measured battery capacity, in amperes (A);

λ is 0,006 K^{-1};

T is the battery temperature at the start of the final discharge cycle, in degrees Celsius (°C).

e) Determine the battery round-trip energy efficiency using the following formula:

$$\eta_b = \frac{E_d}{E_c}$$

where

η_b is the battery's round-trip energy efficiency;

E_d is the battery's energy output during the final discharge cycle, in watt·hours (Wh);

E_c is the energy input to the battery during the final charge cycle, in watt·hours (Wh).

Report the actual capacity (i.e. the value that has been corrected to 25 °C).

K.4.3 Nickel-metal hydride battery test

K.4.3.1 General

The DUT's nickel-metal hydride battery is cycled on a battery analyser, and the data from the final charge-discharge cycle is used to determine the actual battery capacity and battery round-trip energy efficiency.

The nickel-metal hydride battery test procedure refers to the overcharge charging method, whereby the battery is charged at constant current for a fixed duration given by the following formula:

$$T_c = OC \cdot \frac{C_b}{I_c}$$

where

T_c is the duration of the charge cycle, in hours (h);

OC is the overcharge (charge factor) value given in Table K.2;

C_b is the measured or rated battery capacity, in ampere-hours (Ah);

I_c is the charge current, in amperes (A).

K.4.3.2 Equipment requirements

A battery analyser meeting the requirements in Table CC.2 is required.

K.4.3.3 Test prerequisites

The battery may be taken out of the DUT for this test, if desired. The DUT shall have been prepared as described in Annex G. The test shall be carried out at 22 °C ± 5 °C. As specified in IEC 61951-2:2017, the test shall be carried out at a relative humidity of 65 % ± 20 %.

K.4.3.4 Procedure

Perform the capacity test from IEC 61951-2:2017, 7.3.2, using the charging and discharging parameters given in Table K.2, with the following modifications.

- Perform a minimum of five charge-discharge cycles to ensure that the battery is sufficiently exercised prior to determining capacity. Use the final charge-discharge cycle to calculate the battery's actual capacity.
- Record the current at an interval of 1 min or less.

Measure the round-trip energy efficiency using the following procedure:

a) Charge the battery at constant current for a fixed duration, using the charge rate and partial charge duration given in Table K.2. After charging, the battery shall be stored in an ambient temperature of 22 °C ± 5 °C for not less than 1 h and not more than 24 h.

b) Discharge the battery using the discharge information in Table K.2.

c) Repeat steps a) and b) once more. Calculate the battery storage efficiency according to K.4.2.5 using the data from this final charge-discharge cycle.

If the battery contains internal circuitry (refer to F.4.3.5) and either the battery analyser will not start the test or the tester decides that the results from the test are unexpected or faulty in some way, the test may be repeated with the battery analyser connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so.

If the battery analyser does not recognize the battery upon starting any of the above steps, the battery output could have dropped to 0 V. If this is the case, a constant-current charge as specified in Table K.2 of Annex K from a power supply may be used to bring the battery out of a 0 V state of charge before the battery capacity is determined. Alternatively, the battery may be connected back into the DUT to receive a charge via solar or other means according to the product user's manual.

Nickel-based batteries need not be charged prior to storage; however, batteries should be disconnected from the DUT prior to long-term storage to avoid polarity reversal. It is often convenient to end the battery test with a charge to allow for further testing.

K.4.3.5 Calculations

Perform the calculations listed in K.4.2.5, omitting step d). Use the partial charge-discharge cycles conducted in K.4.3.4 a) through c) in the calculation of round-trip energy efficiency.

K.4.4 Lithium-ion battery test

K.4.4.1 General

The DUT's lithium-ion battery is cycled on a battery analyser, and the data from the final charge-discharge cycle is used to determine the actual battery capacity and battery round-trip energy efficiency.

K.4.4.2 Equipment requirements

A battery analyser meeting the requirements in Table CC.2 is required.

For battery packs containing more than one cell in series, a protection circuit that monitors the voltage of each cell (or each set of cells connected in parallel) should be used during charging, if this functionality is not incorporated into the battery pack. This functionality may be built into the battery analyser or may be a separate piece of equipment. The voltage of each individual cell (or each set of cells connected in parallel) should not be allowed to exceed the maximum battery testing voltage given in Table L.2 unless manufacturer-provided battery specifications indicate that such operation can be performed safely. The temperature of each individual cell should not be allowed to exceed 45 °C. Care should be taken that any voltage drop introduced by the protection circuit (e.g. relay contact resistance) does not affect the results.

K.4.4.3 Test prerequisites

The battery may be taken out of the DUT for this test, if desired. The DUT shall have been prepared as described in Annex G. The test shall be carried out at 22 °C ± 5 °C. As specified in IEC 61960-3:2017, the test shall be carried out in still air. Batteries with multiple cells (or parallel cellblocks) in series shall be prepared according to G.4.4 a).

K.4.4.4 Procedure

Perform the capacity test from IEC 61960-3:2017, 7.3.1, with the following modifications.

- Perform a minimum of five charge-discharge cycles to ensure that the battery is sufficiently exercised prior to determining capacity and to ensure that enough data are available to calculate round-trip energy efficiency. Use the final charge-discharge cycle to calculate the battery's actual capacity and round-trip energy efficiency.

- Charge and discharge the battery using the information in Table K.2 – calculated using the battery's rated capacity.
- Record the current at an interval of 1 min or less.

If the battery contains internal circuitry (refer to F.4.3.5) and either the battery analyser will not start the test or the tester decides that the results from the test are unexpected or faulty in some way, the test may be repeated with the battery analyser connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so.

If the battery will be stored after undergoing this test, charge the battery using the charge rate specified in Table K.2 for 2,5 h (i.e., store at 50 % state of charge) and disconnect the battery from the DUT.

If the battery analyser does not recognize the battery upon starting any of the above steps, the battery could have been disconnected by its internal protection circuit. In this case, the voltage at the battery terminals will be zero, which can prevent the battery analyser from recognizing the battery. In this situation, a current-limited constant-voltage charge, at a current no higher than that specified in Table K.2 of Annex K from a power supply may be required to re-enable the battery before the battery capacity is determined. If the cell voltage has decreased below 2,5 V for lithium iron phosphate or 3,0 V for other lithium-ion, perform the charge at 0,1 I_t A. The voltage shall not exceed the value given in Table K.2. It is recommended to set the power supply to the lowest possible voltage that will allow the battery analyser to recognize the battery and complete the charge cycle. Alternatively, the battery may be connected back into the DUT to receive a charge via solar or other means according to the product user's manual. If the battery is suspected to be damaged, it should not be charged using either method. It can be necessary to bypass the battery's internal protection circuit to perform this step; in this case, the cell voltage should be measured prior to charging the battery to ensure that it has not dropped below the minimum battery testing voltage given in Table L.1. If the battery voltage has dropped below the minimum battery testing voltage, charging the battery can be unsafe; the test laboratory should discontinue the test if in the tester's discretion it would be unsafe to continue.

K.4.4.5 Calculations

Perform the calculations listed in K.4.2.5, omitting step d).

K.4.5 Lithium iron phosphate battery test

K.4.5.1 General

The DUT's lithium iron phosphate battery is cycled on a battery analyser, and the data from the final charge-discharge cycle is used to determine the actual battery capacity and battery round-trip energy efficiency.

K.4.5.2 Equipment requirements

A battery analyser meeting the requirements in Table CC.2 is required.

For battery packs containing more than one cell in series, a protection circuit that monitors the voltage of each cell (or each set of cells connected in parallel) should be used during charging, if this functionality is not incorporated into the battery pack. This functionality may be built into the battery analyser or may be a separate piece of equipment. The voltage of each individual cell (or each set of cells connected in parallel) should not be allowed to exceed the maximum battery testing voltage given in Table L.2 unless manufacturer-provided battery specifications indicate that such operation can be performed safely. The temperature of each individual cell should not be allowed to exceed 45 °C. Care should be taken that any voltage drop introduced by the protection circuit (e.g. relay contact resistance) does not affect the results.

K.4.5.3 Test prerequisites

The battery may be taken out of the DUT for this test, if desired. The DUT shall have been prepared as described in Annex G. The test shall be carried out at 22 °C ± 5 °C. As specified in IEC 61960-3:2017, the test shall be carried out in still air.

K.4.5.4 Procedure

Follow the procedure in K.4.4.4.

K.4.5.5 Calculations

Perform the same calculations listed in K.4.2.5.

K.5 Reporting

Report the following in the battery test report.

- Metadata:
  - report name
  - procedure(s) used
  - DUT manufacturer
  - DUT name
  - DUT model number
  - name of test laboratory
  - approving person
  - date of report approval
- Results for tested DUT aspects for samples 1 through n:
  - battery capacity (Ah) and corresponding discharge current (in terms of I_t A);
  - battery round-trip energy efficiency (%).
- Average of n sample results for each DUT aspect tested.
- Coefficient of variation of n sample results for each DUT aspect tested (%).
- DUT's rating for aspects tested, if available.
- Deviation of the average result from the DUT's rating for each aspect tested, if available (%).
- Comments:
  - individual comments, as necessary, for samples 1 through n;
  - overall comments, as necessary, for collective set of samples 1 through n.

Annex L
(informative)

Battery testing recommended practices

L.1 Background

Several tests in this document involve charging or discharging a battery:

- During the charge controller behaviour test (Annex S), the DUT's battery is either charged or discharged to determine if the DUT has appropriate deep discharge protection and overcharge protection.
- During the grid charge test (Annex O), solar charge test (Annex R), and electromechanical charge test (Annex P), the DUT's battery is charged.
- During the full-battery run time test (Annex M), the DUT's battery is discharged.
- In the appliance full-battery run time test (Clause FF.9), if performed, the appliance's internal battery is discharged.
- In the preparation for the appliance operating voltage range test (Clause FF.8) or measurement of steady-state port characteristics (EE.4.2), each appliance's internal battery, if present, is charged and discharged.

In some cases, it is not known whether the DUT provides sufficient protection to avoid damage to the battery or test apparatus or injury to test laboratory personnel. Annex L provides recommended charging and discharging practices to prevent damage to the DUT and ensure safety of test personnel.

A variety of battery chemistry types are used in products meeting the scope of this document, potentially including types that were not in common use at the date of publication. The information in Table L.1 and Table L.2 is intended to prevent damage to the DUT and test apparatus and ensure safety of test personnel for most common battery types. When possible, battery specifications should be obtained from the battery manufacturer to evaluate whether the protection strategy used by the DUT is appropriate for the specific battery used.

L.2 Deep discharge protection specifications by battery type

Table L.1 contains recommended battery deep discharge protection voltages and minimum battery voltages for four common types (i.e. chemistries) of batteries. If the product or battery manufacturer has not provided an appropriate deep discharge protection voltage cutoff design value for the battery in the manufacturer self-reported information (Annex D), the information in Table L.1 may be used when determining if the DUT has appropriate deep discharge protection.

Table L.1 contains two voltage values for each battery type. The "recommended deep discharge protection voltage" is the recommended setpoint for the DUT's deep discharge protection (low voltage disconnect). The tolerance given is intended to account for measurement uncertainty both in the DUT and in the laboratory apparatus. The "minimum battery testing voltage" is intended to ensure laboratory personnel safety and prevent immediate, permanent damage to the battery. The test laboratory should immediately stop charging a battery if the battery voltage reaches the minimum testing voltage.

If the DUT does not have appropriate deep discharge protection, the battery can be damaged during the full-battery run time and the charge controller behaviour tests. As an option, the tester may incorporate a low-voltage disconnect device that will stop the discharge when the battery reaches the minimum battery testing voltage specified in Table L.1.

Table L.1 – Recommended battery deep discharge protection voltage specifications

Battery type	Deep discharge protection voltage V/cell			Minimum battery testing voltage V/cell
	Recommended	Minimum	Maximum	
Lead-acid	≥ 1,87	1,82	--	none
Lithium-ion	≥ 3,00	2,95	--	2,50
Lithium iron phosphate	≥ 2,50	2,45	--	2,00
Nickel-metal hydride	= 1,00	0,95 [a]	1,10 [b]	0,80 [a]

[a] These limits for NiMH batteries only apply to batteries with multiple cells in series. There is no personnel safety risk from discharging batteries below this limit, but there is a risk of polarity reversal, which can cause irreversible damage to the battery. There is no lower voltage limit for single-cell NiMH batteries.

[b] The intent of this upper limit is to prevent reversible capacity loss due to voltage depression ("memory effect") resulting from partial discharge.

L.3 Overcharge protection specifications by battery type

Table L.2 contains recommended battery overcharge protection voltages and maximum battery voltages and cell temperatures specific to four common types (i.e., chemistries) of batteries. If the product or battery manufacturer has not provided an appropriate overcharge protection voltage cutoff or maximum cell temperature design value for the battery in the manufacturer self-reported information (Annex D), the information in Table L.2 may be used when determining if the DUT has appropriate overcharge protection. The maximum cell temperature should not be exceeded at any time when the battery is being charged.

Table L.2 contains two voltage values for each battery type. The "recommended overcharge protection voltage" is the recommended setpoint for the DUT's overcharge protection (overvoltage protection). The tolerance given is intended to account for measurement uncertainty both in the DUT and in the laboratory apparatus. The "maximum battery testing voltage" is intended to ensure laboratory personnel safety and prevent immediate, permanent damage to the battery. The test laboratory should immediately stop charging a battery if the battery voltage reaches the maximum testing voltage.

Table L.2 – Recommended battery overcharge protection voltage and temperature specifications

Battery type	Overcharge protection voltage V/cell			Maximum battery testing voltage	Maximum charging temperature
	Recommended	Minimum	Maximum	V/cell	°C
Lead-acid	= 2,40	2,35	2,45	2,60	45
Lithium-ion	≤ 4,20	--	4,25	4,26	45
Lithium iron phosphate	≤ 3,65	--	3,70	3,85	45
Nickel-metal hydride	≤ 1,45	--	1,50	1,51	60

Annex M
(normative)

Full-battery run time test

M.1 Background

The full-battery run time captures one of the key system-performance metrics from a user's perspective. It combines the relationship between battery capacity, circuit efficiency, and lighting system power consumption under realistic operating conditions.

A stand-alone renewable energy product can often power several appliances, some of which may have variable power settings. Full-battery run time depends on which appliances are running and at what power settings. The full-battery run time test involves completing a full discharge in at least one configuration. Calculations to estimate the full-battery run time in additional configurations may be performed according to the energy service calculations (Annex GG).

The typical configuration of the full-battery run time test involves operating the DUT with all of its lighting appliances without internal batteries connected and set to the brightest setting. In the case of a simple portable product with a built-in light, the light would be set to the brightest setting. The DUT begins the test with a fully charged battery and runs until the light output has decreased to some pre-defined minimum value (70 % in this case). The full-battery run time is defined as when $\Phi_{\mathrm{v,rel}}$ reaches 70 % of the initial luminous flux $\Phi_{\mathrm{v}}(t_{\mathrm{init}})$.[1]

$$\Phi_{\mathrm{v,rel}} = \Phi_{\mathrm{v}}(t) / \Phi_{\mathrm{v}}(t_{\mathrm{init}})$$

where

$\Phi_{\mathrm{v,rel}}$ is the DUT's relative luminous flux, expressed in lumens (lm);

$\Phi_{\mathrm{v}}(t)$ is the DUT's luminous flux, expressed in lumens (lm), corresponding to 70 % of the DUT's initial luminous flux;

$\Phi_{\mathrm{v}}(t_{\mathrm{init}})$ is the DUT's initial luminous flux, expressed in lumens (lm), measured 20 min into the discharge to account for initial voltage drop.

If a product does not include any lighting appliances, the test is conducted using other included appliances or generic appliances, as described in Clause M.7. For such products, the key test outcome is the energy removed from the battery during the discharge. A full-battery run time in hours is calculated for these products as an intermediate step, but for these appliances it is usually more appropriate to assess the full-battery run time using the energy service calculations (Annex GG), as this allows the full-battery run time to be estimated for each appliance individually and for multiple combinations of appliances.

The full-battery run time test (Annex M) applies to main units, and is also used to assess the full-battery run time of included lighting appliances with internal batteries, and other power control units. For included non-lighting appliances with internal batteries, such as fans, television sets, or radios, the full-battery run time for each appliance may be estimated using one of two options described in Annex FF.

M.2 Test outcomes

The test outcomes of the full-battery run time test are listed in Table M.1.

---

1 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).

Table M.1 – Full-battery run time test outcomes

Metric	Reporting units	Related aspects	Notes
Lighting full-battery run time, to L_{70}	Hours (h)	4.2.8.6 Main unit full-battery run time 4.2.8.7 Appliance full-battery run time	Run time to 70 % of initial light output. This metric also applies to lighting appliances with internal batteries.
Typical battery discharge voltage and current	Voltage (V) and current (mA)	4.2.9.1 Luminous flux output 4.2.7.2 Power consumption 4.2.7.6 Appliance charging efficiency	This is the operating point at which the power consumption is equal to the average over the run time. This operating point is used to make light output, power consumption and charging efficiency measurements.
Average power over the full-battery run time	Watts (W)	4.2.8.6 Main unit full-battery run time	Average power consumption over the run time (for products with lighting appliances, while light output is over 70 % of initial light output).
Energy removed from the battery over the L_{70} run time	Watt·hours (Wh)	4.2.8.6 Main unit full-battery run time 4.2.8.7 Appliance full-battery run time	Total energy removed over the run time while light output is over 70 % of initial light output. This outcome can be used as an input to the energy service calculations (Annex GG). This metric also applies to lighting appliances with internal batteries.
Energy removed from the battery until the DUT reaches a low-voltage disconnect or other stopping criterion	Watt·hours (Wh)	4.2.8.6 Main unit full-battery run time	Total energy removed over the run time until the DUT reaches an active deep discharge protection threshold, the test is stopped for safety concerns, or the DUT reached an alternate stopping criterion. This value shall be determined for all DUTs that have active deep discharge protection and any products that do not include lighting appliances. This outcome can be used as an input to the energy service calculations (Annex GG).
Active deep discharge protection	Yes/no	4.2.3.13 Battery protection strategy	This metric can also apply to lighting appliances with internal batteries.
Deep discharge protection voltage	Volts (V)	4.2.3.13 Battery protection strategy	Measured only if the DUT has active deep discharge protection. This metric can also apply to lighting appliances with internal batteries.
Passive deep discharge protection	Yes/no	4.2.3.13 Battery protection strategy	This metric can also apply to lighting appliances with internal batteries.
Passive deep discharge protection battery voltage at 24 h	Volts per cell (V/cell)	4.2.3.13 Battery protection strategy	Required only if tested for passive deep discharge protection. This metric can also apply to lighting appliances with internal batteries.

M.3 Related tests

Annex M is related to the charge controller behaviour test (Annex S) and the energy service calculations (Annex GG). The typical battery discharge voltage from Clause M.8 is used to set up the light output test (Annex I) and light distribution test (Annex T).

M.4 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- If the test is being conducted with lighting appliances:

– Integrating sphere, or other approved measurement cavity.
– Data-logging illuminance meter.

- Battery analyser.
- Voltage data logger.
- Current data logger (e.g. voltage data logger and current transducer).
- Low-voltage disconnect device that will stop the discharge when the DUT's battery reaches a specified voltage (recommended).

The total series resistance added by the test apparatus and all measurement equipment shall be no more than 60 mΩ. This value includes the resistance of the wires and connectors, if any, added in the sample preparation procedure (G.4.4).

This test involves a calculation of electrical power; see Clause CC.3 for related recommendations. In most cases, the use of separate instruments to measure current and power is acceptable. If the current or voltage is observed to vary too rapidly to be captured by the current and data-logging devices, the sampling interval should be decreased or a power-measuring instrument should be used, as described in Clause CC.3.

M.5 Test prerequisites

Cycle the DUT's battery according to the procedures in the battery test annex (Annex K) and the information in the battery testing recommended practices annex (Annex L).

If the test is being conducted on a product without lighting appliances, and any of the appliances used in the test (see Clause M.7, step a)) have internal batteries, discharge the appliance batteries according to the full discharge preparation method (Annex N).

M.6 Apparatus

For products with lighting appliances, the full-battery 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[2] under constant conditions. Three approved measurement cavities are listed below in order of preference[3]. The lighting measurement is taken indirectly (reflected) in the first two types, while it is taken directly in the last type. The enclosure should be large enough to allow heat from the DUT to be dissipated effectively.

- Integrating sphere.
- A self-built photometer box with a baffled measurement of illuminance on a port (i.e. an "integrating cube" as shown in Figure M.1).
- A darkened room or cabinet with direct illuminance measurement under fixed geometry.

If the test is being conducted without lighting appliances, an integrating sphere or other approved measurement cavity is not required. Instead, the product and appliances shall be set in a secure location to avoid disturbance during the test.

2 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 may 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.

3 Any of these cavities can result in identical estimates for full-battery 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).

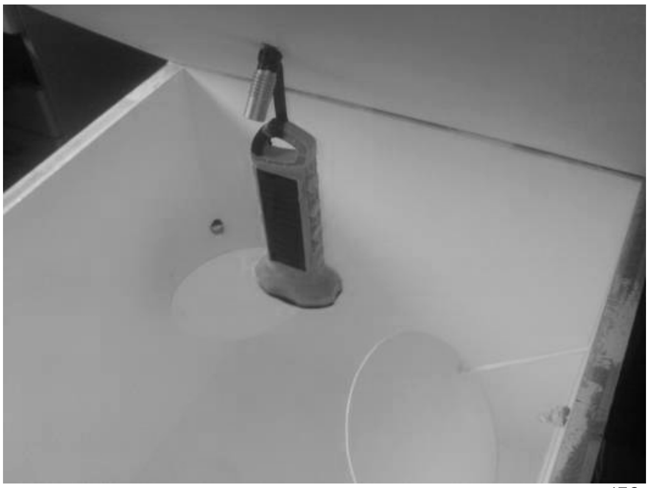


Figure M.1 – Interior view of photometer box with suspended light

M.7 Procedure

Before measurement, fully charge the battery using one of the two procedures according to the DUT's battery chemistry:

- If the battery is of NiMH chemistry, then use the procedures in the nickel-metal hydride battery test (K.4.3.1).
- Otherwise, use the procedures in the active overcharge protection test (S.4.2). If the solar module has not yet been tested, then set up the apparatus according to Figure S.1 and set the current limit to the rated maximum power point current at STC, I_{mpp}. If the rated I_{mpp} is not available, apply the current that results in a battery charge rate as specified in Table K.2.

The run time test shall be started between 1 h and 24 h after the DUT has finished receiving its full charge. When performing this procedure, take note of the DUT's operating current, which may be used to ensure the DUT is operating at the same setting during other tests.

Use the following procedure:

a) Identify the configuration(s) to test.

   1) If the product includes lighting appliances that do not have their own batteries, at minimum, the DUT shall be tested with all lighting appliances without batteries (including built-in appliances according to 4.1.4) connected and set to the brightest setting. In cases where, as identified in F.4.1.5 a) 19) and F.4.1.5 b) 1), multiple lighting appliances can be connected to a single port, these lights may be plugged in to separate ports or a single port. Additional guidance may be provided by the product specification. The configuration should be consistent with that used in the light output test (Annex I) and the power consumption and other appliance tests (Annex FF).

      If there are more lighting appliances than ports, and no splitters or similar devices are included with the product, use the brightest lighting appliances. If the configuration determined using these requirements is impractical for use (for example, if it causes an overload protection device to activate), the most appropriate setting and configuration should be determined by the test laboratory in consultation with the manufacturer.

      Some products have multiple built-in arrays of light sources that cannot be used simultaneously; in this case, test only the brightest array, provided that active deep discharge protection is present and the same deep discharge protection circuit is used by all such arrays. If the arrays could have different deep discharge protection behaviour and cannot be used simultaneously, the full-battery run time test should be conducted separately for each such array.

2) If the test is being conducted without measuring relative light output (i.e. the product does not include any lighting appliances without batteries), use the following procedure to determine the appropriate configuration:

   i) Choose all the appliances (including any built-in appliances and lighting appliances with internal batteries) that the DUT can power. Use appliances that are provided with the DUT when possible. If an appliance is not provided with the DUT (i.e., the packaging advertises that the product can power a radio, but a radio is not provided with the product), then use the appropriate generic appliance, as defined in Annex HH, to simulate its power consumption. Do not plug in a combination of appliances that will exceed the maximum sustained current for any port or combination of ports, according to the output overload protection method (DD.4.2). To ensure that the product's full discharge to the LVD is measured, at least one chosen appliance cannot have an internal battery. If all appliances have internal batteries, replace the appliance with the highest power consumption with a similar generic appliance with no timer, as defined in Annex HH.

   ii) If the DUT has fewer appliance ports than the number of appliances included and/or advertised with the DUT, then use the following criteria to determine which appliances to use during the full-battery run time test.

      a) Prioritize appliances that are included with the DUT.

      b) If more appliances are included with the DUT than the number of ports, then choose appliances that will maximize the power consumption from the DUT's main battery.

      c) If fewer appliances are included with the DUT than number of ports, but the additional advertised appliances exceed the number of ports, then use all appliances possible that are included with the DUT and populate the remaining ports with appropriate generic appliances, as defined in Annex HH, that will maximize the power consumption from the DUT's main battery.

3) If no appliances are included and no appliances are advertised, the tester may use his or her discretion in determining the combination of appliances to use during the full-battery run time test, or may consult the relevant product specification.

4) Some appliances may interfere with data collection or pose other difficulties for inclusion in the test, for example by generating voltage spikes that result in incorrect readings. If this occurs, generic appliances (Annex HH) may be substituted for included appliances.

5) In cases where the main unit includes multiple separate batteries, the testing configuration will depend on the relationship of the batteries to the appliances. If each battery is dedicated to specific loads during discharge (i.e. there are two lights with internal batteries that both connect to a solar module to charge), then conduct a separate full-battery run time test on each battery. If the batteries are connected in parallel during discharge, then conduct a single full-battery run time test with the batteries connected.

6) In cases where, as identified in F.4.1.5 a) 19) and F.4.1.5 b) 1), multiple appliances without internal batteries that provide the same type of service, e.g. lighting, can be connected to a single port, these appliances may be treated as a single appliance or as individual appliances. The appliances should be connected in a configuration that is consistent with the configurations used in other tests.

b) Configure the DUT according to the configuration identified in a) but do not yet turn it on.

c) Secure the DUT inside the test cavity such that it is stable and cannot be jostled. When using an integrating sphere or photometer box, position the DUT so that only reflected light reaches the detector. This can be accomplished by pointing the light point(s) away from the detector and/or by using baffles to shield the detector from direct light. When using a darkened room or cabinet with fixed geometry, direct the light toward the detector. In either case, it is extremely important that the DUT and apparatus do not move during the test.

d) Prepare the voltage data logger to measure voltage across the power control unit battery terminals at intervals of 1 min or less. Prepare the current data logger to measure the current at the negative battery terminal at intervals of 1 min or less. If it is unclear if the DUT has deep discharge protection, the tester may prepare the low-voltage disconnect device so that it stops the discharge if the DUT's battery reaches the minimum battery testing voltage specified in Annex L.

e) Some DUTs that use coulomb counting or similar methods for estimating state of charge will not correctly detect the battery state of charge when a discharge is started immediately after the battery is disconnected. This can result in the DUT turning off or reducing brightness prematurely during the full-battery run time test. The procedure in G.4.4 e) may be used for these products. If this procedure is not used, appropriate steps shall be taken, prior to starting the discharge, to reset the DUT's battery gauge. For example, in some products, charging the product for a few minutes via the PV input using a solar array simulator or power supply configured as described in S.4.2.5 will reset the battery gauge. The test laboratory should consult with the manufacturer to determine an appropriate reset procedure. After the reset procedure, the battery shall not be disconnected from the DUT prior to starting the discharge in step d).

f) Switch on the DUT in the correct configuration and at the correct setting and start taking measurements. Relative light output (luminous flux for the integrating sphere; illuminance for other measurement devices) should be recorded every minute, at a minimum, if applicable. If not measuring relative light output, skip steps g) and h).

g) Determine the initial light output time (t_{init}). This defines the point at which relative light output (RLO) is 100 %. If the DUT steps down to a lower setting after less than 20 min, then t_{init} is the time at which the last light output measurement was recorded at the initial setting. Otherwise, t_{init} is 20 min.

h) Note the light output at time t_{init}.

i) Continue the test until active deep discharge protection is observed. If no active deep discharge protection is observed, continue the test until 24 h after the RLO reaches 70 %. If passive deep discharge protection is not appropriate for the product (see S.4.3.1) or the DUT is not being assessed for deep discharge protection, the test may be terminated when the RLO reaches 10 % or less (i.e. the light output measurement is 10 % of the value at t_{init}).

NOTE A product that operates for more than 24 h after the RLO reaches 70 % can still have active deep discharge protection, particularly if the light output steps down and then remains approximately constant.

If the test is being conducted without lighting appliances and no active deep discharge protection is observed, continue the test until the product reaches any of the stopping criteria for the appliance full-battery run time test (Clause FF.9), or, if passive deep discharge protection is not appropriate for the product (see S.4.3.1) or the DUT is not being assessed for deep discharge protection, until any of the following occurs:

– all the appliances no longer function,

– the battery voltage falls below the value set on the optional low-voltage disconnect device, or

– the power drawn from the battery is 10 % or less of the power measured 20 min after the start of the test.

j) If the DUT turns off due to a timer feature designed into the DUT (see D.3.2.2 x)) that turns the product off after a fixed amount of time regardless of the battery state of charge, turn the product back on within 24 h and continue the test. Repeat this step as needed until the deep discharge protection (active or passive) is detected as in i).

If the data-logging equipment cannot be read out while the test is in progress, it can be impractical to record the exact values of t_{init} and initial light output while the test is in progress. In this case, an approximate value of the initial RLO or initial power may be used to determine when to stop the test. If insufficient data was recorded to determine the full-battery run time and (if necessary) the deep discharge protection voltage, the test shall be repeated.

M.8 Calculations

Analyse the time-series data to estimate the full-battery run time, average power, typical battery discharge voltage, energy removed from the battery over the full-battery run time, and energy removed from the battery until the DUT reaches a low-voltage disconnect or other stopping criterion.

a) Determine the full-battery run time (t_{FBRT}) using 1) or 2) below. If the DUT was restarted in Clause M.7, step j), subtract the duration of the intervals during which the product was turned off. For products with lighting appliances, report the result, expressed in hours (h). For products without lighting appliances, the full-battery run time is an intermediate step in the calculation of energy removed from the battery and need not be reported.

   1) For products with lighting appliances, the full-battery run time is the elapsed time until the RLO reaches 70 % of the initial value at t_{init}.

   2) For products without lighting appliances, the full-battery run time is the elapsed time until one of the following occurs:

      i) Active deep discharge protection turns off the DUT;

      ii) The product reaches any of the stopping criteria for the appliance full-battery run time test (Clause FF.9);

      iii) All the appliances no longer function;

      iv) The battery voltage falls below the value set on the optional low-voltage disconnect device;

      v) The power drawn from the battery is 10 % or less of the power measured 20 min after the start of the test. (This endpoint should only be used if none of the other options are applicable.)

EXAMPLE The DUT turned off due to a timer feature after 8 h, was turned on again at t=22 h, turned off again at t=30 h, was turned on again at t=46 h, and turned off after reaching its active deep discharge protection at t=50 h. The light output remained above L_{70} during the periods when it was on. The full-battery run time is (50 h – (22 h – 8 h) – (46 h – 30 h)) = 20 h.

b) For products with lighting appliances, the recorded data should be presented in a graph of RLO vs. time, as in Figure M.2. The graph should include the full discharge, beginning at 0 min, and can include RLO values greater than 100 %. If more than one brightness level was tested, prepare a separate graph for each test. For products without lighting appliances, a graph of power vs. time should be presented.

c) Determine the average power over the full-battery run time (P_{FBRT}) using the following formula. Exclude from the sum any measurements that were made while the DUT was turned off due to a timer feature.

$$P_{FBRT} = \frac{1}{n} \cdot \sum_{t_i < t_{FBRT}} \left(I_{b,i} \cdot V_{b,i} \right)$$

where

P_{FBRT} is the average power from the battery over the full-battery run time, in watts (W);

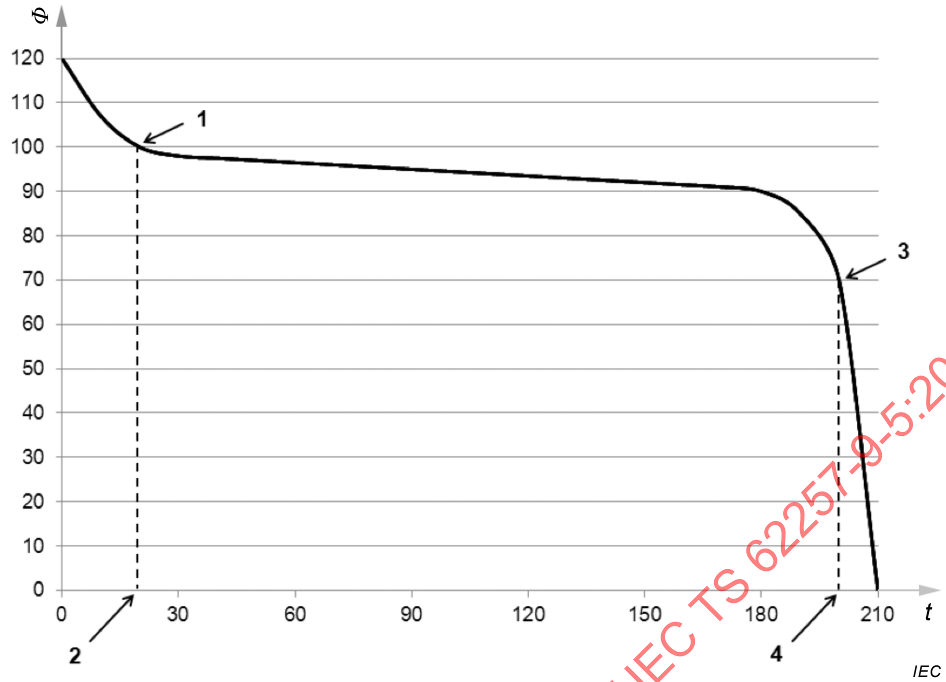
t_i is the elapsed time at measurement i;

t_{FBRT} is the full-battery run time, in hours (h);

$I_{b,i}$ is the battery current at measurement i, in amperes (A);

$V_{b,i}$ is the battery voltage at measurement i, in volts (V);

n is the total number of current and voltage measurements over the full-battery run time (unitless).



Key

t Time (min)

Φ Relative light output (%), which is directly proportional to the luminous flux output

1 Initial light output (RLO of 100 %)

2 t_{init}, time when RLO is defined as 100 % (20 min)

3 L_{70} reached (RLO is 70 %)

4 t_{70}, time when RLO is 70 %

Figure M.2 – Plot of example results for a product with lighting appliances

d) For products with lighting appliances, determine the energy removed from the battery over the L_{70} run time ($E_{b,70}$), including measurements that were made while the DUT was turned off due to a timer feature, using the following formula:

$$E_{b,70} = \sum_{t_i < t_{70}} \left(I_{b,i} \cdot V_{b,i} \cdot \Delta t_i \right)$$

where

$E_{b,70}$ is the energy delivered by the battery over the L_{70} run time, in watt·hours (Wh);

$I_{b,i}$ is the battery current at measurement i, in amperes (A);

$V_{b,i}$ is the battery voltage at measurement i, in volts (V);

Δt_i is the duration associated with each current and voltage point over the L_{70} run time, in hours (h).

e) If the DUT is not being assessed for deep discharge protection, skip steps f) through i) and proceed to step j).

f) Use S.4.1.5 c) and d) to determine if the DUT has active deep discharge protection incorporated into its charge controller and determine the active deep discharge protection voltage. If the DUT has active deep discharge protection, report the active deep discharge protection voltage, in volts (V), and report whether the protection is internal to the battery.

g) If the DUT does not have active deep discharge protection, the product could have passive deep discharge protection (defined and described in S.4.3.1). If no active deep discharge protection was detected, and passive deep discharge protection is appropriate for the product (see S.4.3.1), follow S.4.3.5 e) and f) to determine if the DUT has passive deep discharge protection. The test period mentioned in S.4.3.5 is the full duration of the full-battery run time test until 24 h after the DUT reaches L_{70}, or, for products without lighting appliances, until the 24 h after the DUT reaches any of the stopping criteria listed in a) 2).

h) If the DUT has passive deep discharge protection, report the passive deep discharge protection voltage.

i) If the low-voltage disconnect device provided by the laboratory stopped the discharge during the test, record that the battery voltage reached the minimum battery testing voltage and that no deep discharge voltage was observed. If the battery contains internal circuitry (refer to F.4.3.5) and the measured deep discharge protection voltage is outside of the targets specified by the manufacturer (D.3.2.2) or the battery falls below the recommended deep discharge protection voltage specified in Annex L, the test may be repeated with the voltage data logger connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so. In the test report, note where the reported voltage value was measured.

NOTE If the test is to be repeated for this reason, the active deep discharge protection test (S.4.1.5) or passive deep discharge protection test (S.4.3.5) can be used to reduce the time needed for re-testing.

j) For DUTs that have active deep discharge protection and reach a low-voltage disconnect during the full-battery run time test or products that do not include lighting appliances, determine the energy removed from the battery until the DUT reaches a low-voltage disconnect ($E_{\text{b,LVD}}$) or other stopping criterion, including measurements that were made while the DUT was turned off due to a timer feature, using the following formula:

$$E_{\text{b,LVD}} = \sum_i \left(I_{\text{b},i} \cdot V_{\text{b},i} \cdot \Delta t_i \right)$$

where

$E_{\text{b.LVD}}$ is the energy exiting the battery until the DUT reaches a low-voltage disconnect or other stopping criterion, in watt·hours (Wh);

$I_{\text{b},i}$ is the current exiting the battery at measurement i, in amperes (A);

$V_{\text{b},i}$ is the voltage of the battery at measurement i, in volts (V);

Δt_i is the duration associated with each current and voltage point, in hours (h).

k) Perform the following steps to determine the typical battery discharge voltage (see H.5.2):

1) Calculate the average voltage during the full-battery run time (V_{avg}). Exclude any measurements that were made while the DUT was turned off due to a timer feature.

2) Create a table listing the power and current as a function of voltage operating point for the steady-state operating period – defined as the period beginning 20 min into the tests until the end of the full-battery run time. The table should list each operating voltage during the period in increments of 0,01 V. The average power should be found based on all the steady-state points that fall into each voltage "bin".

3) Linearly interpolate between points in the table created in step 2) to identify all the values of voltage for which the power is equal to the average power P_{FBRT}.

4) If more than one voltage was identified in 3), select the voltage closest to the average voltage (V_{avg}) calculated in 1). This is the typical battery discharge voltage (V_{tbd}).

5) Note the current (I_{tbd}) at the same point selected in 4). This is the current at the typical battery discharge voltage. (This current can be calculated by dividing P_{FBRT} by V_{tbd}.)

l) Optionally, for products with lighting appliances, determine the average relative light output during the L_{70} run time (RLO_{avg}). Exclude any measurements that were made while the DUT was turned off due to a timer feature.

M.9 Reporting

Report the following in the full-battery run time test report.

- Metadata:
  - report name;
  - procedure(s) used;
  - DUT manufacturer;
  - DUT name;
  - DUT model number;
  - DUT setting;
  - name of test laboratory;
  - approving person;
  - date of report approval.
- Results for tested DUT aspects for samples 1 through n:
  - run time to L_{70} (h), for products with lighting appliances;
  - typical operating point that corresponds to the average power (P_{FBRT}), described by the typical battery discharge voltage V_{tbd} (V) and current I_{tbd} (A);
  - average power over the full-battery run time (W);
  - energy removed from the battery over the L_{70} run time (Wh), for products with lighting appliances;
  - energy removed from the battery until the DUT reaches a low-voltage disconnect or other stopping criterion (Wh);
  - presence of active deep discharge protection, if applicable (yes/no);
  - active deep discharge protection voltage, if applicable (V);
  - whether active deep discharge protection is internal to the battery (yes/no);
  - presence of passive deep discharge protection, if applicable (yes/no);
  - passive deep discharge protection voltage at 24 h, if applicable (V).
- Average of n sample results for each DUT aspect tested.
- Coefficient of variation of n sample results for each DUT aspect tested (%).
- DUT's rating for aspects tested, if available.
- Deviation of the average result from the DUT's rating for each aspect tested, if available (%).
- Comments:
  - individual comments, as necessary, for samples 1 through n;
  - overall comments, as necessary, for collective set of samples 1 through n.
- Figures:
  - plot of relative light output (%) or power vs. elapsed time (min), as in Figure M.2;
  - plot of voltage and current vs. elapsed time (min).

Annex N
(normative)

Full discharge preparation

N.1 Background

Some test procedures require that the DUT be fully discharged. When performing the full-battery run time test (Annex M), a DUT is considered fully discharged when it reaches L_{70}. This is the point at which the DUT provides 70 % of the initial light output where the initial light output is the light output reading typically taken at minute 20 of the full-battery run time test. For products without included lighting appliances, the product is considered fully discharged when it reaches its low-voltage disconnect, all the appliances no longer function, the battery voltage falls below the value set on the optional low-voltage disconnect device, or the power drawn from the battery is 10 % or less of the power measured 20 min after the start of its full-battery run time test, whichever occurs first.

The grid charge test (Annex O), electromechanical charge test (Annex P), and solar charge test (Annex R) use a specified charge cycle and the initial state of charge will influence the DUT's performance during the charge. It is important that the DUT be set to a prescribed state of charge to simulate a full discharge prior to commencing the selected run time tests so the results are repeatable and comparable across products.

N.2 Test outcomes

There are no full discharge preparation procedures outcomes.

N.3 Related tests

The full discharge preparation procedure shall be performed on all DUTs prior to conducting the grid charge test (Annex O), electromechanical charge test (Annex P), and solar charge test (Annex R).

N.4 Procedure

N.4.1 General

Each DUT is fully discharged prior to starting any of the tests listed in Clause N.3.

N.4.2 Equipment requirements

One of the following three pieces of equipment is required for the full discharge preparation. Equipment shall meet the requirements in Table CC.2.

a) Battery analyser meeting the requirements in Table CC.2.

b) Electronic load with timer function, meeting the accuracy requirement for battery analysers in Table CC.2.

c) Timer disconnect device consisting of a digital timer and a relay that can break the connection between the DUT's circuit and its battery (e.g. an AC digital timer combined with an AC-actuated mechanical relay).

N.4.3 Test prerequisites

Before performing the procedure, fully charge the battery using one of the following two procedures according to the DUT's battery chemistry and circuit protection.

- If the battery is of NiMH chemistry, then use the procedures in the nickel-metal hydride battery test (K.4.3.1).
- If the cell balancing or individual cell monitoring circuitry is external to its battery, use the procedures in the active overcharge protection test (S.4.2). If the solar module has not yet been tested, then set up the apparatus according to Figure S.1 and set the current limit to the rated maximum power point current at STC, I_{mpp}.
- Otherwise, use either of the following:
  a) the procedures in the active overcharge protection test (S.4.2). If the DUT's solar module has not yet been tested, then set up the apparatus according to Figure S.1 and set the current limit to the rated maximum power point current at STC, I_{mpp}.
  b) the battery test procedures appropriate to the battery chemistry (Annex K) with the following modification: set the maximum charge voltage to the overcharge protection voltage measured in the active overcharge protection test (S.4.2).

In the case where the DUT significantly continues to charge after reaching its overcharge protection voltage, avoid using option a) or stop the charge as soon as the DUT reaches its overcharge protection voltage.

Any following steps shall be started between 1 h and 24 h after the DUT has finished receiving its full charge.

N.4.4 Procedure

N.4.4.1 General

Products generally have one of five types of discharge curves.

a) A constant light output with a sharp turn-off when the product reaches its low-voltage disconnect (LVD) such that the light output does not drop below L_{70} prior to turning off.
b) A relatively constant light output that begins to decrease in light output just prior to experiencing a sharp turn-off when the product reaches its LVD such that the light output drops below L_{70} prior to turning off.
c) A cascade of constant light outputs such that the product steps down in its light setting during its discharge, often reaching an LVD after providing some light in its lowest setting.
d) A gradually decreasing light output as the product discharges, reaching an LVD after reaching L_{70}.
e) A gradually decreasing light output as the product discharges with no LVD.

If the product discharges as type a), proceed with N.4.4.2 if using the product's low-voltage disconnect, N.4.4.3 if using a battery analyser or electronic load, or N.4.4.4 if using a timer disconnect device. If the product discharges as type b), c), d), or e), proceed with N.4.4.3 or N.4.4.4; do not use N.4.4.2.

If the product does not include lighting appliances and its full-battery run time test was stopped by active deep discharge protection, any of the three methods, N.4.4.2, N.4.4.3 or N.4.4.4, may be used. If the product does not include lighting appliances and its full-battery run time was stopped due to one of the other stopping criteria, N.4.4.2 shall not be used.

For products that use coulomb counting or similar methods for estimating state of charge, for which special preparation was required during the full-battery run time test in Clause M.7, step e), ensure that the same preparation is carried out prior to starting the discharge preparation, if the battery has been disconnected from the DUT at any time after the product was fully charged according to N.4.3 or if otherwise required by the product's design.

If the full-battery run time test has been conducted for multiple settings or configurations of appliances, use the results for the setting or configuration described in Clause M.7, step a) (i.e., all lighting appliances without batteries, set to the brightest setting). If the same sample is required to undergo the full discharge preparation multiple times (e.g., a sample is tested on high setting and again on low setting), the same channel of the battery analyser or electronic load should be used each time to improve the consistency of the results.

N.4.4.2 Procedure using the product's low-voltage disconnect

The following steps shall be followed.

a) Set the DUT in a secure location.

b) Turn the DUT on in the same configuration that was used in the full-battery run time test.

c) Allow the DUT to discharge uninterrupted until its LVD automatically turns it off.

d) After the DUT finishes discharging, wait at least 1 h but no longer than 24 h prior to commencing the selected charging test.

N.4.4.3 Procedure using a battery analyser or electronic load

The following steps shall be followed.

a) Calculate the average discharge current measured from the DUT's battery during the full-battery run time test (Annex M) until it reached L_{70}. For products that do not include lighting appliances, calculate the average discharge current measured from the DUT's battery during the full-battery run time test until one of the stopping criteria in Clause M.8, step k) 2), is met

b) Use the battery analyser or electronic load to discharge the DUT at the average discharge current calculated in step a) for a duration equal to its full-battery run time to L_{70}, measured in Annex M. For products that do not include lighting appliances, use the duration equal to the full-battery run time until one of the stopping criteria was met.

c) After the DUT finishes discharging, wait at least 1 h but no longer than 24 h prior to commencing the selected charging test.

N.4.4.4 Procedure using a timer disconnect device

The following steps shall be followed.

a) Program the timer for a duration equal to the full-battery run time to L_{70}, measured in Annex M. For products that do not include lighting appliances, use the duration equal to the full-battery run time until one of the stopping criteria was met.

b) Connect the DUT to the timer device such that the timer device relay will disconnect the DUT circuit from the battery upon reaching the programmed discharge time. Turn the DUT on in the same configuration that was used in the full-battery run time test, as described in Clause M.7, step a).

c) After the DUT finishes discharging, wait at least 1 h but no longer than 24 h prior to commencing the selected charging test.

N.4.5 Calculations

No calculations are required with the full discharge preparation procedures.

N.5 Reporting

No reporting is required with the full discharge preparation procedures.

Annex O
(normative)

Grid charge test

O.1 Background

The possibility of grid charging improves the usability of an LED lighting product, even if it is designed for use in remote areas. Annex O describes the method for measuring the energy that can be delivered to the battery in a typical day (8 h) of grid charging. This value can be used in the energy service calculations (Annex GG) to determine the service (e.g. run time) provided by a day of grid charging.

The DUT is grid charged via the provided power adapter for 8 h.

O.2 Test outcomes

The test outcomes of the grid charge test are listed in Table O.1.

Table O.1 – Grid charge test outcomes

Metric	Reporting units	Related aspects	Notes
Grid-charge energy	Watt·hours (Wh)	--	Used as input for the energy service calculations

O.3 Related tests

The grid charge test requires the full-battery run time test (Annex M) to be performed before the test. Also, if the charge controller behaviour test (Annex S) is performed before the grid charge test and it is determined the DUT has overcharge protection, no overcharge protection device is required during the grid charge test.

O.4 Procedure

O.4.1 General

The DUT sample is charged by the grid for 8 h to determine the grid charge run times.

O.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- AC power adapter supplied with the DUT.
- AC power supply.
- DC voltage data logger.
- DC current data logger (e.g. voltage data logger and current transducer).
- Timer disconnect device.
- Overcharge disconnect device (if necessary).
- Surface-mounted thermocouple(s) and a thermocouple reader (optional).

If the utility voltage and frequency available at the laboratory match the requirements of the AC power adapter supplied with the DUT, then utility power may be used to supply power to the AC adapter, and it is not necessary to use a separate AC power supply. Many products are supplied with "universal" AC adapters that accept wide voltage and frequency ranges. The type of AC power supply used should be noted in the test report, but it is not necessary to record the AC voltage, current, or power.

This test involves a calculation of electrical power; see Clause CC.3 for related recommendations. For products with pulse-width modulation (PWM) charge controllers, a power-measuring instrument should be used, as described in Clause CC.3.

O.4.3 Test prerequisites

The following steps shall be followed.

a) Discharge the DUT battery according to the full discharge preparation procedure (Annex N).
b) If it is unknown whether the DUT has an overcharge protection disconnect, an overcharge protection disconnect device should be used to protect the battery during the test.

O.4.4 Apparatus

A suitable location for the DUT to be undisturbed for 8 h while grid charging is required.

O.4.5 Procedure

The following steps shall be followed.

a) Set up the circuit cutoff device to disconnect the AC power circuit after 8 h of testing.
b) If it is unknown whether the DUT has an overcharge protection disconnect, integrate the overcharge protection disconnect device into the setup. Optionally, monitor the battery temperature to ensure that it does not exceed a safe value. The maximum allowable voltage setpoint for the overcharge disconnect device and the maximum allowable cell temperature may be selected from Table L.2. If temperature monitoring is used, lithium-based batteries shall not be allowed to exceed 45 °C unless higher temperatures are allowed by the battery manufacturer.
c) Plug the AC power adapter supplied with the DUT into the timer disconnect device.
d) Set up the current and voltage sensors to monitor the charge into the battery and set data logging for 1 min intervals or shorter.
e) Enable the timer disconnect device and begin the 8 h charging cycle.
f) After 8 h of grid charging, disconnect the equipment and check for data consistency.

O.4.6 Calculations

The following calculations shall be made:

a) Find the instantaneous power for each data point by multiplying current and voltage.
b) Find the total energy input to the battery during the 8 h charging cycle by multiplying each instantaneous power by the time step duration and summing the energy. This is the measured grid-charge energy.
c) If the product stopped charging before the end of the 8 h period, determine and record the actual duration of grid charging. The procedure in R.4.4 e) 1) may be used to identify the time when the product stopped charging. If the product continued to charge for the full 8 h period, record a grid charging duration of >8 h. Note the grid charging duration in the test report.
d) Calculate the available grid-charge energy using the following formula:

$$E_{\text{grid}} = E_{\text{meas}} \cdot \frac{8\ \text{h}}{t_{\text{grid}}}$$

where

E_{grid} is the energy available to the battery from 8 h of grid charging, in watt·hours (Wh);

E_{meas} is the measured grid-charge energy, calculated in b), in watt·hours (Wh);

t_{grid} is the measured duration of grid charging, calculated in c), in hours (h).

NOTE This quantity is the energy available for charging the battery or operating appliances during one day of grid charging, not limited by the battery capacity. (The battery capacity limitation is accounted for in the energy service calculations.)

O.5 Reporting

Report the following in the grid charge test report.

- Metadata:
  - report name;
  - procedure(s) used;
  - DUT manufacturer;
  - DUT name;
  - DUT model number;
  - name of test laboratory;
  - approving person;
  - date of report approval.
- Results for tested DUT aspects for samples 1 through n:
  - grid-charge energy (Wh).
- Comments:
  - individual comments, as necessary, for samples 1 through n;
  - overall comments, as necessary, for collective set of samples 1 through n.

Annex P
(normative)

Electromechanical charge test

P.1 Background

A number of lighting products provide mechanical crank-charging as an alternative to grid and/or PV module charging.

Annex P describes a procedure for measuring the power generated by electromechanical charging under predetermined conditions. This value can be used in the energy service calculations (Annex GG) to determine the service (e.g. run time) provided by a specified period of electromechanical charging.

P.2 Test outcomes

The test outcomes of the electromechanical charge test are listed in Table P.1.

Table P.1 – Mechanical charge test outcomes

Metric	Reporting units	Related aspects	Notes
Electromechanical charger power or energy output	Watts (W) or watt·hours (Wh)	4.2.8.9 Electromechanical charger power or energy output	--

P.3 Related tests

The electromechanical charge test requires the full-battery run time test (Annex M) to be performed before the test.

P.4 Procedure

P.4.1 General

The DUT sample is electromechanically charged for 5 min with measurements of the current and voltage available to charge the battery.

P.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Voltage data logger.
- Current data logger.
- Stopwatch or clock.

This test involves a calculation of electrical power; see Clause CC.3 for related recommendations. If the electromechanical charger does not produce a constant current or voltage, a power-measuring instrument should be used, as described in Clause CC.3.

P.4.3 Test prerequisites

The DUT battery should be discharged according to full discharge preparation procedure (Annex N).

P.4.4 Apparatus

No particular apparatus is required. For electromechanical chargers that require a fixed position (e.g. bicycle crank chargers), a special apparatus may need to be built or used.

P.4.5 Procedure

The following steps shall be followed.

a) Attach the voltage and current sensors to the product to measure charge into the battery. Set the data-logging interval for 2 s or less and begin logging.

b) Electromechanically charge the DUT for 5 min at a speed (or other operating condition) corresponding to typical operation of the charging mechanism, following instructions in the user documentation if provided. Typically, a rotational speed of 120 rpm for a hand crank or 60 rpm for a bicycle crank charger is appropriate. If the DUT provides user feedback regarding the speed or operating conditions (e.g. an indicator light that illuminates when the crank is being turned at the correct speed), follow the guidance provided by the feedback mechanism. Note the speed and/or other operating conditions in the test report.

c) Download the data and check for consistency.

P.4.6 Calculations

The following calculations shall be made.

a) Find the actual duration of the time series according to the dataset.

b) Calculate the instantaneous power input to the battery for each data point in the time series by multiplying current and voltage.

c) Find and report the average power input over the charging period.

P.4.7 Modifications for atypical products

The procedure given in P.4.5 and P.4.6 is appropriate for appliances in which the electromechanical charging action is performed continuously for a duration of time, such as hand-crank or bicycle crank chargers, and charges a battery (or another electrical or electrochemical storage device, such as a supercapacitor). However, many variations on this model are possible. For alternative products, the following modifications may be used:

- For products in which a single action (e.g. lifting a weight) initiates the electromechanical operation, which then continues for a period of time, the energy provided by a single operation may be reported instead of the average power over five minutes. In this case, also report the duration of charging provided by the action, as well as any information necessary to replicate the test.

EXAMPLE Lifting the 10 kg weight provides 0,012 Wh of energy to the battery over a period of 1 h.

- For products without a battery, in which the electromechanical generator directly powers the appliances, report the power or energy at an appropriate location, typically the output of the generator, under the load conditions defined in the full-battery run time test (Annex M). For such products, the following modifications may be made to the other test procedures in this document:
  - In the protection tests (Annex DD) and assessment of DC ports (Annex EE), and any other test requiring the battery to be replaced by a power supply, connect the power supply to the location where the power or energy output of the electromechanical generator was measured.

– In place of the typical battery discharge voltage, use the voltage corresponding to the average power output of the generator, calculated using a procedure analogous to that in Clause M.8.

– The concept of standby loss (S.4.5) is generally not applicable to these products.

NOTE Many electromechanically powered products without batteries fall outside the scope of this document, since they do not include an energy storage device. However, products can include a mechanical form of energy storage, and it can be useful to test such devices according to the test methods in this document.

P.5 Reporting

Report the following in the electromechanical charge test report.

- Metadata:
  - report name;
  - procedure(s) used;
  - DUT manufacturer;
  - DUT name;
  - DUT model number;
  - name of test laboratory;
  - approving person;
  - date of report approval.
- Results for tested DUT aspects for samples 1 through n:
  - electromechanical charger power or energy.
- Comments:
  - individual comments, as necessary, for samples 1 through n;
  - overall comments, as necessary, for collective set of samples 1 through n.

Annex Q
(normative)

Photovoltaic module I-V characteristics test

Q.1 Background

The purpose of the photovoltaic (PV) module I-V characteristics test is to validate the DUT manufacturer's PV module data (if available) and determine the PV module's I-V characteristic curve under standard test conditions (STC) and at typical module operating temperature (TMOT).

Solar LED lamp units are often powered by PV modules with power ratings as low as 0,3 W.[4] When selecting a measurement instrument, it is important to ensure that it is able to make accurate measurements of modules in the desired size range. This is particularly important for modules rated at less than 3,0 W since most measurement equipment is not designed for very small modules.

The PV module may be measured with a solar simulator in accordance with IEC 60904-1:2006 and corrected to STC and TMOT with IEC 60891:2009. This is the preferred technique for characterizing PV modules and laboratories with access to a solar simulator should use this procedure. The test may also be performed with an instrument that is designed to make outdoor performance measurements of small solar modules.

Q.2 Test outcomes

The test outcomes of the photovoltaic module I-V characteristics test are listed in Table Q.1.

Table Q.1 – Photovoltaic module I-V characteristics test outcomes

Metric	Reporting units	Related aspects	Notes
Short-circuit current (I_{sc}) at STC	Amperes (A)	4.2.6.1 Solar I-V curve parameters	Report at STC
Open-circuit voltage (V_{oc}) at STC	Volts (V)	4.2.6.1 Solar I-V curve parameters	Report at STC
Maximum power point power (P_{mpp}) at STC	Watts (W)	4.2.6.1 Solar I-V curve parameters	Report at STC
Maximum power point current (I_{mpp}) at STC	Amperes (A)	4.2.6.1 Solar I-V curve parameters	Report at STC
Maximum power point voltage (V_{mpp}) at STC	Volts (V)	4.2.6.1 Solar I-V curve parameters	Report at STC
Short-circuit current ($I_{sc,TMOT}$) at TMOT	Amperes (A)	4.2.6.1 Solar I-V curve parameters	Report at TMOT
Open-circuit voltage ($V_{oc,TMOT}$) at TMOT	Volts (V)	4.2.6.1 Solar I-V curve parameters	Report at TMOT
Maximum power point power ($P_{mpp,TMOT}$) at TMOT	Watts (W)	4.2.6.1 Solar I-V curve parameters	Report at TMOT
Maximum power point current ($I_{mpp,TMOT}$) at TMOT	Amperes (A)	4.2.6.1 Solar I-V curve parameters	Report at TMOT
Maximum power point voltage ($V_{mpp,TMOT}$) at TMOT	Volts (V)	4.2.6.1 Solar I-V curve parameters	Report at TMOT

4 This is the nominal power a PV module shows under standard test conditions (STC). Since being at STC is extremely rare in practice, the achieved power is usually lower.

Metric	Reporting units	Related aspects	Notes
Relative temperature coefficient of open-circuit voltage	Percent per degree Celsius (%/°C)	4.2.6.1 Solar I-V curve parameters	Based on temperature variation in $V_{oc.}$
STC I-V curve dataset	Volts (V), Amperes (A)	4.2.6.1 Solar I-V curve parameters	Delimited dataset

Q.3 Related tests

Annex Q should be completed before the solar charge test (Annex R).

Q.4 Procedure

Q.4.1 Substitution of IEC 61215-2 test results

The I-V characteristics of the DUT's PV module may be determined using the "Performance at STC and NMOT" test of IEC 61215-2. Test results provided by the manufacturer of the DUT may be accepted if the tests were performed at a laboratory accredited to perform the tests by a recognized accrediting body (e.g. an ILAC MRA signatory, to ISO/IEC 17025) and if the test results include full datasets for the I-V curves.

If the module's nominal module operating temperature (NMOT), as determined in IEC 61215-2, is within the range 50 °C ± 5 °C, the performance at TMOT may be assumed to be identical to the performance at NMOT. Otherwise, the I-V curve at TMOT (50 °C cell temperature, solar irradiance of 1 000 W/m^2, and air mass 1,5) shall be calculated from the performance at STC and NMOT using any of the correction procedures in IEC 60891:2009. Correction procedure 3 (IEC 60891:2009, 3.4) is recommended as it requires no additional measurements other than the two I-V curves.

The IEC 61215 (all parts) certification is typically extended to a product family based on testing of one or more module types. For modules with IEC 61215 certification from an accredited certification body, of types which have not been tested, the I-V curve data from the tested module type may be used with the following corrections:

$$I = I_t \cdot \frac{I_{sc,DUT}}{I_{sc,t}}$$

where

I is the corrected current, in amperes (A);

I_t is the current from the IEC 61215-2 test data for the tested module type, at each point on the I-V curve, in amperes (A);

$I_{sc,DUT}$ is the rated short-circuit current for the DUT's PV module, at STC, in amperes (A);

$I_{sc,t}$ is the short-circuit current from the IEC 61215-2 test report for the tested module type, in amperes (A).

and

$$V = V_t \cdot \frac{V_{oc,DUT}}{V_{oc,t}}$$

where

V is the corrected voltage for the DUT's PV module, in volts (A);

V_t is the voltage from the IEC 61215-2 test data for the tested module type, at each point on the I-V curve, in volts (V);

$V_{oc,DUT}$ is the rated open-circuit voltage for the DUT's PV module, at STC, in volts (V);

$V_{oc,t}$ is the open-circuit voltage from the IEC 61215-2 test report for the tested module type, in volts (V).

When IEC 61215-2 test data are used, modifications are required to the solar charge test procedure (Annex R); see R.4.2.3.3.

Q.4.2 Test programme using a solar simulator

Q.4.2.1 Test prerequisites

If the PV module is amorphous silicon or otherwise could be subject to degradation (e.g. because it is thin film or of unknown technology), it shall sun-soak for 30 days prior to performing this test.

Q.4.2.2 I-V curve measurements

Use the procedure defined in IEC 60904-1:2006, with the following modifications.

- The spectral mismatch correction described in IEC 60904-1:2006, Clause 3 a), may be omitted if the reference device is a PV cell or module made using the same cell technology or using optical filtration to achieve a spectral response typical of the cell technology of the DUT. For example, a monocrystalline PV cell with KG5 glass window may be used with an amorphous silicon DUT.
- For measurements in steady-state simulated sunlight, the irradiance sensor of IEC 60904-1:2006, 4.2 d), may be omitted.
- For temperature measurements, a single thermocouple, meeting the accuracy requirements of Q.4.3.2 and positioned directly behind a cell near the centre of the module, may be used. If the back of the module is inaccessible, the front-mounted thermocouple procedure detailed in the outdoor test procedure (Q.4.3.5.3) shall be used for the indoor test.
- If the PV module charges the DUT via a cable extended from the PV module's junction box, measure the I-V curve from the end of the cable that plugs into the DUT for charging by cutting the connector from the end of the PV module cable, leaving as much of the cable connected to the PV module as possible, and strip the wire ends. However, if the PV module's performance deviates from the advertised values by more than the truth-in-advertising tolerance specified in the product specification, the I-V curve test may be repeated measuring the I-V curve from the PV module's junction box (before the PV module's charging cable). The results from the original test shall be used as input for the solar charge test and both sets of results shall be reported for the photovoltaic module I-V characteristics test.

  If the junction box contains components that prevent the I-V curve measurement from being carried out at the end of the cable, the I-V curve may be measured at the junction box or at another point that enables the measurement to be performed. Record the location of the measurement in the test report. If the junction box is potted, this testing can require obtaining additional samples of the PV module without the potting compound. If the test is subject to a random sampling requirement (Annex E), the additional samples shall be obtained in a way that complies with this requirement; for example, samples could be collected by a sampling agent at the PV module supplier's factory before the potting compound is added.

  Take note of the special instructions in R.4.2.3.3 that apply when the I-V curve is not measured at the end of the cable.

Q.4.2.3 I-V curve adjustment for STC and TMOT

The I-V curve measured in Q.4.2.1 shall be adjusted to STC (25 °C cell temperature, solar irradiance of 1 000 W/m^2, and air mass 1,5) and TMOT (50 °C cell temperature, solar irradiance of 1 000 W/m^2, and air mass 1,5) using either of the following two procedures, ensuring that all voltage measurements are taken with the same device and all temperature measurements are taken with the same device:

Procedure 1: Use any of the correction procedures defined in IEC 60891:2009. For temperature coefficient measurements, a single thermocouple, meeting the accuracy requirements of Annex CC and positioned directly behind a cell near the centre of the module, may be used. If the back of the module is inaccessible, the front-mounted thermocouple procedure detailed in the outdoor test procedure (Q.4.3.5.3) shall be used.

NOTE Correction procedure 3 (IEC 60891:2009, 3.4) allows temperature correction using two I-V curves at different temperatures. If no irradiance correction is needed, this method is likely to be the simplest for a low-cost test.

Procedure 2: Measure the temperature coefficient of voltage ($T_{c,voc}$) using the procedure defined in Q.4.3, under either natural or simulated sunlight, then use the calculations in Q.4.3.5.4 to adjust the curve to STC and TMOT.

Some PV modules include a zener diode in the junction box to limit the open-circuit voltage. For these modules, procedure 2 cannot be used, because the temperature coefficient of open-circuit voltage is determined by the zener diode characteristics and does not reflect the behaviour of the PV module at the typical operating point. These modules can be tested using procedure 1 or by measuring the I-V curve at the junction box with the zener diode removed. Modules with zener diodes can be identified by physical inspection of the junction box or by measurement of the relative temperature coefficient of open-circuit voltage (β_{rel}). Zener diodes used for this application typically have temperature coefficients in the range of -0,1 %/°C to +0,1 %/°C, compared to -0,5 %/°C to -0,2 %/°C for typical PV modules.

Q.4.2.4 Extraction of parameters

The following parameters shall be extracted from the adjusted I-V curves and reported for STC and TMOT:

- Short-circuit current (I_{sc})
- Open-circuit voltage (V_{oc})
- Maximum power (P_{mpp})
- Maximum power point voltage (V_{mpp})
- Maximum power point current (I_{mpp})

In some cases, depending on the equipment used to measure the I-V curve, it is not possible to obtain a corrected data point at exactly short-circuit (V=0) or open-circuit (I=0). In this case linear interpolation should be used to calculate these parameters. If two points that bracket V=0 or I=0 are not available, the closest available point should be used.

NOTE This approach is less accurate than that allowed by other standard test methods, but allows for the use of low-cost test equipment. The values of I_{sc} and V_{oc} are of less importance than P_{mpp} in assessing the overall performance of a solar lighting product.

The maximum power point voltage (V_{mpp}) should be calculated by fitting a curve to the measured data. The following method, based on ASTM E948-15:2015, 8.5, is recommended, but modifications may be made as appropriate:

a) Calculate the power at each point on the corrected I-V curve by multiplying the current and voltage values.
b) Identify the point (I_m,V_m) on the corrected I-V curve with the highest power value (P_m).
c) Identify the points on the corrected I-V curve meeting the following criteria:

$$0{,}75\,I_{\mathrm{m}} \leq I \leq 1{,}15\,I_{\mathrm{m}}$$

$$0{,}75\,V_{\mathrm{m}} \leq V \leq 1{,}15\,V_{\mathrm{m}}$$

d) Perform a fourth-order polynomial least-squares curve fit to the P vs. I data.

e) Calculate the derivative of the polynomial obtained in d).

f) Find the root of the derivative obtained in e) using V_{m} as the initial guess. The Newton-Horner method with deflation is recommended. The value of this root is V_{mpp}.

g) Substitute V_{mpp} into the polynomial determined in d) to calculate P_{mpp}.

h) Divide P_{mpp} by V_{mpp} to find I_{mpp}.

In some cases, especially when the data points measured by the I-V curve analyser are not equally spaced, the polynomial curve fit can be inaccurate due to overfitting. In some cases, it is appropriate to use additional data points or a lower-order polynomial to correct this problem. However, overfitting often indicates that the test should be repeated with higher resolution.

If the relative temperature coefficient of open-circuit voltage (β_{rel}) has not yet been determined in the process of correcting the I-V curves to STC and TMOT, it shall be determined and reported using the following formula (or alternatively by following the procedure in IEC 60891:2009, 4.5). The two measurements of V_{oc} may be performed separately (as in Q.4.3.5), or, if the I-V curve was measured at two different temperatures in Q.4.2.1, the V_{oc} measurements extracted from the measured curves may be used.

$$\beta_{\mathrm{rel}} = \frac{1}{V_{\mathrm{oc,STC}}} \cdot \frac{V_{\mathrm{oc,1}} - V_{\mathrm{oc,2}}}{T_1 - T_2} \times 100\ \%$$

where

β_{rel} is the relative temperature coefficient of open-circuit voltage, in percent per degree Celsius (%/°C);

T_1 is the temperature at which the first measurement of open-circuit voltage is performed, in degrees Celsius (°C);

T_2 is the temperature at which the second measurement of open-circuit voltage is performed, in degrees Celsius (°C);

$V_{\mathrm{oc,1}}$ is the measured open-circuit voltage at T_1, in volts (V);

$V_{\mathrm{oc,2}}$ is the measured open-circuit voltage at T_2, in volts (V);

$V_{\mathrm{oc,STC}}$ is the calculated open-circuit voltage at STC, in volts (V).

The value of β_{rel} for PV modules is typically between -0,5 %/°C and -0,2 %/°C; results falling outside this range should be investigated and noted in the test report. A zener diode or other components in the junction box (Q.4.2.3) can cause this behaviour.

Q.4.3 Outdoor photovoltaic module I-V characteristics test

Q.4.3.1 General

The PV module is tested outdoors to obtain its characteristic I-V curve, from which the maximum power (P_{mpp}), open-circuit voltage (V_{oc}), and short-circuit current (I_{sc}) are determined.

Q.4.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Outdoor I-V curve analyser. The analyser may include an integrated pyranometer, provided it is fast-response (i.e. silicon PV-based pyranometer).
- Fast-response (i.e. silicon PV-based) pyranometer.
- Voltmeter or multimeter.
- Surface-mounted thermocouple(s) and a thermocouple reader.

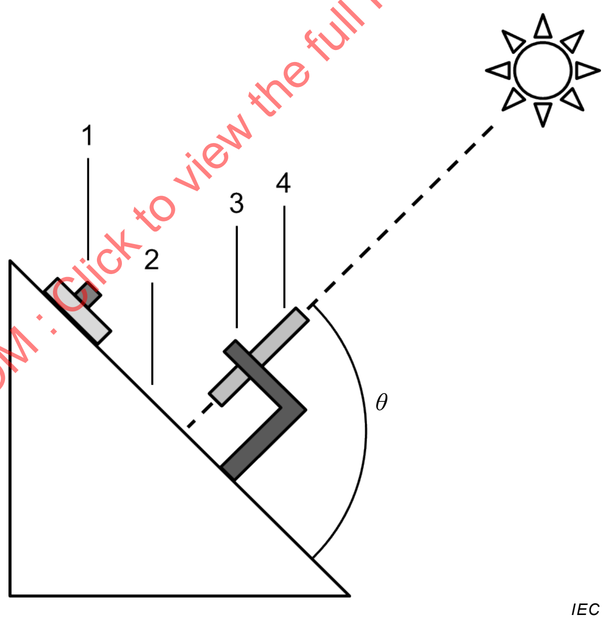
Q.4.3.3 Test prerequisites

The following prerequisites shall be met.

- Constant atmospheric conditions (i.e. a clear, sunny day with no clouds).
- Incident solar irradiance between 850 W/m^2 and 1 150 W/m^2 and an ambient temperature between 15 °C and 35 °C.
- Air mass less than or equal to 2.
- If the PV module is amorphous silicon or otherwise could be subject to degradation (e.g. because it is thin film or of unknown technology), it shall sun-soak for 30 days prior to performing this test.

Q.4.3.4 Apparatus

There should be an appropriate stand to hold the PV module and pyranometer in the same plane, directly normal to the sun. The PV module should be placed as close as possible to the pyranometer to ensure that each device "sees" the same sky view. A sighting tube with bracket may be used to ensure the stand is directly normal to the sun (Figure Q.1).



Key

1 Pyranometer

2 Board or other flat surface

3 Bracket

4 Sighting tube

θ 90°

Figure Q.1 – PV module I-V curve testing rack

Q.4.3.5 Procedure

Q.4.3.5.1 General

Determine the appropriate thermocouple mounting technique based on PV panel configuration. If the PV module is separate from the lighting product or can be easily removed without damaging the active PV material and the back of the PV module is accessible, use the back-mounted thermocouple procedure (Q.4.3.5.2). Otherwise, use the front-mounted thermocouple procedure (Q.4.3.5.3).

Procedure 1 of Q.4.2.3 (which references IEC 60891:2009) may be used as an alternative means to adjust the I-V curve to STC and TMOT (as opposed to using the methods provided below in Q.4.3.5.2 and Q.4.3.5.3). This would involve taking I-V curve measurements at two different module temperatures, rather than only taking I-V curve measurements when the module has reached thermal equilibrium after warming under natural sunlight. This can result in a more accurate temperature correction, but the benefit can be offset by the need to perform an I-V curve measurement when the temperature is not stable, particularly when using equipment with long sweep times (such as a manually actuated rheostat load).

Although procedure 1 of Q.4.2.3 can be used to correct for both irradiance and temperature, this usually requires at least three I-V curve measurements under different irradiance and temperature conditions. To simplify testing, the calculations in Q.4.3.5.2 may be used for the irradiance correction even when Procedure 1 of Q.4.2.3 is used for the temperature correction.

Some PV modules include a zener diode in the junction box to limit the open-circuit voltage. Procedure 2 of Q.4.2.3 cannot be used with these modules, which can be identified as described in Q.4.2.3.

Q.4.3.5.2 Back-mounted thermocouple

The following steps shall be followed.

a) Before the PV module is exposed to sunlight, perform the following steps.

   1) If the PV module charges the product via a cable extended from the PV module's junction box, measure the I-V curve from the end of the cable that plugs into the product for charging by cutting the connector from the end of the PV module cable, leaving as much of the cable connected to the PV module as possible, and strip the wire ends.

      If the PV module's I-V curve results show that the PV module's performance deviates from the advertised values by more than the truth-in-advertising tolerance specified in the product specification, the I-V curve test shall be repeated measuring the I-V curve from the PV module's junction box (before the PV module's charging cable). The results from the original test shall be used as input for the solar charge test and both sets of results shall be reported for the photovoltaic module I-V characteristics test.

      If the junction box contains components that prevent the I-V curve measurement from being carried out at the end of the cable, the I-V curve may be measured at the junction box or at another point that enables the measurement to be performed. Note the location of the measurement in the test report. If the junction box is potted, this testing can require obtaining additional samples of the PV module without the potting compound. If the test is subject to a random sampling requirement (Annex E), the additional samples shall be obtained in a way that complies with this requirement; for example, samples could be collected by a sampling agent at the PV module supplier's factory before the potting compound is added.

   2) Connect a voltage meter or multimeter (DC voltage range) to the PV module.

   3) Fix the thermocouple to the back of the PV module directly behind a cell near the centre of the active area and affix insulating material (e.g. foil-backed foam tape) over the thermocouple.

b) Expose the PV module to direct normal sunlight and immediately measure and record the open-circuit voltage ($V_{oc,1}$) and the PV module temperature (T_1).

c) Leave the PV module in direct normal sunlight until thermal equilibrium is reached (i.e. the PV module temperature is not changing by more than 1 °C/min).

d) Connect the PV module to the I-V curve analyser per the I-V curve analyser's manufacturer's instructions.

e) Execute the I-V measurement per the I-V curve analyser's manufacturer's instructions and record the PV module temperature (T) and incident solar irradiance.

f) After the I-V curve measurement, measure and record the PV module temperature again (T_2) using the same instrument that was used in step a).

g) Measure the record the PV module's open-circuit voltage at T_2 ($V_{oc,2}$) using the same instrument that was used in step a).

Q.4.3.5.3 Front-mounted thermocouple

The following steps shall be followed.

a) Before the PV module is exposed to sunlight, perform the following steps:
   1) Perform step Q.4.3.5.2.a) 1).
   2) Connect a voltage meter or multimeter (DC voltage range) to the PV module.
   3) Fix the thermocouple to the front of the PV module directly over a cell in the centre of the active area and affix insulating material (e.g. foil-backed foam tape) over the thermocouple.

b) Expose the PV module to direct normal sunlight and immediately measure and record the PV module temperature (T_1), then quickly remove the thermocouple and insulating material from the front of the PV module, and measure and record the open-circuit voltage ($V_{oc,1}$).

c) After measuring ($V_{oc,1}$), again fix the thermocouple to the front of the PV module directly over a cell in the centre of the active area in the same location as before and affix insulating material (e.g. foil-backed foam tape) over the thermocouple.

d) Leave the PV module in direct normal sunlight until thermal equilibrium is reached (i.e. the PV module temperature is not changing by more than 1 °C/min).

e) Connect the PV module to the I-V curve analyser per the I-V curve analyser's manufacturer's instructions.

f) Remove the thermocouple.

g) Measure and record the PV module's open-circuit voltage at T_2 ($V_{oc,2}$) using the same instrument that was used in step a).

h) Immediately after obtaining $V_{oc,2}$, affix the thermocouple and insulating material to the front of the PV module (i.e. the same place as in step a)) and measure and record the temperature of the PV module (T_2 and T) using the same instrument that was used in step a).

i) Immediately remove the thermocouple and execute the I-V measurement per the I-V curve analyser's manufacturer's instructions.

Q.4.3.5.4 Calculations

The following calculations shall be made.

a) If correcting for irradiance and temperature using procedure 1 of Q.4.2.3 (see Q.4.3.5.1), perform the temperature and irradiance correction, then skip steps b) through g) and proceed to step h).

b) Convert all of the current measurements to STC using the following formula:

$$I = I_m \times \frac{1\,000\ \text{W/m}^2}{G}$$

where

I is the PV module's current at STC, in amperes (A);

I_m is the PV module's measured current, in amperes (A);

G is the measured incident solar irradiance during the I-V curve measurement, in watts per square metre (W/m^2).

c) If correcting for temperature (but not irradiance) using procedure 1 of Q.4.2.3 (see Q.4.3.5.1), perform the temperature correction, then skip steps d) through g) and proceed to step h).

d) Calculate the open-circuit voltage of the measured I-V data ($V_{oc,m}$) using the guidelines in Q.4.2.4.

e) Determine the temperature coefficient for the voltage ($T_{c,voc}$) using the following formula:

$$T_{c,voc} = \frac{\left(V_{oc,1} - V_{oc,2}\right)/V_{oc,m}}{T_1 - T_2}$$

where

$T_{c,voc}$ is the PV module's temperature coefficient for the voltage, per degree Celsius (1/°C);

$V_{oc,1}$ is the PV module's open-circuit voltage immediately after exposure to sunlight, in volts (V);

$V_{oc,2}$ is the PV module's open-circuit voltage after the I-V measurement is taken, in volts (V);

$V_{oc,m}$ is the PV module's open-circuit voltage measured during the I-V measurement, in volts (V);

T_1 is the PV module's temperature immediately before exposure to sunlight, in degrees Celsius (°C);

T_2 is the PV module's temperature after the I-V curve measurement is taken, in degrees Celsius (°C).

NOTE 1 This temperature coefficient is used only for the temperature correction and is not the value provided in the test report, which is denoted β_{rel}.

f) Convert all of the voltage measurements to STC using the following formula:

$$V = V_m\left[1 + T_{c,voc}\left(T_{stc} - T\right)\right]$$

where

V is the PV module's voltage at STC, in volts (V);

V_m is the PV module's measured voltage, in volts (V);

$T_{c,voc}$ is the PV module's temperature coefficient for the voltage, per degree Celsius (1/°C);

T_{stc} is the temperature at STC, 25 °C;

T is the PV module's temperature during the I-V curve measurement, in degrees Celsius (°C).

g) Repeat steps e) and f) for TMOT in place of STC, where TMOT is defined as 50 °C.

h) Determine and report the short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), maximum power point power (P_{mpp}), maximum power point current (I_{mpp}), and maximum power point voltage (V_{mpp}) at STC and TMOT and the relative temperature coefficient of open-circuit voltage (β_{rel}) according to Q.4.2.4.

NOTE 2 If procedure 1 of Q.4.2.3 is not used, the relative temperature coefficient of open-circuit voltage calculated according to step g) is equivalent to the temperature coefficient calculated in d) except that $V_{oc,STC}$ is used in the denominator instead of $V_{oc,m}$.

Q.5 Reporting

Report the following in the photovoltaic module I-V characteristics test report.

- Metadata:
  – report name;
  – procedure(s) used;
  – lighting product manufacturer;
  – lighting product name;
  – lighting product model number;
  – name of test laboratory;
  – description of location of test;
  – approving person;
  – date of report approval.
- Results for tested PV module aspects for samples 1 through n:
  – short-circuit current at STC (A);
  – open-circuit voltage at STC (V);
  – maximum power point power at STC (W);
  – maximum power point current at STC (A);
  – maximum power point voltage at STC (V);
  – short-circuit current at TMOT (A);
  – open-circuit voltage at TMOT (V);
  – maximum power point power at TMOT (W);
  – maximum power point current at TMOT (A);
  – maximum power point voltage at TMOT (V);
  – relative temperature coefficient of open-circuit voltage (%/°C).
- Average of n sample results for each PV module aspect tested.
- Coefficient of variation of n sample results for each PV module aspect tested (%).
- PV module's rating for aspects tested, if available.
- Deviation of the average result from the PV module's rating for each aspect tested, if available (%).
- Comments:
  – individual comments, as necessary, for samples 1 through n;
  – overall comments, as necessary, for collective set of samples 1 through n.
- Figures:
  – single plot showing the I-V and power-voltage curves for every PV module sample.
- Datasets:
  – comma-delimited or tabular dataset listing current (A) and voltage (V) adjusted to STC across the full measured I-V curve.

Annex R
(normative)

Solar charge test

R.1 Background

The solar charge test provides estimates for two key sources of energy loss during solar charging: suboptimal operation of the solar module ("solar operation efficiency") and losses from the DUT's internal electronic circuits that charge the battery(-ies) ("battery-charging circuit efficiency"). Along with the battery round-trip energy efficiency (Annex K), these values are used in the daily energy service calculations (Annex GG) to calculate the energy service (e.g. run time) provided in a typical day of solar charging.

A power supply along with two resistors is used to simulate a solar module and charge the DUT's battery(-ies). The voltage operating point during the test combined with the solar I-V curve is used to calculate the solar operating efficiency. Measurements of energy input to the DUT solar charging port and DUT battery(-ies) are used to estimate the battery-charging circuit efficiency.

R.2 Test outcomes

The test outcomes of the solar charge test are listed in Table R.1.

Table R.1 – Solar charge test outcomes

Metric	Reporting units	Related aspects	Note
Solar operation efficiency ($\eta_{sol\text{-}op}$)	Percentage	4.2.6 Solar module aspects	This is representative of the efficiency with respect to optimal operation of the PV module (where optimal operation is at the maximum power point).
Battery-charging circuit efficiency (η_{bcc})	Percentage	4.2.7.4 Battery-charging circuit efficiency	This is a lump figure for the whole product and is not disaggregated by main unit.
Average charging voltage	Volts (V)	n/a	This value is used in the assessment of DC ports (Annex EE) when a typical charging voltage is needed.
Solar charging system characteristics	n/a	n/a	This describes key features of the solar charging circuit
Energy allocation ratios	Percentage	n/a	Percentage of energy delivered to each unit's battery in the case that the test consists of multiple units. This outcome is not required when the test consists of only one battery.

R.3 Related tests

The solar charge test is related to the battery test (Annex K), the photovoltaic module I-V characteristics test (Annex Q), the full-battery run time test (Annex M), and the energy service calculations (Annex GG).

R.4 Procedure

R.4.1 General

In this test, the DUT is charged using an apparatus to simulate the PV module during a typical day of solar charging. The PV simulation shall be performed using a resistor network and programmable laboratory power supply or a solar array simulator meeting the requirements of Table CC.2. The voltage and current at the DUT's PV input and battery(-ies) are recorded at one-minute or shorter intervals.

R.4.2 Test method using a resistor network

R.4.2.1 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Programmable power supply with constant-voltage and constant-current modes and ability to automatically step through a timed program, or alternative apparatus described below.
- Voltage data loggers (one for the PV input and one for each of the batteries).
- Current data loggers (e.g. voltage data logger and current transducer) (one for the DUT's PV input and one for each battery charged during the test).

NOTE Most products have only one battery that is charged during the solar charge test; see R.4.2.2.

- Series and parallel resistors (or variable resistors) for simulating PV input.
- Variable resistor for measuring the I-V curve from the PV simulator (optional).
- Resistance meter or multimeter.
- Surface-mounted thermocouple(s) and a thermocouple reader or other suitable surface-mounted temperature measurement devices (optional).
- Overcharge disconnect device that will stop the charge cycle (e.g. by disconnecting the battery) when the battery reaches a specified voltage (if necessary).

This test involves a calculation of electrical power; see Clause CC.3 for related recommendations. For products with pulse-width modulation (PWM) charge controllers, or if the current and voltage vary rapidly for any reason, power-measuring instruments should be used, as described in Clause CC.3. One instrument is required for the PV socket and one for each battery included in the test. An instrument with an integration function, to calculate cumulative energy, should be used. The power-measuring instrument should also record voltage and current; if this is not possible, separate instruments may be used for the voltage and current measurements, which are used to calculate the corrected solar operation efficiency in R.4.4 k).

Instead of a programmable power supply, an electronic apparatus designed to simulate the PV module's diode characteristic may be used. The characteristics of the apparatus shall be modelled and incorporated into the circuit simulation described in R.4.2.4 a). An example of an apparatus intended for this purpose is described by Stütz (2014). The use of such an apparatus can improve the curve-fitting accuracy and dynamic performance, especially with DUTs that use pulse-width modulation (PWM) or maximum power point tracking (MPPT). The laboratory shall ensure that any such apparatus has voltage and current accuracy at least equivalent to the overall accuracy of the resistor network with a power supply meeting the requirements above.

The series resistance added by the test apparatus and all measurement equipment between the DUT and the battery, shall be no more than 90 mΩ. This value includes the resistance of the wires and connectors, if any, added in the sample preparation procedure (G.4.4). Some products, particularly with currents exceeding approximately 1 A and low battery voltages, require a lower resistance to charge normally. Excessive resistance often results in a premature charge cutoff, a reduced current at the higher simulated solar irradiance steps, or intermittent operation. In products with lithium-based batteries containing multiple cells in series, excessive resistance can interfere with the correct operation of cell balancing features, particularly if the balancing circuit is not internal to the battery pack.

The resistance of any wiring between the power supply and resistors shall be kept low enough to meet the power supply accuracy voltage requirement in Table CC.2. Since the resistance of wiring and instruments between the resistor network and DUT can be lumped into the measured value of the series resistance R_s, this resistance need not be limited but should be minimized to the degree practical.

R.4.2.2 Test prerequisites

The DUT's battery should be at a state of charge that corresponds to the "end of discharge," which shall be accomplished using procedures in Annex N. Additionally, this test shall be performed after completion of the PV module I-V characteristics measurements (Annex Q), since the I-V curve information from the PV module during that test are needed to set up the inputs to the power supply for the electronics efficiency test. The results from the battery test (Annex K) and full-battery run time test (Annex M) are required for the calculations.

Special charging features that do not operate during a normal charge cycle, such as equalization or boost charging, shall not be enabled during this test, unless it is not possible to disable these features. Lights and appliances not containing batteries shall be disconnected and the DUT shall be turned off or set to standby mode (i.e. the mode in which the DUT's functionality is not active but the battery can be charged).

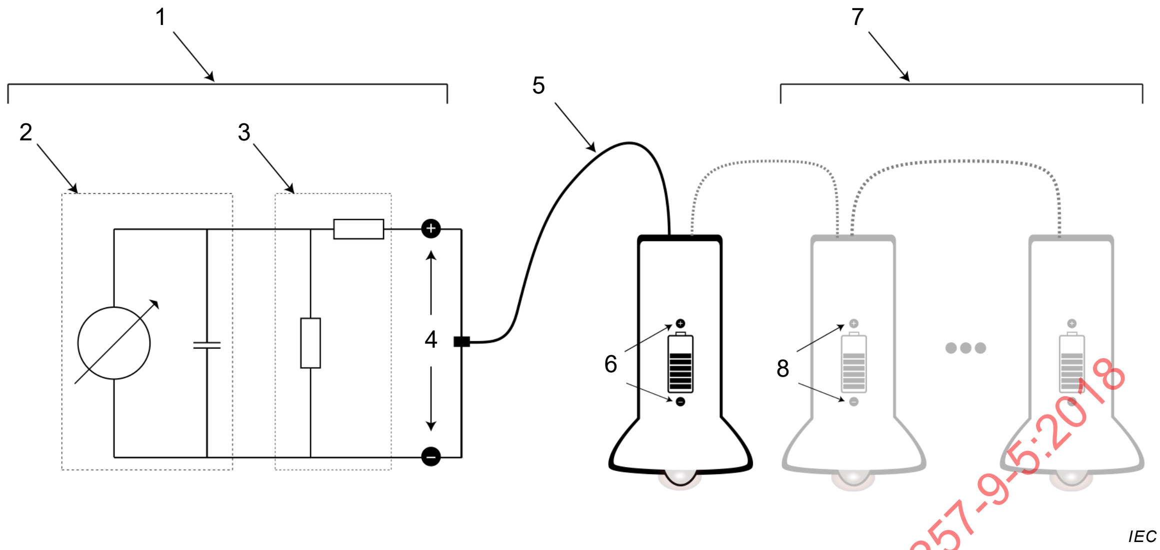
In some cases a product can contain multiple components with batteries that can charge from the PV module. In this case, the test is conducted with all batteries connected except those batteries that can be charged from another battery in the system (i.e. batteries that can be charged at night). For example, if a system contains two battery units that connect to a single PV module via a splitter cable, both battery units would be connected for this test. However, a radio, torch, or portable lamp that contains a battery and charges from the DUT's power control unit battery (e.g. via a USB port) would not be connected. Run times for lighting units and appliances that are not connected during the solar charge test shall be calculated using the methods in Annex GG.

In some cases, such as unusual configurations of batteries and appliances, the battery preparation procedure and product configuration described above is not applicable or appropriate. In these cases, the laboratory shall determine the most appropriate configuration and sample preparation procedure. The procedure used shall be documented in the test report.

R.4.2.3 Apparatus

R.4.2.3.1 General

The apparatus for the solar charge test is shown schematically in Figure R.1. The PV simulation circuit consists of two resistances (which can be constructed using combinations of fixed and/or variable resistors) and a power supply with constant-voltage and constant-current mode and programmable capability. This circuit implements an approximation of the single-diode model for a photovoltaic module.



Key

1 PV simulation circuit

2 Laboratory power supply

3 Series and parallel resistors (or variable resistors)

4 PV simulation circuit output (measures current and voltage here during simulated solar charging)

5 Connection cable from PV simulation circuit to lighting unit

6 Lighting product battery (measures current and voltage here during simulated solar charging)

7 [optional] Additional lighting units with separate batteries that are included with the product

8 [optional] Additional lighting unit battery(-ies) (measure current and voltage here during simulated solar charging)

Figure R.1 – Schematic of the power supply and DUT connection for the solar charge test

The following quantities are measured at intervals of no more than 1 min:

- voltage at the DUT’s PV input socket, or other location where the PV module connects to the DUT;
- current at the DUT’s PV input socket, or other location where the PV module connects to the DUT;
- battery voltage for each battery (measured as close as possible to the DUT’s printed circuit board);
- battery current for each battery.

R.4.2.3.2 Special instructions for products with cell balancing

For products with cell balancing functionality implemented external to the battery pack (i.e. on the DUT’s printed circuit board), particular care should be used, because the resistance of the measurement apparatus can cause the product to detect a spurious out-of-balance condition. If the balancing functionality operates during the test, the measured battery current and the battery-charging circuit efficiency can be incorrect. The following methods may be used to test such products:

- The current and voltage may be monitored at each cell or parallel cellblock. However, this option is often impractical since the resistance of the measurement apparatus can easily result in excessive voltage drop. This method should be used only with caution, especially if the voltage drop cannot be limited to less than approximately 10 mV per cell. Any of the following signs indicate that the results of this method are not usable:
  - operation of the balancing circuit even though the cells are in balance;

– intermittent charging or behaviour similar to pulse-width modulation (PWM) due to the total pack voltage exceeding the overcharge protection limit.

- The test may be conducted with no current or voltage monitoring, or with voltage monitoring only, at the batteries. The battery-charging circuit efficiency is then calculated using the alternative method given in R.4.5.

If these methods are unsuccessful, alternative methods may be used if the laboratory can demonstrate that the results obtained are equivalent to the result of one of the permitted methods had that method been possible.

R.4.2.3.3 Special instructions for alternative I-V curve measurement locations

When the I-V curve was measured at a location other than the end of the PV module cable, the resistance of the cable and any other components between the I-V curve measurement point and the DUT shall be taken into account in the solar charge test, using one of the following methods.

a) Insert the PV module cable, including any electronic components in the junction box that were bypassed or removed in the I-V curve test, between the resistor network apparatus or solar array simulator and the DUT's PV input socket. (That is, the PV simulator is placed at the same location in the circuit where the I-V curve was taken.) If the cable cannot be detached non-destructively from the junction box, the cable shall be cut as close to the junction box as practical. The PV simulator current and voltage is measured at the end of the PV cable connected to the PV simulator. If a resistor network is used, the resistance of the cable is not included in the measurement of the series resistance R_s.

   If the junction box is potted and contains electronics, it is sometimes necessary to obtain additional samples of the PV module cable and electronics without the potting compound, as described in Q.4.2.2.

b) The cable (and all other components between the I-V curve measurement location and the DUT) may be replaced by a resistor having a resistance within 1 % of the measured resistance of the PV module cable. The resistance measurement may be made on a single sample; only the omitted portion of the cable should be measured. (For example, if a connector equivalent to the connector at the end of the cable is used to connect the test apparatus to the PV socket, the connector should not be included in the resistance measurement.) A four-wire measurement is typically necessary. The resistor may be constructed using a length of wire having similar characteristics to the PV module cable.

c) The cable (and all other components between the I-V curve measurement location and the DUT) may be omitted and a correction applied to each voltage value in the TMOT I-V curve. The resistance of the cable shall be measured as in b); the measurement may be made on a single sample. Use the following formula for the voltage correction:

$$V_{corr} = V_{TMOT} - I_{TMOT} \cdot R_{cable}$$

   where

   V_{corr} is the corrected voltage at each point on the corrected I-V curve, in volts (V);

   V_{TMOT} is the voltage at each point on the TMOT I-V curve for the DUT obtained from the IEC 61215-2 test data, in volts (V);

   I_{TMOT} is the current at each point on the TMOT I-V curve for the DUT obtained from the IEC 61215-2 test data, in amperes (A);

   R_{cable} is the measured resistance of the PV module cable, in ohms (Ω).

Options a) through c) above are applicable if IEC 61215-2 test results are used in place of the photovoltaic module I-V characteristics test (Annex Q) or if the I-V curve could not be measured at the end of the cable for technical reasons, for example due to a zener diode or anti-tampering device in the PV module junction box. Options b) and c) shall not be used if the If the components between the I-V curve measurement location and the DUT cannot be modelled accurately as a series resistance.

When one of these options is used, the term "PV socket" throughout the solar charge test procedure refers to the I-V curve measurement location.

R.4.2.4 Procedure

Perform the following steps.

a) Use the TMOT I-V curve (from Annex Q) to find appropriate resistor values and power supply set points to simulate the PV module operating at TMOT during the charging cycle. A computer spreadsheet or program should be used for this step.

   – The spreadsheet or program is used to estimate the response curve of the PV simulator circuit over the range of voltages that corresponds to the I-V curve.
   – The input variables to the spreadsheet shall be the following:
     - series resistance;
     - parallel resistance;
     - voltage setpoint;
     - current setpoints corresponding to each level of simulated solar irradiance listed in Table R.2.
   – The circuit simulation shall be based on Ohm's law. When the diode characteristic is simulated using an apparatus other than a laboratory power supply, as described in R.4.2.1, the behaviour of the apparatus shall be included in the circuit model.
   – The spreadsheet or program shall estimate the TMOT current at evenly spaced voltage points by linearly interpolating between points on the measured I-V curve.
   – The spreadsheet or program shall scale the interpolated I-V curve for each level of simulated solar irradiance listed in Table R.2 by multiplying the interpolated current values by the ratio of the desired solar irradiance level to 1 000 W/m^2:

$$I_{\text{pv}}(V) = I_{\text{interp}}(V) \times \frac{G}{1\,000\ \text{W/m}^2}$$

   where

   $I_{\text{pv}}(V)$ is the scaled, interpolated current at each solar irradiance level i and voltage V, in amperes (A);

   $I_{\text{interp}}(V)$ is the interpolated current at TMOT and 1 000 W/m^2 at voltage V, in amperes (A);

   G is the simulated solar irradiance, in watts per square metre (W/m^2).

   – The spreadsheet or program shall use a non-linear minimization technique to minimize the weighted sum of the squared residuals (SSR) between the scaled, interpolated TMOT I-V curve values and the simulated I-V curve of the PV simulator by altering the input variables. To give preference for close agreement near the maximum power point, the SSR at each point shall be weighted by the product of the duration of each solar irradiance step (from Table R.2) and the power in the scaled TMOT curve:

$$\text{weighted SSR} = \sum_{G}\left(\Delta t_G \cdot \sum_{V} I_{\text{pv},G}(V) \cdot V \cdot \left(I_{\text{fit},G}(V) - I_{\text{pv},G}(V)\right)^2\right)$$

   where

   G is the simulated solar irradiance, in watts per square metre (W/m^2);

   Δt_G is the duration corresponding to each solar irradiance level i, in hours (h);

   V is the voltage at each point in the interpolated I-V curve, in volts (V);

   $I_{\text{pv},G}(V)$ is the scaled, interpolated current at solar irradiance level G and voltage V, in amperes (A);

$I_{fit,G}(V)$ is the fitted simulated current at solar irradiance level G and voltage V, in amperes (A);

– The outcomes of the spreadsheet or program are the best fit input variables:

- series resistance (R_s);
- parallel resistance (R_p);
- voltage setpoint (V_{sim});
- current setpoints ($I_{sim,1000}$, $I_{sim,900}$, $I_{sim,700}$, $I_{sim,500}$, $I_{sim,300}$).

b) Build a PV simulator circuit as in Figure R.1 using fixed or variable resistors with appropriate power ratings wired in parallel and series with the power supply. Use a resistance meter or multimeter to verify that the actual resistance values meet the accuracy requirement in Table CC.2. The measurement of R_s shall include the resistance of the wiring and measuring instruments between the resistor network and the PV socket (or I-V curve measurement point as described in R.4.2.3.3).

c) For each simulated solar irradiance level, check that the simulated I-V curve is a reasonable approximation of the true curve by calculating the deviation ratio between the simulated and scaled, interpolated TMOT I-V curves. The deviation ratio is defined as the simulated current divided by the scaled, interpolated TMOT current at each voltage point. For this calculation, use the true values of the input variables rounded to the precision of the test equipment. In the example below (Figure R.2), the deviation ratio is close to unity (between 0,95 and 1,05, or less than 5 % error) in the key parts of the I-V curve (at and to the left of the maximum power point).

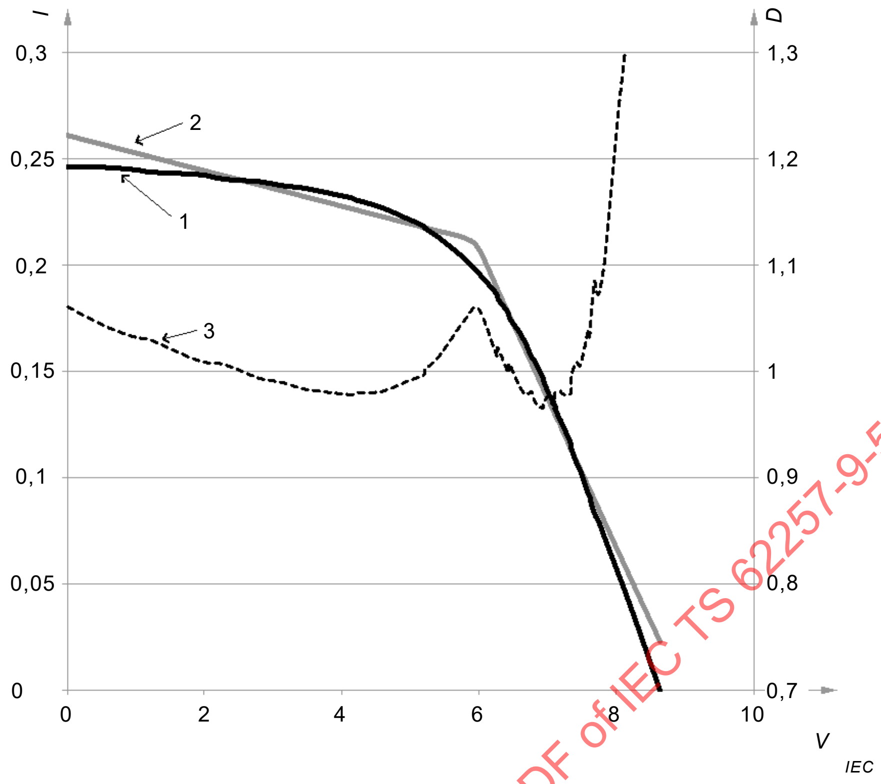
d) (optional step) Experimentally verify the calculated deviation for the 1 000 W/m^2 I-V curve, using the following procedure. Alternatively, the I-V curve analyser specified in Annex Q may be used to trace the I-V curve of the simulated solar module.

1) Connect data-logging current and voltage sensors to the PV simulator output. Set the sensors to log data at very short intervals, 1 s or less.
2) Simulate a PV module at TMOT and 1 000 W/m^2. Set the power supply current and voltage setpoints to $I_{sim,1000}$ and V_{sim}.
3) Measure an I-V curve for the PV simulator. Connect a variable resistor between the positive and negative terminals of the PV simulator and slowly sweep from high to low resistance and back.
4) Disconnect the resistor and stop the data collection.
5) Check to ensure the quality of the I-V curve data; cross check with the original (target) I-V curve to ensure the PV simulator is reasonably close, particularly in the region with voltages slightly below the maximum power point. Figure R.2 shows an example comparison. The true I-V curve (line 1) is compared to the simulated I-V curve (line 2).

e) Set up the prepared DUT (see requirements in R.4.2.2) and PV simulator circuit with current and voltage sensors, ensuring the PV simulator circuit is connected such that it replaces only the part of the PV module assembly included in the I-V curve (i.e. the PV simulator circuit is connected at the same point the I-V curve data were measured). Set the data-logging interval to 1 minute or less. Record the following quantities:

– current entering the DUT's battery(-ies), in amperes (A);
– voltage across the DUT's battery(-ies), in volts (V);
– current provided by the PV simulator circuit, in amperes (A);
– voltage across the PV simulator circuit output, in volts (V).

f) Program the power supply to simulate a "standard solar day" of charging using the steps indicated below (Table R.2). To facilitate identification of solar irradiance levels during data analysis, short pauses at 0 V may be inserted between steps.



Key

I current with units of amperes on the primary vertical axis

V voltage with units of volts on the horizontal axis

D deviation ratio (unitless) on the secondary vertical axis

1 measured "true" I-V curve, plotted on the primary axis

2 I-V curve from the PV simulator ($I_{fit,G}(V)$), plotted on the primary axis

3 deviation ratio as a function of voltage, plotted on the secondary axis

Figure R.2 – Example "true" and simulated I-V curves plotted with the deviation ratio

Table R.2 – Simulated solar day power supply settings

Step duration h	Simulated solar irradiance W/m²	Current setpoint	Voltage setpoint
0,5	300	$I_{sim,300}$	V_{sim}
0,5	500	$I_{sim,500}$	V_{sim}
1	700	$I_{sim,700}$	V_{sim}
1	900	$I_{sim,900}$	V_{sim}
1	1 000	$I_{sim,1000}$	V_{sim}
1	900	$I_{sim,900}$	V_{sim}
1	700	$I_{sim,700}$	V_{sim}
0,5	500	$I_{sim,500}$	V_{sim}
0,5	300	$I_{sim,300}$	V_{sim}

g) The DUT's battery voltage shall be continuously monitored such that the battery voltage shall not exceed a safety limit, either relying on the internal charge controller or based on the judgement of the laboratory. If necessary, integrate the overcharge protection disconnect device into the setup. The overcharge protection device shall disconnect if battery voltage rises above safety limits that are determined by the laboratory. Refer to the battery recommended testing practices (Annex L) for recommended maximum battery testing voltage values (refer to Table L.2). Optionally, monitor the battery temperature to ensure that it does not exceed Table L.2. If temperature monitoring is used, lithium-based batteries shall not be allowed to exceed 45 °C unless higher temperatures are allowed by the battery manufacturer. If the charge cycle is stopped by an overcharge or overtemperature protection device added by the test laboratory, the test results shall be considered invalid.

h) Check the connections and setpoints, then begin data logging and start the simulated charging cycle. Caution: Do not disconnect the product after having started the simulated charging cycle. The electronics of some DUTs can be damaged if their batteries are disconnected while voltage is applied to the PV input.

i) After the 7 h charging cycle is complete, stop the power supply, stop the data logging, disconnect the product from the PV simulator, and verify that the current and voltage data are valid with a quick check.

R.4.3 Test method using a solar array simulator (SAS)

R.4.3.1 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Solar array simulator meeting the accuracy requirement specified in Table CC.2, including footnote d.
- Voltage data loggers (one for the DUT’s PV input and one for each of the DUT’s batteries).
- Current data loggers (e.g. voltage data logger and current transducer) (one for the DUT’s PV input and one for each battery charged during the test).

NOTE Most products have only one battery that is charged during the solar charge test; see R.4.2.2.

- Surface-mounted thermocouple(s) and a thermocouple reader or other suitable surface-mounted temperature measurement devices (optional).
- Overcharge disconnect device that will stop the discharge when the battery reaches a specified voltage (if necessary).

If the solar array simulator includes data-logging functionality, this functionality may be used instead of the voltage and current data loggers at the PV input, provided the accuracy and resolution requirements for data loggers (Table CC.2) are met.

The resistance limits and the recommendations regarding power measurement given in R.4.2.1 apply.

R.4.3.2 Test prerequisites

The test prerequisites are identical to those for the test method using a resistor network (R.4.2.2).

R.4.3.3 Apparatus

The apparatus is identical to that for the test method using a resistor network (R.4.2.3), except the PV simulator circuit (item 1 in Figure R.1) is replaced with a solar array simulator.

R.4.3.4 Procedure

The following steps shall be followed.

a) Configure the solar array simulator to simulate the DUT’s I-V curve at TMOT.

b) If the solar array simulator does not meet the accuracy requirement described in Table CC.2 according to the manufacturer's specifications, measure the simulator's I-V curve and verify that the simulated current is within the tolerance specified in Table CC.2 for all applicable voltage values. If the measured current is not within the specified tolerance, the solar array simulator shall not be used for this DUT. If the solar array simulator meets the accuracy requirement described in Table CC.2 according to the manufacturer's specifications, this step is optional.

c) Set up the prepared DUT (see requirements in R.4.3.2) and PV simulator circuit with current and voltage sensors, ensuring the PV simulator circuit is connected such that it replaces only the part of the PV module assembly included in the I-V curve (i.e. the PV simulator circuit is connected at the same point the I-V curve data were measured). Set the data-logging interval to 1 min or less. Record the following quantities:
   - Current entering the DUT's battery(s), in amperes (A).
   - Voltage across the DUT's battery(s), in volts (V).
   - Current provided by the PV simulator circuit, in amperes (A).
   - Voltage across the PV simulator circuit output, in volts (V).

d) Program the solar array simulator to simulate a "standard solar day" of charging using the steps indicated in Table R.2. To facilitate identification of solar irradiance levels during data analysis, short pauses at 0 V may be inserted between steps. Adjust the curve to the reduced solar irradiance levels by adjusting the current only, according to the following formula:

$$I_{SAS} = I_{TMOT} \cdot \frac{G_{sim}}{G_{TMOT}}$$

where

I_{SAS} is the current at each point on the simulated I-V curve, in amperes (A);

I_{TMOT} is the current at each point on the measured I-V curve, adjusted to TMOT, in amperes (A);

G_{sim} is the simulated solar irradiance from Table R.2, in watts per square metre (W/m^2).

G_{TMOT} is the solar irradiance at TMOT (1 000 W/m^2).

e) The DUT's battery voltage shall be continuously monitored such that the battery voltage shall not exceed a safety limit, either relying on the internal charge controller or based on the judgement of the laboratory. If necessary, integrate the overcharge protection disconnect device into the setup. The overcharge protection device shall disconnect if battery voltage rises above safety limits that are determined by the laboratory. Refer to the battery recommended testing practices (Annex L) for recommended maximum battery testing voltage values (refer to Table L.2). Optionally, monitor the battery temperature to ensure that it does not exceed a safe value (refer to Table L.2). If temperature monitoring is used, lithium-based batteries shall not be allowed to exceed 45 °C unless higher temperatures are allowed by the battery manufacturer. If the charge cycle is stopped by an overcharge or overtemperature protection device added by the test laboratory, the test results shall be considered invalid.

f) Check the connections and setpoints, then begin data logging and start the simulated charging cycle. Caution: Do not disconnect the battery after having started the simulated charging cycle. The electronics of some DUTs can be damaged if their batteries are disconnected while voltage is applied to the PV input.

g) After the 7 h charging cycle is complete, stop the power supply, stop the data logging, disconnect the battery from the PV simulator, and verify that the current and voltage data are valid with a quick check.

R.4.4 Calculations

The following calculations shall be made.

NOTE 1 In the following procedure, "PV simulator" refers to the resistor network or solar array simulator, whichever is applicable to the test method used.

a) Determine the maximum power available from the PV simulator ($P_{\text{max,sim},G}$) at each simulated solar irradiance level G, using the following formula:

$$P_{\text{max,sim},G} = \max_V \left(I_{\text{pvsim},G}(V) \cdot V \right)$$

where

$P_{\text{max,sim},G}$ is the maximum power available from the PV simulator at simulated solar irradiance level G, in watts(W);

V is the voltage at each point in the interpolated I-V curve, in volts (V);

$I_{\text{pvsim},G}(V)$ is the simulated current at solar irradiance level G and voltage V, in amperes (A). If a resistor network is used, this is the fitted current $I_{\text{fit},G}(V)$ calculated in step a) of R.4.2.4, as a function of voltage. If a solar array simulator is used, this is the I-V curve programmed into the solar array simulator, as a function of voltage.

NOTE 2 Regardless of the test method used, this quantity is the power at the maximum power point of the simulated I-V curve. This quantity is calculated from the simulated I-V curve, not from the measurements performed for this test.

b) For each measurement at time t, identify the maximum power available from the PV simulator ($P_{\text{max,sim}}(t)$). This is the maximum available power $P_{\text{max,sim},G}$ at the solar irradiance level $G(t)$ corresponding to time t.

c) For each measurement at time t, compute the power supplied by the PV simulator ($P_{\text{pvsim}}(t)$) using the following formula:

$$P_{\text{pvsim}}(t) = I_{\text{pvsim}}(t) \cdot V_{\text{pvsim}}(t)$$

where

$P_{\text{pvsim}}(t)$ is the power supplied by the PV simulator at time t, in watts (W);

$I_{\text{pvsim}}(t)$ is the current supplied by the PV simulator at time t, in amperes (A);

$V_{\text{pvsim}}(t)$ is the voltage supplied by the PV simulator at time t, in volts (V).

d) For each measurement at time t and each battery i, compute the power delivered to the battery ($P_{\text{b},i}(t)$) using the following formula:

$$P_{\text{b},i}(t) = I_{\text{b},i}(t) \cdot V_{\text{b},i}(t)$$

where

$P_{\text{b},i}(t)$ is the power supplied by the PV simulator at time t, in watts (W);

$I_{\text{b},i}(t)$ is the current supplied by the PV simulator at time t, in amperes (A);

$V_{\text{b},i}(t)$ is the voltage across battery i at time t, in volts (V).

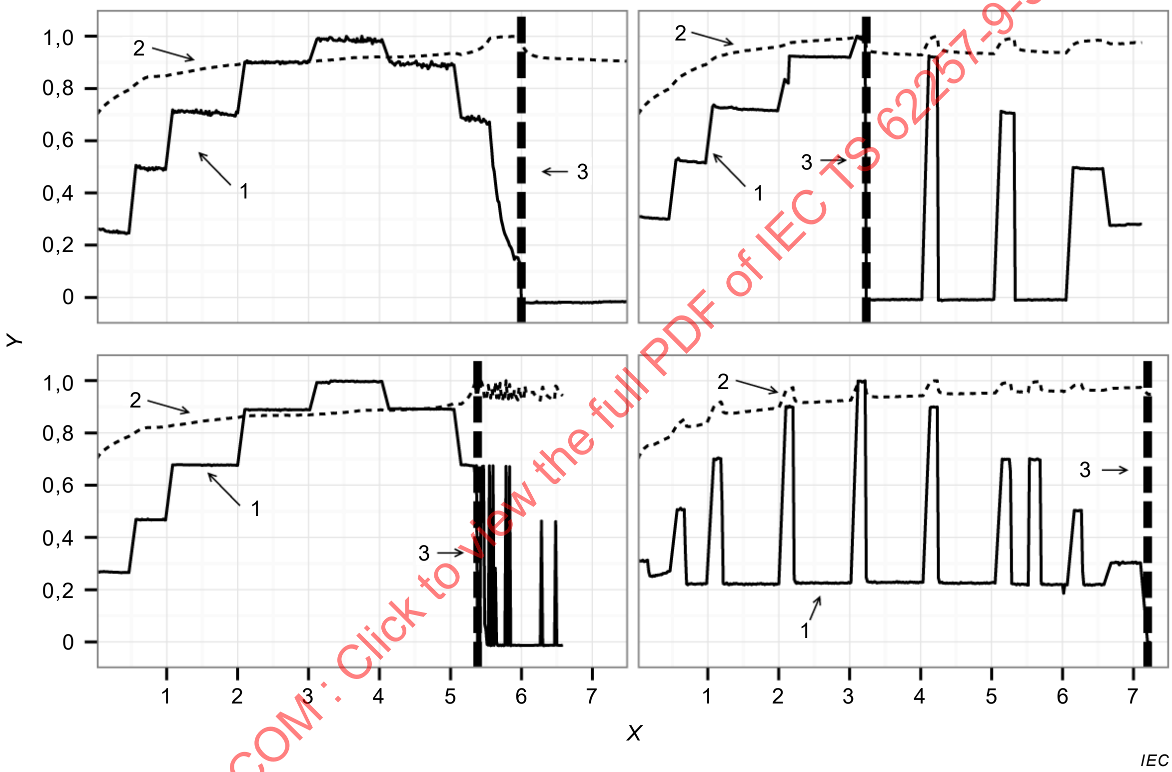
e) If the charge controller terminates the battery charge during the test (for example, if the battery is full), the battery-charging circuit efficiency and solar operation efficiency shall be calculated based on the current and voltage data prior to charge termination. To identify the charge termination time and detect if the event has occurred, the following procedure shall be used.

1) For each battery i, identify the battery-specific charge termination time ($t_{\text{end},i}$) by plotting the current into the battery vs. time and identifying the time at which the current drops to zero or becomes negative. If the current does not drop to zero, but there is a clear change in the charging regime as the battery approaches a full charge, the tester may use his or her discretion in determining whether charging has stopped. If the current drops to zero due to a full battery, but then increases (for example, if the battery voltage drops below the overcharge protection voltage and charging resumes), the earliest cutoff time should be used. In any case, the tester may use his or her discretion to determine the most accurate charge termination time. See Figure R.3 below for examples.

An automated method, such as a spreadsheet or computer program, may be used to identify a possible value for the charge termination time, provided the result obtained by such a method is checked for correctness by examining the plot of the current vs. time. The tester should also check that the current dropped to zero due to the behaviour of the DUT, not due to a data collection error, loose connection, or other fault in the test apparatus or DUT.

Due to noise or measurement error, the current will sometimes be observed to drop to a low but nonzero value rather than to zero. For this step, the current should be considered to have dropped to zero if it drops to a value that is indistinguishable from zero due to the uncertainty in the current measurement.

If pauses were inserted between solar irradiance steps to facilitate identification of solar irradiance levels, some DUTs could restart charging after a pause, even if charging had previously stopped. In this case, the charge termination time should be the first time that charging stopped, before the pause.



Key

X time with units of hours on the horizontal axis

Y current or voltage in arbitrary units on the vertical axis

1 current into the battery, in arbitrary units

2 battery voltage, in arbitrary units

3 indicates the charge termination time

NOTE 1 The thick dashed line indicates the correct charge termination time for each battery. The battery voltage is also plotted for reference.

NOTE 2 Plotting the battery voltage can be helpful in determining whether the charge has terminated due to the behaviour of the DUT's charge controller or due to a fault in the apparatus or DUT. Usually, the battery voltage will reach a local maximum at the charge termination time and then remain constant or decrease after charging stops.

Figure R.3 – Example plots of current vs. time for four different DUT batteries

2) Determine the overall data analysis end time (t_{end}) as the largest value of $t_{\text{end},i}$ for all batteries:

$$t_{\text{end}} = \max_i \left(t_{\text{end},i} \right)$$

where

t_{end} is the overall data analysis end time, in hours (h);

$t_{\text{end},i}$ is the battery-specific data analysis end time for battery i, in hours (h).

For the remaining calculation steps, all energy totals (E_{pvsim}, $E_{\text{max,sim}}$, and $E_{\text{b,i}}$) shall be calculated using only the values for times less than t_{end}.

f) Determine the energy supplied by the PV simulator (E_{pvsim}) using the following formula:

$$E_{\text{pvsim}} = \sum_{t=0}^{t_{\text{end}}} \left(P_{\text{pvsim}}(t) \cdot \Delta t \right)$$

where

E_{pvsim} is the energy supplied by the PV simulator, in watt·hours (Wh);

t is the elapsed time, in hours (h);

t_{end} is the overall data analysis end time, in hours (h);

$P_{\text{pvsim}}(t)$ is the power supplied by the PV simulator at time t, in watts (W);

Δt is the duration of time associated with each measurement, in hours (h).

g) Calculate the maximum available simulated PV energy ($E_{\text{max,sim}}$) using the following formula:

$$E_{\text{max,sim}} = \sum_{t=0}^{t_{\text{end}}} \left(P_{\text{max,sim}}(t) \cdot \Delta t \right)$$

where

$E_{\text{max,sim}}$ is the maximum available simulated PV energy, in watt·hours (Wh);

t is the elapsed time, in hours (h);

t_{end} is the overall data analysis end time, in hours (h);

$P_{\text{max,sim}}(t)$ is the maximum power available from the PV simulator at time t, in watts (W);

Δt is the duration of time associated with each measurement, in hours (h).

h) Determine the energy delivered to each battery ($E_{\text{b},i}$) using the following formula:

$$E_{\text{b},i} = \sum_{t=0}^{t_{\text{end}}} \left(P_{\text{b},i}(t) \cdot \Delta t \right)$$

where

$E_{\text{b},i}$ is the energy delivered to battery i, in watt·hours (Wh);

t is the elapsed time, in hours (h);

t_{end} is the overall data analysis end time, in hours (h);

$P_{\text{b},i}(t)$ is the power delivered to battery i at time t, in watts (W);

Δt is the duration of time associated with each measurement, in hours (h).

i) Determine the energy allocation ratio for each battery using the following formula:

$$\alpha_i = \frac{E_{\text{b},i}}{\sum_i E_{\text{b},i}}$$

where

α_i is the energy allocation ratio for battery i, a unitless ratio;

$E_{b,i}$ is the energy delivered to battery i, in watt·hours (Wh).

j) Determine the battery-charging circuit efficiency (η_{bcc}) using the following formula. If the calculated value exceeds 100 %, use a value of 100 %; however, the reason for the result should be investigated. A value of battery-charging circuit efficiency slightly more than 100 % can occur due to measurement error, but often indicates a problem with the test apparatus.

$$\eta_{bcc} = \frac{\sum_i E_{b,i}}{E_{pvsim}}$$

where

η_{bcc} is the battery-charging circuit efficiency as a fraction, from the battery test (Annex K);

$E_{b,i}$ is the energy delivered to battery i, in watt·hours (Wh), from the full-battery run time test (Annex M);

E_{pvsim} is the energy supplied by the PV simulator, in watt·hours (Wh).

k) Estimate the solar operation efficiency ($\eta_{sol\text{-}op}$).

NOTE 3 The procedure below calculates solar operation efficiency using two different methods. The first method, calculated in step 1), is the ratio of the actual energy delivered by the PV simulator to the maximum possible energy based on the characteristics of the PV simulator. The second method attempts to determine the point at which the DUT's actual PV module would have operated, had the DUT been charging using the PV module in sunlight. The correction procedure works well for products without a DC-DC converter or maximum power point tracking; however, it is an approximation since in such products the PV module voltage is a function of the battery charge. Since the maximum power point voltage of the PV simulator apparatus can differ from that of the actual module, the correction procedure can underestimate the efficiency in products with maximum power point tracking that successfully identifies the maximum power point of the PV simulator.

1) Calculate the uncorrected solar operation efficiency ($\eta_{sol\text{-}op,u}$) using the following formula. If the calculated value exceeds 100 %, use a value of 100 %; however, the reason for the result should be investigated. A value of uncorrected solar operation efficiency greater than 100 % often indicates that the circuit parameters (R_s, R_p, V_{sim}, or $I_{sim,G}$) during the test did not match the calculated values. If the discrepancy was greater than the permitted tolerances, the test should be repeated.

$$\eta_{sol\text{-}op,u} = \frac{E_{pvsim}}{E_{max,sim}}$$

where

$\eta_{sol\text{-}op,u}$ is the uncorrected solar operation efficiency as a fraction;

$E_{max,sim}$ is the maximum available simulated PV energy, in watt·hours (Wh);

E_{pvsim} is the energy supplied by the PV simulator, in watt·hours (Wh).

2) For each measurement at time t, identify the maximum power available from the DUT's PV module ($P_{max,mod}(t)$), using the following formula:

$$P_{max,mod} = P_{mpp,TMOT} \cdot \frac{G(t)}{G_{TMOT}}$$

where

$P_{max,mod}$ is the power available from the DUT's PV module, in watts (W);

$P_{mpp,TMOT}$ is the maximum power of the DUT's PV module at TMOT, in watts (W);

t is the elapsed time, in hours (h);

$G(t)$ is the simulated solar irradiance at time t, in watts per square metre (W/m^2);

G_{TMOT} is the solar irradiance at TMOT (1 000 W/m^2).

3) If the test was conducted using a solar array simulator, the solar operation efficiency ($\eta_{sol\text{-}op}$) is equal to the uncorrected solar operation efficiency ($\eta_{sol\text{-}op,u}$). Skip steps 4)

through 9) and continue with step l). If the test was conducted using a resistor network and an electronic apparatus designed to simulate the PV module's diode characteristic, steps 4) through 9) may also be omitted if the apparatus accurately emulates the shape of the measured I-V curve and $P_{max,sim}$ is within 1 % of $P_{max,mod}$ for all simulated irradiance values. Otherwise, continue with step 4).

4) For each measurement at time t, calculate the corrected current at time t according to the formula

$$I_{corr}(t) = I_{pvsim}(t)\frac{I_{pv,G(t)}\left(V_{pvsim}(t)\right)}{I_{fit,G(t)}\left(V_{pvsim}(t)\right)}$$

where

$I_{corr}(t)$	is the corrected PV simulator current at time t, in amperes (A);
$I_{pvsim}(t)$	is the current supplied by the PV simulator at time t, in volts (V);
$G(t)$	is the simulated solar irradiance level at time t;
$I_{fit,G(t)}(V)$	is the fitted current from R.4.2.4 as a function of voltage at the irradiance level $G(t)$, in amperes (A);
$I_{pv,G(t)}(V)$	is the scaled, interpolated current from R.4.2.4 as a function of voltage at the irradiance level $G(t)$ (i.e. the measured I-V curve, corrected for irradiance), in amperes (A);
$V_{pvsim}(t)$	is the voltage supplied by the PV simulator at time t, in volts (V).

NOTE 4 The fraction in the formula is the deviation ratio defined in R.4.2.4. The corrected current is the current that would be supplied by the PV module at the measured PV simulator voltage.

5) For each measurement at time t, compute the corrected PV simulator power ($P_{corr}(t)$) using the following formula:

$$P_{corr}(t) = I_{corr}(t) \cdot V_{pvsim}(t)$$

where

$P_{corr}(t)$	is the corrected PV simulator power supplied by the PV simulator at time t, in watts (W);
$I_{corr}(t)$	is the corrected PV simulator current at time t, in amperes (A);
$V_{pvsim}(t)$	is the voltage supplied by the PV simulator at time t, in volts (V).

6) Calculate the corrected PV simulator energy (E_{corr}) using the following formula:

$$E_{corr} = \sum_{t=0}^{t_{end}}\left(P_{corr}(t) \cdot \Delta t\right)$$

where

E_{corr}	is the corrected PV simulator energy, in watt·hours (Wh);
t	is the elapsed time, in hours (h);
t_{end}	is the overall data analysis end time, in hours (h);
$P_{corr}(t)$	is the corrected power supplied by the PV simulator at time t, in watts (W);
Δt	is the duration of time associated with each measurement, in hours (h).

7) Calculate the maximum energy available from the PV module ($E_{max,mod}$) using the following formula:

$$E_{max,mod} = \sum_{t=0}^{t_{end}}\left(P_{max,mod}(t) \cdot \Delta t\right)$$

where

$E_{max,mod}$ is the maximum energy available from the PV module, in watt·hours (Wh);

t is the elapsed time, in hours (h);

t_{end} is the overall data analysis end time, in hours (h);

$P_{max,mod}(t)$ is the maximum power available from the DUT's PV module at time t, in watts (W);

Δt is the duration of time associated with each measurement, in hours (h).

8) Calculate the corrected solar operation efficiency ($\eta_{sol\text{-}op,corr}$): using the following formula:

$$\eta_{sol\text{-}op,corr} = \frac{E_{corr}}{E_{max,mod}}$$

where

$\eta_{sol\text{-}op,corr}$ is the corrected solar operation efficiency as a fraction;

$E_{max,mod}$ is the maximum available PV energy from the DUT's PV module, in watt·hours (Wh);

E_{corr} is the corrected PV simulator energy, in watt·hours (Wh).

9) The solar operation efficiency ($\eta_{sol\text{-}op}$) is the maximum of $\eta_{sol\text{-}op,u}$ and $\eta_{sol\text{-}op,corr}$. However, for some products, the correction procedure can result in an operating point ($V_{pvsim}(t)$, $I_{corr}(t)$) that is not reflective of typical operation. This is more likely to occur in products where the operating voltage ($V_{pvsim}(t)$) is greater than the maximum power point voltage and in products with maximum power point tracking, particularly when a resistor network is used. In this case, use the uncorrected solar operation efficiency $\eta_{sol\text{-}op,u}$. (The plot generated in r) below can be useful in making this determination.)

l) For each time t, calculate the instantaneous battery-charging circuit efficiency ($\eta_{bcc}(t)$) using the following formula:

$$\eta_{bcc}(t) = \frac{\sum_i P_{b,i}(t)}{P_{pvsim}(t)}$$

where

$\eta_{bcc}(t)$ is the instantaneous battery-charging circuit efficiency at time t as a fraction;

$P_{b,i}(t)$ is the power delivered to battery i at time t, in watts (W);

$P_{pvsim}(t)$ is the power supplied by the PV simulator at time t, in watts (W).

m) For each time t, calculate the instantaneous solar operation efficiency ($\eta_{sol\text{-}op}(t)$). Use the following formula if the uncorrected solar operation efficiency was taken as the solar operation efficiency in step k):

$$\eta_{sol\text{-}op}(t) = \frac{P_{pvsim}(t)}{P_{max,sim}(t)}$$

where

$\eta_{sol\text{-}op}(t)$ is the instantaneous solar operation efficiency at time t as a fraction;

$P_{pvsim}(t)$ is the power supplied by the PV simulator at time t, in watts (W);

$P_{max,sim}(t)$ is the maximum power available from the PV simulator at time t, in watts (W).

Use the following formula if the corrected solar operation efficiency was used in step k):

$$\eta_{sol\text{-}op}(t) = \frac{P_{corr}(t)}{P_{max,mod}(t)}$$

where

$\eta_{\text{sol-op}}(t)$ is the instantaneous solar operation efficiency at time t as a fraction;

$P_{\text{corr}}(t)$ is the corrected PV simulator power at time t, in watts (W);

$P_{\text{max,mod}}(t)$ is the maximum power available from the DUT's PV module at time t, in watts (W).

Use the same formula for all values of t; that is, do not repeat the selection procedure in step k) 9) for each value of t.

NOTE 5 Steps l) and m) are used to produce the required plots (see Clause R.5). The instantaneous values of battery-charging circuit efficiency and solar operation efficiency are not used in any further calculations. The plots produced in Clause R.5 are useful in validating the results of the test and in diagnosing problems. For example, instantaneous solar operation efficiency values exceeding 100 % can indicate a problem with the equipment configuration (e.g. the wrong current or resistance values were used).

n) Based on the test data, determine whether a DC-DC converter is present in the circuit between the solar module and the battery. If a DC-DC converter is present, one of the following will typically be true:

   – The voltage at any battery is greater than the voltage at the PV socket

   – The sum of the currents at the batteries is greater than the current at the PV socket

   If a DC-DC converter is not present, the battery voltage will be less than or equal to the voltage at the PV input, and the sum of the currents at the batteries will be less than or equal to the current at the PV input. Generally, the difference between the battery and PV current will be small; if the sum of the battery currents is much less than the current at the PV module, and the voltage at the batteries is also less than the voltage at the PV input, there may be a problem with the test; the issue should be investigated.

   For products with more than one battery, it is possible for some batteries to charge using a DC-DC converter while others do not.

o) Optionally, determine whether the product uses a series (linear) voltage regulator and calculate the equivalent resistance and diode characteristics of the circuit. If this type of charge control is present, the sum of the current entering all batteries equals the current delivered from the PV simulator throughout the test. Optionally, plot voltage drop as a function of current and fit a line to determine the approximate resistance and/or diode characteristics of the circuit. The voltage drop as a function of current in this case will be equal to a constant term (diode) plus a linear term (resistor).

p) For each battery i, calculate the average voltage from the start of the test to $t_{\text{end},i}$. This is the average charging voltage.

Steps q) through s) are not required, but are recommended in order to verify that the test was conducted correctly. The plots generated in steps q) and r) need not be included in the test report.

q) Plot the measured PV simulator current and voltage values (I_{pvsim} and V_{pvsim}) superimposed on the simulated I-V curve that is calculated from the circuit model or input into the solar array simulator. This step can identify many common errors in conducting the test, including incorrect configuration of the equipment and incorrect detection of the simulated irradiance steps. If the measured operating points do not fall on the calculated curves, the reason for the discrepancy should be investigated.

r) Plot the corrected PV simulator current (I_{corr}) and PV simulator voltage (V_{pvsim}) superimposed on the scaled I-V curves of the PV module. This step is analogous to r), but can be used to determine whether the corrected PV current corresponds to a realistic, typical operating point of the PV module.

s) Calculate the PV current from the PV voltage using the circuit model or I-V curve values that were input into the solar array simulator, and plot as a function of time. On the same graph, plot the measured current as a function of time. Any significant difference between the two values should be investigated. This plot can identify many of the same problems as the plot in step q), but is more useful for showing irradiance steps that were omitted, irradiance step transitions that were not detected correctly, periods in which the DUT did not charge, and periods with missing data.

R.4.5 Alternative method to measure battery-charging circuit efficiency

R.4.5.1 General

The following method may be used to measure battery-charging circuit efficiency for products in which the battery current cannot be measured without influencing the charging behaviour. For these products, the battery-charging circuit efficiency is measured indirectly, by discharging the battery and measuring the energy extracted. This method is not permitted unless a direct measurement of the battery current is known to be impossible, for one of the following reasons:

- The laboratory has attempted the procedure specified in R.4.2 or R.4.3 and demonstrated that the measurement cannot be performed using the laboratory's equipment.
- Prior laboratory experience with the same product, or a product having identical charge control behaviour (e.g. another model in the same series from the same manufacturer), has demonstrated that the measurement cannot be performed using the laboratory's equipment.
- The voltage drop calculated from the measured resistance of the laboratory apparatus at the expected charging current is clearly sufficient to interfere with the product's charge control strategy.

R.4.5.2 Procedure

Perform the following steps.

a) Prior to the solar charge test, prepare the product according to G.4.4 e).

b) Conduct the solar charge test using the apparatus and procedures in R.4.2 or R.4.3, except do not monitor the battery current. The battery voltage may optionally be measured and recorded. Disconnect the DUT from the PV simulator no more than 15 min after the end of the simulated solar charge. Do not disconnect the battery from the PCB.

c) Allow the DUT to rest for at least 1 h but no more than 24 h.

d) Use the procedure in G.4.4 e) to transfer the DUT to the full-battery run time test apparatus without disconnecting the battery.

e) Discharge the DUT's battery using the procedures in the full-battery run time test (Annex M), but without charging the battery. Do not disconnect the battery from the DUT at any time between the completion of the simulated solar charge cycle and the start of the discharge. Ensure that the configuration of the DUT (e.g., connected appliances and settings) is exactly the same as when the full-battery run time test was carried out.

R.4.5.3 Calculations

Perform the following calculations to determine the battery-charging circuit efficiency, in place of R.4.4 l).

a) From the DUT's full-battery run time test data (not the discharge data from R.4.5.2), identify the current at the full-battery run time endpoint (for most products, this is the current at L_{70}).

b) Determine the discharge duration, Δt_{d}, defined as the elapsed time in the discharge in R.4.5.2 at which the current identified in a) is reached. (This is often less than the full-battery run time because the DUT is not always fully charged in the solar charge test.)

c) Calculate the battery-charging circuit efficiency using the following formula:

$$\eta_{\mathrm{bcc}} = \min\left(100\ \%, \frac{\Delta t_{\mathrm{d}} \cdot P_{\mathrm{FBRT}}}{E_{\mathrm{pvsim}} \cdot \eta_{\mathrm{batt}}}\right)$$

where

η_{bcc} is the battery-charging circuit efficiency, as a fraction;

Δt_{d} is the discharge duration calculated in b), in hours (h);

P_{FBRT} is the average power from the full-battery run time test (Clause M.8), in watts (W);

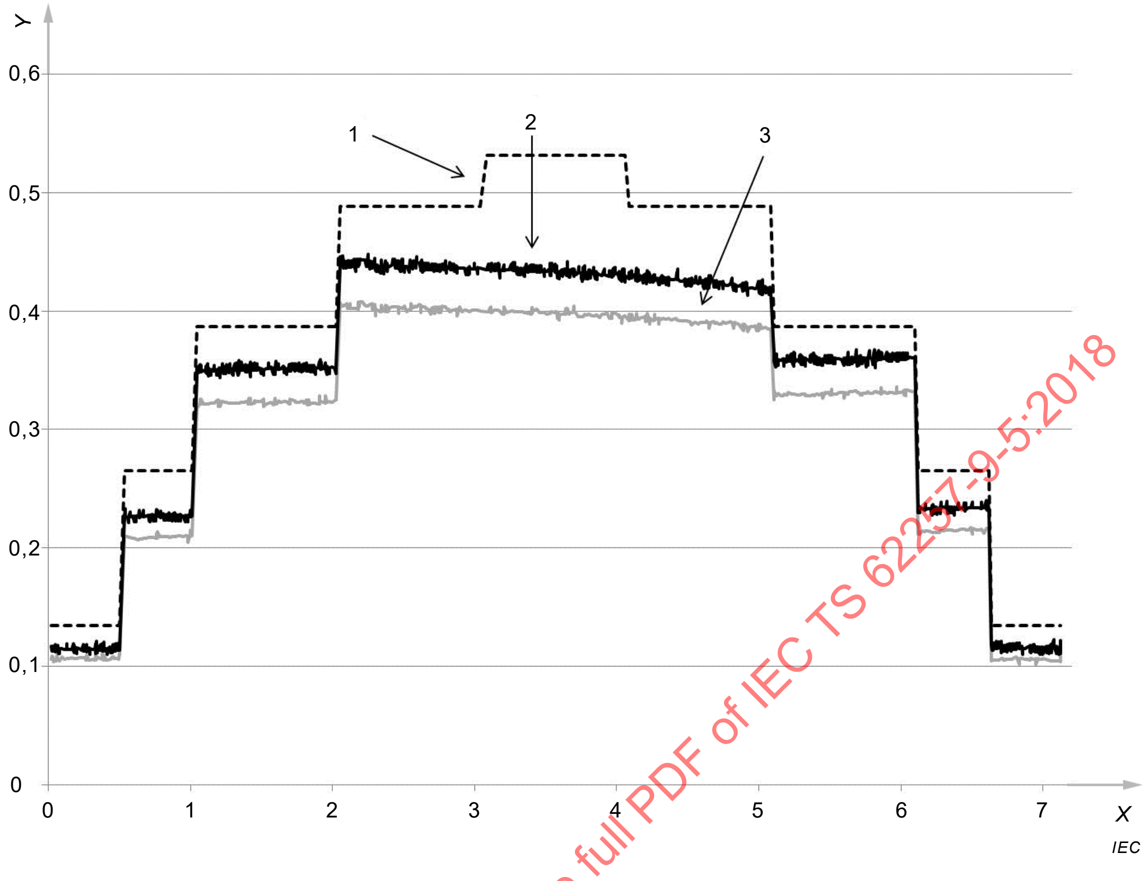
E_{pvsim} is the energy delivered by the PV simulator, calculated in R.4.4 f), in watts (W);

η_{batt} is the battery round-trip energy efficiency from the battery test (Annex K), as a fraction.

R.5 Reporting

Report the following in the electronics efficiency test report.

- Metadata:
  - report name;
  - procedure(s) used;
  - DUT manufacturer;
  - DUT name;
  - DUT model number;
  - name of test laboratory;
  - approving person;
  - date of report approval.
- Results for tested DUT aspects for samples 1 through n:
  - battery-charging circuit efficiency (%);
  - solar operation efficiency (%);
  - average charging voltage for each battery (V)
  - energy allocation ratios (%).
- Average of n sample results for tested DUT aspects.
- Coefficient of variation of n sample results for tested DUT aspects.
- Solar charging circuit characteristics.
- Comments:
  - individual comments, as necessary, for samples 1 through n;
  - overall comments, as necessary, for collective set of samples 1 through n.
- Figures
  - Plot showing the solar charging cycle for each sample in time series over the 7 h charging period including the maximum power available from the PV simulator ($P_{max,sim}(t)$), actual power supplied by the PV simulator ($P_{pvsim}(t)$), and power delivered to the batteries ($P_{b,i}(t)$) (see Figure R.4 for an example plot). (This may be plotted as the sum over all batteries or separately for each battery.) In a separate plot or on a secondary axis show the instantaneous solar operation efficiency and instantaneous battery-charging circuit efficiency in time series (see Figure R.5 for an example plot).



Key

X time with units of hours on the horizontal axis

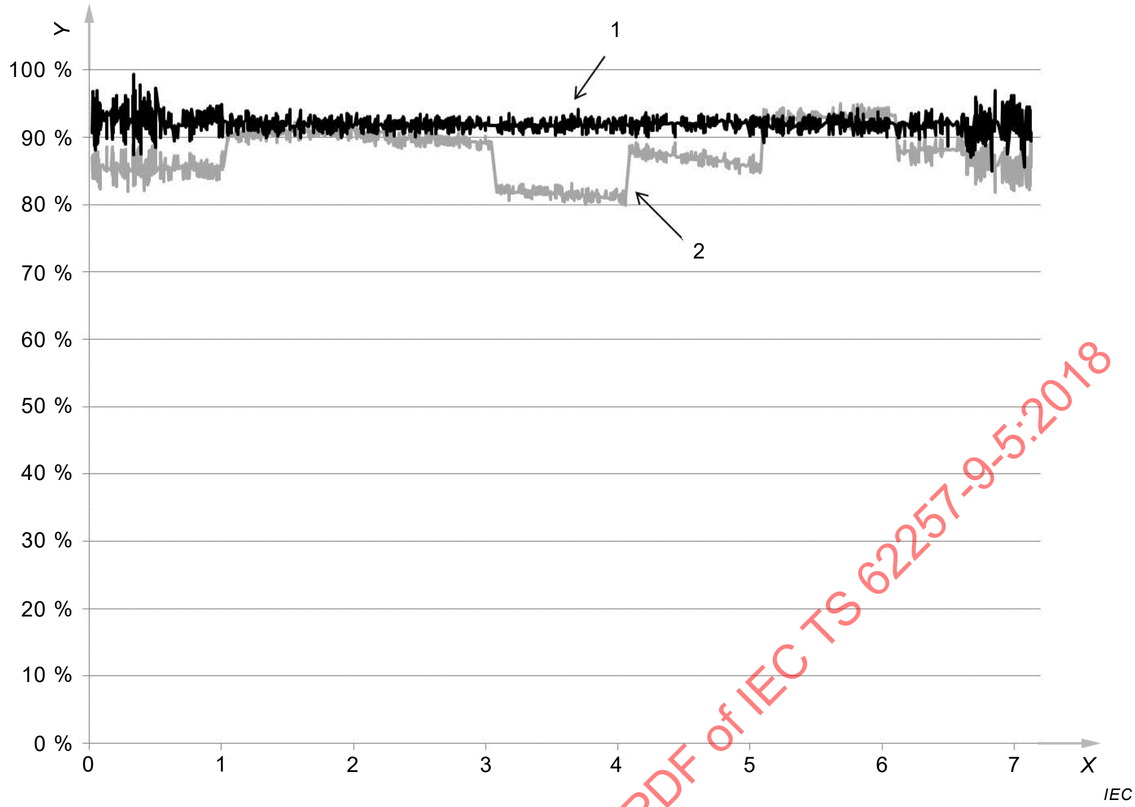
Y power with units of watts on the vertical axis

1 maximum power available from the PV simulator ($P_{max,sim}(t)$), in watts

2 actual power supplied by the PV simulator ($P_{pvsim}(t)$), in watts

3 power delivered to the batteries ($P_{b,i}(t)$), in watts

Figure R.4 – Example time series plot of the solar charging cycle showing the maximum power available from the PV simulator, actual power supplied by the PV simulator, and power delivered to the batteries



Key

X time with units of hours on the horizontal axis

Y efficiency as a percent on the vertical axis

1 instantaneous battery-charging circuit efficiency ($\eta_{bcc}(t)$), as a percent

2 instantaneous solar operation efficiency ($\eta_{sol\text{-}op}(t)$), as a percent

Figure R.5 – Example time series plot of the solar charging cycle showing the instantaneous battery-charging circuit efficiency and solar operation efficiency

Annex S
(normative)

Charge controller behaviour test

S.1 Background

Deep discharge and overcharge protection is important for user safety and battery longevity. Charge control is most critical for products with lead-acid, Li-ion, and $LiFePO_4$ batteries.

The charge controller behaviour test contains five methods to examine the DUT's charge controller. Every DUT shall be tested with the active deep discharge method, where the DUT is discharged until reaching its low-voltage disconnect (LVD) voltage or appropriately exceeding its recommended deep discharge voltage threshold. Every DUT shall also be tested with the active overcharge protection method, where the DUT is charged until reaching its overvoltage protection (OVP) voltage or appropriately exceeding its recommended OVP voltage threshold. For DUTs that have no active deep discharge protection, the passive deep discharge protection method shall be used when appropriate (see S.4.3.1); in this method, the battery voltage is examined for safety during a long-term discharge. For DUTs with NiMH batteries that have no active overcharge protection, the passive overcharge protection method shall be used, where the DUT's long-term charging current is examined for safety.

Every DUT shall also be examined for standby losses. A product's electronics can draw substantial amounts of energy from the battery while the product is not in use, and this standby loss can lead to shorter run times or problems when storing the product for long periods of time.

The choice of test methods and assessment of the appropriateness of charge control should include input from the battery manufacturer and/or system integrator about the approach to charge control and the design values for cutoff or other control algorithms. The best practice for testing is to establish what the design algorithm and setpoints are and measure for those using the appropriate methods. The assessment of whether charge control is present and appropriate shall then be based on the combination of two factors: the appropriateness of the design values and whether the design was accurately realized as shown during the tests.

S.2 Test outcomes

The test outcomes of the charge controller behaviour test are listed in Table S.1.

Table S.1 – Charge controller behaviour test outcomes

Metric	Reporting units	Related aspects	Notes
Active deep discharge protection	Yes/no	4.2.3.13 Battery protection strategy	--
Deep discharge protection voltage	Volts (V)	4.2.3.13 Battery protection strategy	Measured only if the DUT has active deep discharge protection
Active overcharge protection	Yes/no	4.2.3.13 Battery protection strategy	--
Overcharge protection voltage	Volts (V)	4.2.3.13 Battery protection strategy	Measured only if the DUT has active overcharge protection
Passive deep discharge protection	Yes/no	4.2.3.13 Battery protection strategy	--
Passive deep discharge protection battery voltage at 24 h	Volts per cell (V/cell)	4.2.3.13 Battery protection strategy	Required only if tested for passive deep discharge protection
Passive overcharge protection	Yes/no	4.2.3.13 Battery protection strategy	Measured only for NiMH batteries with no active overcharge protection
Passive overcharge protection continuous charging current	Amperes (A)	4.2.3.13 Battery protection strategy	Required only if tested for passive overcharge protection
Standby loss current	Amperes (A)	4.2.3.13 Battery protection strategy	Current that is drawn from a product's battery when the product is switched off when at 50 % state of charge Multiple standby loss current values may be reported for products that switch to low-power modes
Time before switching to low-power mode	Hours (h)	4.2.3.13 Battery protection strategy	Some products may switch to a low-power mode after being turned off for a set period of time

S.3 Related tests

The results of the active deep discharge protection test (S.4.1) may be substituted with results of the full-battery run time test (Annex M).

The results of the passive deep discharge protection test (S.4.3) may be substituted with results of the full-battery run time test (Annex M).

Annex S shall be performed after the photovoltaic module IV characteristics test (Annex Q) for solar-charged products because the active overcharge protection test (S.4.2) requires the DUT's maximum power point current (I_{mpp}) and the passive overcharge protection test (S.4.4) requires the DUT's entire I-V curve data set.

The DUT's full-battery run time from the full-battery run time test procedure (Annex M) is required to set the battery to the proper state of charge during the standby loss test.

S.4 Procedure

S.4.1 Active deep discharge protection test

S.4.1.1 General

The DUT is discharged until its battery voltage reaches the DUT's LVD voltage or appropriately exceeds its recommended deep discharge voltage threshold.

S.4.1.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- DC voltmeter or multimeter.
- Voltage data logger (recommended).
- Ammeter or current data logger (e.g. voltage data logger with a current transducer) (current data-logger recommended).
- Low-voltage disconnect device that will stop the discharge when the battery reaches a specified voltage (recommended).

The total series resistance added by the test apparatus and all measurement equipment shall be no more than 60 mΩ. This value includes the resistance of the wires and connectors, if any, added in the sample preparation procedure (G.4.4).

S.4.1.3 Test prerequisites

The DUT shall be either fully charged at the start of the test or charged enough to provide at least 20 min of service before reaching its deep discharge protection voltage or reaching sufficiently below the recommended deep discharge protection voltage threshold for the DUT's battery chemistry (see Table L.1 for recommended thresholds).

If the DUT's battery needs to be charged, charge the battery using one of the two procedures according to the battery chemistry.

- If the battery is of NiMH chemistry, then use the procedures in the battery test (Annex K).
- If the battery is of any other chemistry, then use the procedures in the active overcharge protection test (S.4.2). If the DUT's solar module has not yet been tested, then set up the apparatus according to Figure S.1 and set the current limit to the rated maximum power point current at STC, I_{mpp}.

S.4.1.4 Apparatus

The DUT shall be set in a secure location such that its parameters can be monitored and/or data-logged.

If necessary, a low-voltage disconnect device may be used that monitors the battery voltage and can cut the battery circuit if the voltage drops below a predetermined level.

S.4.1.5 Procedure

The following steps shall be followed.

a) If it is unclear if the DUT has deep discharge protection for its battery, the tester may prepare the low-voltage disconnect device so that it stops the discharge if the battery reaches the minimum battery testing voltage specified in Annex L.

b) Secure the DUT in a safe location. Select appliances and configure the DUT following the full-battery run time test procedure (Clause M.7, step a)). Turn on the DUT to begin discharging the battery. The DUT service(s) shall be on in highest setting(s) (i.e., lights in their brightest setting, fan in its fastest speed). Continuously monitor the battery terminal voltage and current at the negative battery terminal. The battery voltage and current shall be collected at intervals less than or equal to 1 min.

   In case of pulse-width modulation (PWM) controllers, aliasing effects (beat effects) can occur when data logging due to unsynchronised PWM frequency and sampling frequency of the current logger. This can lead to "chaotic" measurements which are difficult to interpret. In this case, the sampling interval may be decreased or the test may be conducted using a power-measuring instrument meeting the requirements in Table CC.2. It is not necessary to calculate power or to follow the guidelines in Clause CC.3.

c) If the DUT has active deep discharge protection, one of two behaviours can be observed:

   1) an abrupt drop will occur in the DUT's light output (or other appliance operation) and current will quickly decrease to 0 A, or

   2) a relatively quick drop will occur in the DUT's light output (or other appliance operation) and current will ultimately decrease to 0 A.

   In either case, the minimum battery voltage recorded up to the time at which the battery current reaches zero is the active deep discharge protection voltage.

d) Report whether the deep discharge protection is internal to the battery. Typically, if the deep discharge protection circuit is external to the battery, the battery voltage will remain constant or increase after the deep discharge protection circuit disconnects the battery. If the deep discharge protection is internal to the battery pack, the voltage will drop to zero once the deep discharge protection voltage is reached. (In the latter case, ensure that the reported deep discharge protection voltage occurred before the internal protection circuit isolated the battery. If the battery voltage drops quickly, this can be difficult to determine.)

e) If the battery contains internal circuitry (refer to F.4.3.5) and the measured deep discharge protection voltage is outside of the targets specified by the manufacturer (D.3.2.2) or the DUT's battery voltage falls below the recommended deep discharge protection voltage specified in Annex L, the test may be repeated with the voltage data logger connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so. In the test report, note where the reported voltage value was measured.

f) If no active deep discharge protection is observed, perform the passive deep discharge protection test (S.4.3).

g) If the low-voltage disconnect device stops the discharge during the test, record that the battery voltage reached the minimum battery testing voltage and that no active deep discharge voltage was observed.

S.4.1.6 Calculations

There are no calculations for the active deep discharge protection test.

S.4.2 Active overcharge protection test

S.4.2.1 General

The DUT is charged until its battery voltage reaches the DUT's OVP voltage or the overcharge protection disconnect device's set point, or if the battery's temperature exceeds a safe value (refer to Table L.2).

S.4.2.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- DC power supply or solar array simulator.
- DC voltmeter or multimeter.
- DC ammeter or multimeter.
- Voltage data logger (optional).
- Current data logger (e.g. voltage data logger with a current transducer) (optional).
- Series resistor or series and parallel resistors (or variable resistors) for simulating PV input (when using a DC power supply as opposed to a solar array simulator).
- Surface-mounted thermocouple(s) and a thermocouple reader (optional).
- AC power adapter supplied with the DUT (for DUTs with a grid-charging option and no solar-charging option).
- Overcharge disconnect device that will stop the discharge when the battery reaches a specified voltage (if necessary).

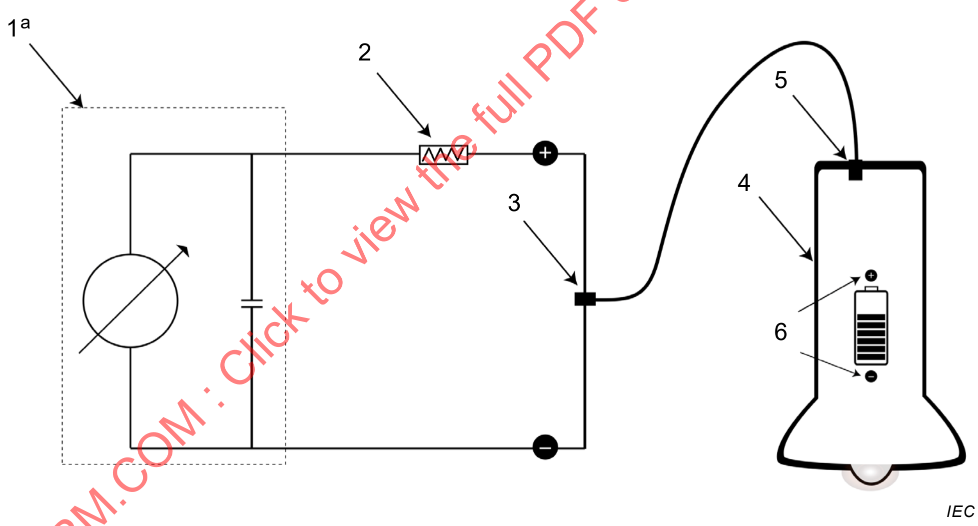
The total series resistance added by the test apparatus and all measurement equipment shall be no more than 90 mΩ. This value includes the resistance of the wires and connectors, if any, added in the sample preparation procedure (G.4.4).

S.4.2.3 Test prerequisites

The DUT shall be either fully discharged at the start of the test or discharged enough to accept at least 20 min of charging before reaching its overcharge protection voltage or the overcharge disconnect device's cutoff, which may be selected based on information in Table L.2 if the overcharge voltage set point is not supplied by the manufacturer.

S.4.2.4 Apparatus

The DUT shall be set in a secure location such that its parameters can be monitored and/or data-logged. If the DUT has a solar-charging option, the DUT is charged via the PV module socket from a DC power supply with a series resistor in place (Figure S.1). An alternative is to charge the DUT via the PV module socket from a DC power supply with a series resistor and parallel resistor in place (Figure R.1), or using a solar array simulator. If the DUT's solar module is integrated, as opposed to external, charge the DUT by directly connecting to the DUT's PV module leads from where the integrated PV module was detached. If the product does not have a solar-charging option, the DUT shall be charged via its provided grid charger or charged via its electromechanical charging process or by a DC power supply configured to simulate the electromechanical charging device.



Key

1 DC power supply

2 Series protection resistor

3 Plug

4 DUT

5 DUT's PV module input socket

6 Battery

a Set current limiting with the maximum power point current at STC, I_{mpp}, from the outdoor photovoltaic module I-V characteristics test (Annex Q), or, if the product is charged with other means set the current to the typical delivery current for the charging system.

Figure S.1 – Schematic of the DC power supply-DUT connection using a series protection resistor

S.4.2.5 Procedure

The following steps shall be followed if the DUT has a solar charging option.

a) If the setup includes the parallel resistor (Figure R.1), adjust the current limiting value of the DC power supply to the current setpoint at 1 000 W/m^2 irradiance, $I_{sim,1000}$, calculated in the solar charge test (Annex R). Also adjust the voltage of the DC power supply, V_{ps}, to the voltage setpoint, V_{sim}, calculated in the solar charge test (Annex R). Also set the series resistance, R_s, and the parallel resistance, R_p, to the values calculated in the solar charge test (Annex R). Skip steps b) through f) and proceed to step g).

b) If the setup uses a solar array simulator, configure the solar array simulator as for the solar charge test (Annex R) to simulate the I-V curve at an irradiance of 1 000 W/m^2. Skip steps c) through f) and proceed to step g).

c) If the setup includes a series resistor only (Figure S.1), adjust the current limiting value of the DC power supply to the PV module's maximum power point current at TMOT, $I_{mpp,TMOT}$ (refer to the results of the photovoltaic module I-V characteristics test (Annex Q)).

d) Due to voltage drops from the PV module's blocking diode, cable losses, and the series resistor, set the power supply output voltage, V_{ps}, using the following formula:

$$V_{ps} = 1{,}25 \times V_{b,max}$$

where

V_{ps} is the DC power supply output voltage, in volts (V);

$V_{b,max}$ is the DUT's battery's maximum charge voltage, in volts (V), which may be obtained from the battery testing recommended practices annex (Annex L).

e) Connect the PV module socket of the DUT to the DC power supply in series with a protection resistor. In cases where the DUT has an integrated PV module, connect the positive and negative wires from the DUT that were attached to the PV module to the DC power supply in series with a protection resistor. (This protection resistor is only needed in cases where a "shunt regulator" is built in; however, as a schematic of the DUT's electronics is usually not provided, this resistor should be used in all cases for safety reasons). The voltage drop in the series resistor should be between 10 % and 15 % of the voltage setting of the DC power supply (V_{ps}); therefore, size the resistor based on the following formula:

$$\frac{0{,}1 \times V_{ps}}{I_{mpp,TMOT}} \le R_s \le \frac{0{,}15 \times V_{ps}}{I_{mpp,TMOT}}$$

where

V_{ps} is the DC power supply output voltage, in volts (V);

$I_{mpp,TMOT}$ is the PV module's maximum power point current at TMOT, in amperes (A), obtained from the photovoltaic module I-V characteristics test (Annex Q);

R_s is the resistance of the series resistor, in ohms (Ω).

f) Ensure the series resistor's power dissipation rating is greater than or equal to the value given by the following formula:

$$P_{rs} \ge I_{mpp,TMOT}^2 \cdot R_s$$

where

P_{rs} is the series resistor's minimum required power dissipation, in watts (W);

$I_{mpp,TMOT}$ is the PV module's maximum power point current at TMOT, in amperes (A), obtained from the photovoltaic module I-V characteristics test (Annex Q);

R_s is the resistance of the series resistor, in ohms (Ω).

g) If it is unknown whether the DUT has an overcharge protection disconnect, integrate the overcharge protection disconnect device into the setup. The overcharge protection device shall disconnect if the battery voltage rises above safety limits that are determined by the laboratory. In some cases, the DUT's charge controller is designed with an OVP voltage that is greater than the overcharge protection device setpoint; therefore, the tester may allow the battery voltage to proceed above the recommended OVP voltage threshold if deemed safe and necessary. For Li-ion batteries, the battery voltage shall not exceed the maximum safe value specified by the battery supplier, or 4,26 V/cell if no supplier-provided information is available; otherwise there is a risk of explosion. Optionally, monitor the DUT's battery temperature to ensure that it does not exceed a safe value (refer to Table L.2). If temperature monitoring is used, lithium-based batteries shall not be allowed to exceed 45 °C unless higher temperatures are allowed by the battery manufacturer.

h) Charge the DUT while continuously monitoring the DUT's battery terminal voltage and current at the negative battery terminal. The battery voltage and current shall be collected at intervals less than or equal to 1 min.

   In case of pulse-width modulation (PWM) controllers, aliasing effects (beat effects) can occur when data logging due to unsynchronised PWM frequency and sampling frequency of the current logger. This can lead to "chaotic" measurements which are difficult to interpret. In this case, the sampling interval may be decreased or the test may be conducted using a power-measuring instrument meeting the requirements in Table CC.2. It is not necessary to calculate power or to follow the guidelines in Clause CC.3.

i) If the DUT automatically stops accepting charge, the DUT has active overcharge protection, and the highest voltage measured during the test is the DUT's overcharge protection voltage. For some DUTs, the current will not stop completely, but will begin tapering off when the battery voltage reaches the overcharge protection voltage. Continue monitoring until two measurements of battery voltage, taken six hours apart, show an increase of less than 0,01 V.

j) Report whether the active overcharge protection is internal to the battery. Typically, if the overcharge protection circuit is external to the battery, the battery voltage will remain constant or decrease after the overcharge protection circuit disconnects the battery. If the overcharge protection is internal to the battery pack, the voltage will typically increase to the open-circuit voltage of the PV module or PV simulator apparatus when the overcharge protection voltage is reached. (In the latter case, ensure that the reported overcharge protection voltage occurred before the internal protection circuit isolated the battery.)

k) If the battery contains internal circuitry (refer to F.4.3.5) and the measured overcharge protection voltage is outside of the targets specified by the manufacturer (D.3.2.2) or the DUT's battery voltage exceeds the recommended overcharge protection voltage specified in Annex L, the test may be repeated with the voltage data logger connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so. In the test report, note where the reported voltage value was measured.

l) If the battery terminal voltage reaches the overcharge protection cutoff device's voltage threshold, record that no active overcharge protection is incorporated into the DUT's charge controller.

m) If in the case of a NiMH battery the battery voltage levels off or begins to decrease before reaching the recommended overcharge protection voltage, but the current does not go to zero, no active overcharge protection is detected.

The following steps shall be followed if the DUT does not have a solar charging option.

n) If it is unknown whether the DUT has an overcharge protection disconnect, integrate the overcharge protection disconnect device into the setup. The overcharge protection device shall disconnect if the battery voltage rises above safety limits that are determined by the laboratory. In some cases, the DUT's charge controller will be designed with an OVP battery voltage that is greater than the overcharge protection device's cutoff; therefore, the tester has the discretion to allow the battery voltage to proceed above the recommended OVP voltage threshold if deemed safe and necessary. For Li-ion batteries, the battery voltage shall not exceed the maximum safe value specified by the battery supplier, or 4,26 V/cell if no supplier-provided information is available; otherwise there is a risk of explosion. Optionally, monitor the DUT's battery temperature to ensure that it does not exceed a safe value (refer to Table L.2). If temperature monitoring is used, lithium-based batteries shall not be allowed to exceed 45 °C unless higher temperatures are allowed by the battery manufacturer.

o) If the product has a grid-charging option, plug the AC power adapter supplied with the DUT into an outlet with AC voltage that is suitable for the supplied AC power adapter.

p) If the product does not have a grid-charging option, but has an electromechanical charging option, electromechanically charge the DUT continuously according to the electromechanical charge test procedure (Annex P) or use a power supply to source current that is equal to the charging current measured in the electromechanical charge test.

q) Charge the DUT while continuously monitoring the DUT's battery terminal voltage and current at the negative battery terminal. The battery voltage and current shall be collected at intervals less than or equal to 1 min.

r) Follow steps i) through k) above.

s) If the battery terminal voltage exceeds the predetermined overvoltage limit (e.g. the maximum battery testing voltage from Table L.2), no active overcharge protection is incorporated into the DUT's charge controller.

S.4.2.6 Calculations

There are no calculations for the active overcharge protection test.

S.4.3 Passive deep discharge protection test

S.4.3.1 General

If the DUT does not have active deep discharge protection, the product could have passive deep discharge protection. In this form of deep discharge protection, the load and battery characteristics are matched so that the load cannot discharge the battery excessively in a reasonable period of time, even though it remains connected. Generally, passive deep discharge protection is not appropriate for products with ports, since the load properties are not known. However, passive deep discharge protection may be used for built-in appliances (such as internal lights or radios) if the ports are separately provided with appropriate active deep discharge protection.

In the passive deep discharge protection test, the DUT is left to discharge for 24 h and the minimum voltage within the 24 h period is recorded. This method is only performed on products that show no active deep discharge protection and for which passive deep discharge protection is appropriate.

S.4.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- DC voltmeter or multimeter.
- Voltage data logger (recommended).
- Ammeter or current data logger (e.g. voltage data logger with a current transducer) (optional).
- Low-voltage disconnect device that will stop the discharge when the battery reaches a specified voltage (recommended).

The total series resistance added by the test apparatus and all measurement equipment shall be no more than 60 mΩ. This value includes the resistance of the wires and connectors, if any, added in the sample preparation procedure (G.4.4).

S.4.3.3 Test prerequisites

The DUT shall have undergone the active deep discharge protection test. The battery shall be in the same state of charge as when the DUT reaches L_{70} (70 % of its initial light output during the full-battery run time test), or, for products without lighting appliances, the state of charge corresponding to approximately 24 h before one of the stopping criteria of the appliance full-battery run time test (Clause FF.9) would be met.

S.4.3.4 Apparatus

The DUT shall be placed in a secure location where it can discharge for 24 h.

If necessary, a low-voltage disconnect device may be used that monitors the battery voltage and can cut the battery circuit if the voltage drops below a predetermined level.

S.4.3.5 Procedure

The following steps shall be followed.

a) Determine the accepted 24 h passive deep discharge battery protection voltage. This voltage may be selected based on information from Table L.1, if it is not supplied by the DUT or battery manufacturer.

b) If it is unclear if the DUT has deep discharge protection for its battery, the tester may prepare the low-voltage disconnect device so that it stops the discharge if the DUT's battery reaches the minimum battery testing voltage specified in Annex L.

c) Secure the DUT in a safe location. Select appliances and configure the DUT following the full-battery run time test procedure (Clause M.7, step a)).

d) Turn on the DUT and discharge the battery for 24 h. For products without lighting appliances, discharge until one of the stopping criteria for the appliance full-battery run time test (Clause FF.9) is met. The DUT appliance(s) shall be on in highest setting(s) (i.e., lights in their brightest setting, fan in its fastest speed). Continuously monitor the DUT's battery terminal voltage and optionally monitor the battery current at the negative battery terminal. The battery voltage and optional current shall be collected at intervals less than or equal to 1 min.

   In case of pulse-width modulation (PWM) controllers, aliasing effects (beat effects) can occur when data logging due to unsynchronised PWM frequency and sampling frequency of the current logger. This can lead to "chaotic" measurements which are difficult to interpret. In this case, the sampling interval may be decreased or the test may be conducted using a power-measuring instrument meeting the requirements in Table CC.2. It is not necessary to calculate power or to follow the guidelines in Clause CC.3.

e) Report if passive deep discharge protection was observed in the DUT. If the DUT has passive deep discharge protection, a gradual decrease will occur in the DUT's light output (or other appliance operation) and current will gradually decrease to a relatively low value. If the DUT's battery voltage remains greater than or equal to the selected deep discharge protection voltage threshold (see Clause L.2) for the full 24 h period, then the product has appropriate passive deep discharge protection, provided that the design of the product allows passive deep discharge protection.

f) If the DUT has passive deep discharge protection, report the DUT's passive deep discharge protection voltage at 24 h, in volts (V). Determine the passive deep discharge protection voltage by identifying the minimum battery voltage during the 24 h test period. (Since the battery voltage typically continues to decrease during the 24 h test period, this is generally the voltage at 24 h.)

g) If the battery contains internal circuitry (refer to F.4.3.5) and the measured deep discharge protection voltage is outside of the targets specified by the manufacturer (D.3.2.2) or the DUT's battery voltage falls below the recommended deep discharge protection voltage specified in Annex L, the test may be repeated with the voltage data logger connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so. In the test report, note where the reported voltage value was measured.

h) If the low-voltage disconnect device provided by the test laboratory stops the discharge during the test, record that the battery voltage reached the minimum battery testing voltage and that no passive deep discharge voltage was observed.

S.4.3.6 Calculations

There are no calculations for the passive deep discharge protection test.

S.4.4 Passive overcharge protection test

S.4.4.1 General

This method is only performed on products with NiMH batteries that show no active deep discharge protection.

In some cases, the PV module's short circuit current alone proves that the DUT has passive overcharge protection; otherwise, the DUT is overcharged and the charging current is observed to determine if the DUT has passive overcharge protection. If the product does not have a solar-charging option, the DUT shall be charged via its provided grid charger or charged via its electromechanical charging process. This method is only performed on products with NiMH batteries that show no active overcharge protection.

S.4.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- DC power supply or solar array simulator.
- DC ammeter or multimeter.
- Voltage data logger (optional).
- Current data logger (e.g. voltage data logger with a current transducer) (optional).
- Series resistor or series and parallel resistors (or variable resistors) for simulating PV input (when using a DC power supply as opposed to a solar array simulator).
- AC power adapter supplied with the DUT (for products with a grid-charging option and no solar-charging option).
- Surface-mounted thermocouple(s) and a thermocouple meter (optional).

The total series resistance added by the test apparatus and all measurement equipment shall be no more than 90 mΩ. This value includes the resistance of the wires and connectors, if any, added in the sample preparation procedure (G.4.4).

S.4.4.3 Test prerequisites

The DUT shall have undergone the active overcharge protection test, such that its battery voltage has just passed its recommended overcharge protection voltage (Table L.2) when charging or, if the battery voltage does not reach the recommended overcharge protection voltage, the battery has reached the maximum voltage observed during the active overcharge protection test (i.e. the battery voltage has levelled off or peaked and begun to decrease).

S.4.4.4 Apparatus

The DUT shall be set in a secure location such that its parameters can be monitored and/or data-logged. If the DUT has a solar-charging option, the DUT is charged via the PV module socket from a DC power supply using a series resistor or series and parallel resistor identical to those used in the active overcharge protection test (S.4.2.4).

S.4.4.5 Procedure

The following steps shall be followed if the DUT has a solar charging option and the product's battery-charging circuit does not include a DC-DC converter (see R.4.4, step n)).

a) Determine the accepted passive overcharge protection continuous battery charging current. A passive overcharge protection continuous battery charging current of less than or equal to 0,2 I_t A is recommended for NiMH batteries.

b) Compare the PV module's short-circuit current at STC (I_{sc}) to the passive overcharge protection continuous battery charging current (I_{sc} may be obtained from the photovoltaic module I-V characteristics test (Annex Q)). If I_{sc} is the smaller of the two, the DUT has passive overcharge protection and no further testing is necessary.

c) Plot the PV module's I-V curve at typical module operating temperature TMOT from the photovoltaic module I-V characteristics test (Annex Q).

d) If the passive overcharge protection test follows the active overcharge protection test using a parallel resistor (Figure R.1), use the same current limiting and voltage values and resistor values that were used in the active overcharge protection test (S.4.2.5).

e) If the passive overcharge protection test follows the active overcharge protection test using a solar array simulator, use the same solar array simulator configuration that was used in the active overcharge protection test (S.4.2.5).

f) If the passive overcharge protection test follows the active overcharge protection test with a series resistor only (Figure S.1), set the current limiting and voltage values of the DC power supply to the PV module's maximum power point current at TMOT, $I_{mpp,TMOT}$ and $V_{oc,TMOT}$ (refer to the results of the photovoltaic module I-V characteristics test (Annex Q)), respectively. Use the same series resistor value as was used in the active overcharge protection test (S.4.2.5).

g) Connect the DC power supply via the resistor(s) and the product's entire PV cable to the DUT's PV module input socket. If the DUT is has an integrated PV module, connect the DC power supply to the ends of the internal leads where the PV module connects to the DUT's circuitry. Let charge for 5 min. After the 5 min period is complete, determine the voltage drop, V_{drop}, between the power supply's output and the DUT's battery terminals. Optionally, monitor the battery temperature to ensure that it does not exceed a safe value (refer to Table L.2).

h) Add V_{drop} to the charge voltage, V_{charge}, which is determined by multiplying the number of battery cells in series by the recommended overcharge protection voltage for NiMH batteries (Table L.2). This sum is the total charge voltage, V_{max}.

i) Plot a vertical line at V_{max} on the TMOT I-V curve (see step c)) that extends from the voltage axis to the I-V curve.

j) Plot a horizontal line that intersects the TMOT I-V curve at the same point V_{max} does and extends to the current axis. The current where the horizontal line intersects the current axis is the charging current.

k) If the charging current is less than or equal to 0,2 I_t A, the DUT has passive overcharge protection.

These steps shall be followed if the product does not have a solar charging option or if the product utilizes a DC-DC converter:

l) Determine the DUT's accepted passive overcharge protection continuous battery charging current. A passive overcharge protection continuous battery charging current of less than or equal to 0,2 I_t A is recommended for products with NiMH batteries.

m) Compare the passive overcharge protection continuous battery-charging current to the average charging current observed over the final 5 min from when carrying out the active overcharge protection test procedure (S.4.2). If the average charging current is the smaller of the two, the DUT has passive overcharge protection.

S.4.4.6 Calculations

There are no calculations for the passive overcharge protection test.

S.4.5 Standby loss measurement

S.4.5.1 General

This measurement quantifies the standby loss of a DUT when not in use. If the standby loss is substantial, it can affect the use of the DUT. The DUT shall be configured to best simulate how it would be left in the home while not in use.

S.4.5.2 Equipment requirements

An ammeter (data-logging functionality is optional) and a timer. Equipment shall meet the requirements in Table CC.2.

S.4.5.3 Test prerequisites

Set the DUT's battery to a state of charge of approximately 50 %. This may be accomplished by the procedure described below.

a) First, fully charge the battery using one of the following:
   1) the appropriate charging procedures in the battery test (Annex K), or
   2) the procedures in the active overcharge protection test (S.4.2). If the DUT's solar module has not yet been tested, then set up the apparatus according to Figure S.1 and set the current limit to the rated maximum power point current at STC, I_{mpp}.
b) After the battery is fully charged, discharge the battery to a state of charge of approximately 50 % using one of the following:
   1) use the appropriate discharging procedures in the battery test (Annex K) modified to end when the battery reaches a 50 % state of charge, or
   2) turn the DUT on its brightest setting. Stop the discharge once the discharge duration equals (50 ± 25) % of the DUT's full-battery run time.

S.4.5.4 Apparatus

The DUT shall be set in a secure location such that its battery current can be recorded for 15 min.

S.4.5.5 Procedure

The following steps shall be followed.

a) Configure the DUT to simulate how it would be left in the home while not in use. Connect all the included appliances with no internal battery that can be turned off with an on/off switch to the product. For example, it is unlikely that a user unplugs a light point that has an on/off switch every time he or she wants to turn off the light; it is more likely that the user will turn off the light point via its switch. If the DUT does not have enough ports to connect all the included appliances with no internal battery that have on/off switches, connect the appliances with no internal battery that are estimated to maximize the standby loss. In addition, turn on/off system power switches on. For example, if the power control unit has a system on/off switch that connects the battery to the rest of the system, keep the switch in the on position. It is unlikely that a user will turn the system's power switch off when the system is not in use.
b) For products with external solar modules, connect the solar module. For all products with solar modules, prevent light from reaching the PV material (e.g. cover the solar module with an opaque dark cloth or turn the module upside down so that its PV material is facing downwards over an opaque surface).
c) Break the circuit at the battery's negative terminal, connect the current meter in series, and ensure that all power buttons and switches on the DUT are turned off, with the exception of the system power switch, as described in step a).

d) Turn on one of the DUT's appliances, e.g. turn on a light, to check that the DUT is still functioning after connecting it to the current meter. Briefly shining a light on the PV module is sometimes required to activate the DUT after connecting the current meter in series. Turn the appliance off once functionality is confirmed.

e) Wait 5 min to allow the DUT to stabilize. Then, over a 10 min period, record (or data-log) the current at the battery's negative terminal at intervals less than or equal to 1 min.

f) Report the average battery current over the 10 min data-collection period.

If the manufacturer indicates that the product enters a low-power mode ("sleep mode" or "standby mode") after a delay longer than 5 min (see D.3.2.2 x)), or such behaviour is observed by the laboratory during testing, repeat the test after allowing the product to enter the low-power mode. Both sets of results shall be reported. Record the time required for the product to enter the low-power mode.

S.4.5.6 Calculations

There are no calculations for the standby loss measurement.

S.5 Reporting

Report the following in the charge controller behaviour test report.

- Metadata:
  - report name;
  - procedure(s) used;
  - DUT manufacturer;
  - DUT name;
  - DUT model number;
  - name of test laboratory;
  - approving person;
  - date of report approval.
- Results for tested DUT aspects for samples 1 through n:
  - presence of active deep discharge protection (yes/no);
  - active deep discharge protection voltage, if applicable (V);
  - presence of active overcharge protection (yes/no);
  - active overcharge protection voltage, if applicable (V);
  - presence of passive deep discharge protection (yes/no);
  - passive deep discharge voltage (V/cell);
  - presence of passive overcharge protection (yes/no);
  - passive overcharge protection continuous charging current (mA);
  - standby loss current (A);
  - time required for product to enter low-power standby mode, if applicable (h).
- Average of n sample results for each DUT aspect tested.
- Coefficient of variation of n sample results for each DUT aspect tested (%).
- DUT's rating for aspects tested, if available.
- Deviation of the average result from the DUT's rating for each aspect tested, if available (%).
- Comments:

  - individual comments, as necessary, for samples 1 through *n*;
  - overall comments, as necessary, for collective set of samples 1 through *n*. In particular, include an assessment of the appropriateness of the charge control strategy given the information available.
- Figures:
  - plots of voltage and current vs. time in the active overcharge test, active deep discharge protection test, and passive deep discharge protection test.

Annex T
(normative)

Light distribution test

T.1 Background

Luminous flux and light distribution are two primary metrics used to assess the performance of a lighting product. Measurements of luminous flux (the total amount of light emitted by a source) are appropriate for any type of light and are discussed in Annex I. Measurements of light distribution are also appropriate for any type of light, with particular relevance to the performance of task lights that have focused light outputs.

The light distribution of lighting appliances can vary greatly, ranging from very narrow-beam task lights to omnidirectional ambient lights. While there is no distribution that is necessarily "ideal," some distributions are more appropriate for certain applications than others. Annex T is intended to characterize a product’s light distribution so purchasers can select products that are appropriate for the applications in which they are used.

The most common applications for lighting appliances are:

- ambient lighting,
- task lighting from a mounted or suspended fixture, and
- task lighting from a fixture placed on the surface to be illuminated (e.g. a desk light).

Ambient lights, products that have wide or omnidirectional light output, are best characterized by measuring total luminous flux (Annex I). A full width half maximum (FWHM) angle measurement may be used to help categorize a light distribution (ambient or task), and some lights may be considered for both ambient and task lighting applications. In circumstances where it is not clear how to classify a light, the use of both luminous flux and light distribution testing is appropriate.

Task lights that have directed light distributions may be characterized by measuring the illuminance on a specified task plane. The task plane used in the light distribution test is 1 m^2 and is positioned relative to the DUT according to the type of task light use (desk light or suspended light).

T.2 Test outcomes

The light distribution test outcomes are listed in Table T.1.

Table T.1 – Light distribution test outcomes

Metric	Reporting units	Related aspects	Notes
Vertical and horizontal full width half maximum (FWHM) angles	Degrees (°)	4.2.9.2 Full width half maximum (FWHM) angle	--
Usable area with illuminance greater than a specified threshold	Square metres (m^2)	4.2.9.3 Average light distribution characteristics	Determined from a specified distance
Work surface illuminance	Lux (lx)	4.2.9.3 Average light distribution characteristics	Maximum possible over testing surface
Luminous flux	Lumens (lm)	4.2.9.1 Luminous flux output	Only obtained when using multi-plane (T.5.3) or goniophotometer (T.5.2) test methods

T.3 Related tests

The light distribution test is related to the light output test (Annex I). Specifically, either the multi-plane method described in I.4.4 of Annex I or the goniophotometer method described in I.4.2 may be used to gather all needed data to generate polar plots, surface plots, and FWHM angles for ambient and suspended task lights.

T.4 Substitution of results from IEC TS 62257-12-1

For lighting appliances without internal batteries, the light distribution test of IEC TS 62257-12-1 may be used in place of the light distribution test in this document. Since the voltage supplied to the lighting appliance in IEC TS 62257-12-1 can be different from the appliance operating voltage (Clause FF.5), the results of the IEC TS 62257-12-1 light distribution test shall be adjusted as follows:

- Full width half maximum angles need not be adjusted.
- Luminous flux values shall be adjusted by multiplying by the relative light output percentage value determined in I.4.2 a).

T.5 Approved test methods

T.5.1 General

Annex T includes multiple test procedures with varying test outcomes, summarized in Table T.2. If more than one identical lighting appliance is included with the product, it is only necessary to test one of each type of identical lighting appliances for each sample. Also, if the product has multiple unique lighting appliances, each unique lighting appliance shall be tested.

The test method to be used should be selected based on the capabilities of the laboratory, the required outcomes (as specified in the product specification), and the product application(s). If only FWHM angles are required by the product specification, the illuminance on a plane and illuminance on a desktop procedures need not be performed. While the turntable method is generally of limited utility for desktop task lights, it may be performed on these products if measurement of the FWHM angles is desired or required by the product specification.

Table T.2 – Summary of testing options for characterizing lamp distributions

Test method	Application(s)	Test outcomes
Goniophotometer or multi-plane	Ambient light Suspended task light Desktop task light	• Vertical and horizontal FWHM angles • Usable area with illuminance greater than a specified threshold • Luminous flux (see Annex I) • Work surface illuminance
Illuminance on a plane	Ambient light Suspended task light	• Usable area with illuminance greater than a specified threshold • Vertical and horizontal FWHM angles, if determined • Work surface illuminance
Turntable	Ambient light Suspended task light	• Vertical and horizontal FWHM angles
Illuminance on a desktop	Desktop task light	• Usable area with illuminance greater than a specified threshold • Work surface illuminance

The following steps shall be followed before performing the test by any method.

a) Determine the "horizontal" and "vertical" planes for the purposes of the light distribution measurement, using the following guidelines. Describe the selected orientation in the test report. Photographs or diagrams can be useful in describing the product orientation, but are not required if the text description is unambiguous.

1) These guidelines consider two types of light points: omnidirectional and directed. If the distribution of illuminance is measured on an imaginary sphere surrounding an omnidirectional product, the maximum illuminance will occur at the equator and local minima will occur at the poles. For a directional product, the maximum illuminance will occur at one pole and the minimum will occur at the other pole. Typical omnidirectional light points include lanterns and some bulbs; typical directed light points include torches and suspended task lights.

2) For an omnidirectional light point, the horizontal plane is the plane of maximum illuminance, typically parallel to the ground, and the vertical plane is the plane perpendicular to the horizontal plane containing the point of maximum illuminance (Figure T.1). In some cases there are multiple possible choices of vertical plane, if the maximum illuminance value occurs at more than one point. In this case, the test laboratory should select one plane to measure.

3) Some directed light points have identifiable top and bottom surfaces. For example, the bottom surface could be flat for desktop mounting and the power button could be located on the top of the light point. In this case, the vertical plane is the plane that contains the point of maximum illuminance and the centres of the top and bottom surfaces of the light point, and the horizontal plane is the plane perpendicular to the vertical plane that contains the point of maximum illuminance. See Figure T.2.

4) For light points with no identifiable top and bottom, the choice of horizontal and vertical planes may be arbitrary.

5) If the light point contains a two-dimensional array of light sources (e.g. LEDs) and multiple choices of horizontal and/or vertical planes are available following the above criteria, it is preferable to align the light point such that the intersections of the horizontal and vertical planes with the array plane are lines of symmetry of the array configuration, if possible. For example, if the product contains LEDs in a grid pattern, the grid lines should be parallel with the horizontal and vertical plane.

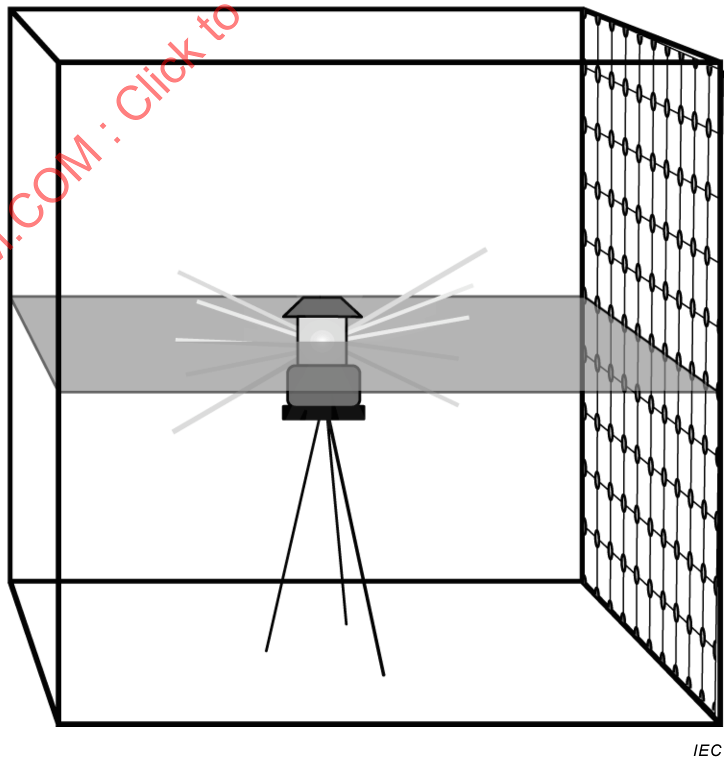


Figure T.1 – Horizontal plane for determining FWHM angle and radial illuminance distribution, for an omnidirectional light point

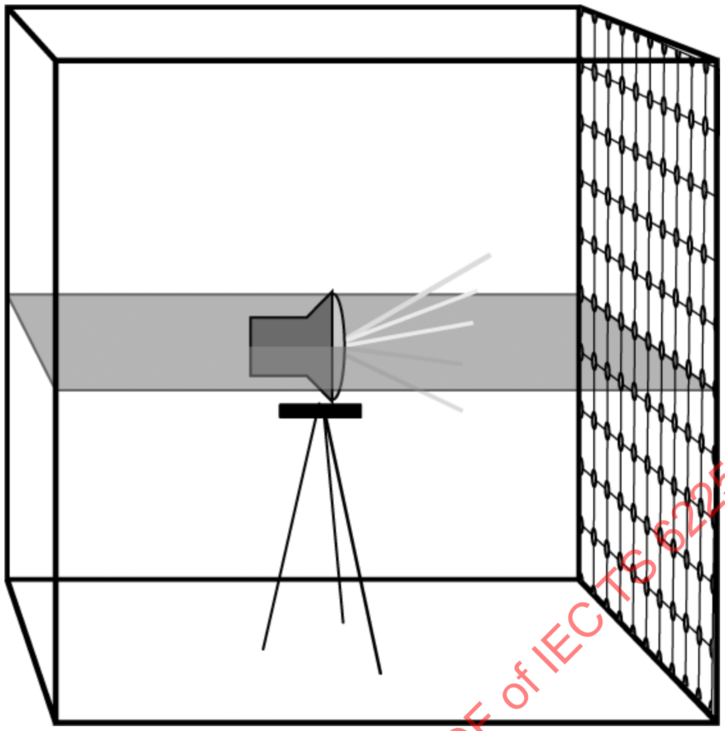


Figure T.2 – Horizontal plane for determining FWHM angle and radial illuminance distribution, for a directed light point

6) If the light point contains a three-dimensional array of light sources (e.g. LEDs) and multiple choices of horizontal and/or vertical planes are available following the above criteria, it is preferable to align the light point such that the horizontal and vertical planes are planes of symmetry of the array configuration, if possible. For example, if the light point contains four LED PCBs with outward-facing LEDs at 90° angles, the vertical plane could be chosen to pass through the centres of two of the LED PCBs.

7) In all cases, the intersection of the horizontal and vertical planes should contain the line segment that connects the centre of the light source with the point of maximum illuminance.

8) Sometimes, as in the case of LED bulbs, it can be difficult to determine whether a light point should be treated as omnidirectional prior to conducting the test. In some cases, it is necessary to perform the test with multiple choices of horizontal and vertical planes. Generally, the radial distribution of illuminance in the vertical plane of an omnidirectional product will have two local maxima at or near 90° and 270°. If a light point is tested as directed but exhibits this characteristic, or if the horizontal and vertical FWHM angles are greater than 180°, the possibility should be considered that the light point should be tested as omnidirectional.

NOTE The terms "horizontal" and "vertical" are used for notational convenience; the horizontal and vertical planes for the purposes of light distribution are not necessarily horizontal and vertical relative to the ground when the light point is in use or when the measurement is being performed. The orientation of the light point in the laboratory does not necessarily correspond to the product’s intended use.

b) Prepare the test sample for lighting evaluation as described in I.4.1.

The procedure for calculating FWHM angles presented in T.5.3.6, T.5.4.6, and T.5.5.6 are adequate for most products. For products with unusual distributions for which these procedures do not accurately describe the shape of the distribution, the test laboratory should use its discretion and provide documentation of the procedure used. In such a situation the laboratory may report multiple FWHM angles for different parts of the distribution or may report that the FWHM angles could not be determined.

T.5.2 Goniophotometer

A goniophotometer may be used to measure both the light distribution characteristics of a light source and also the total luminous flux. Operation of a goniophotometer is beyond the scope of this document, and testing with a goniophotometer device should be conducted according to the following standard test methods, with the DUT operated using a laboratory power supply as described in I.4.1:

- CIE 084
- CIE 127
- IESNA LM-79-08

T.5.3 Multi-plane method

T.5.3.1 General

The multi-plane method, described in I.4.4, can be used to measure luminous flux and characterize light distribution of ambient lights, suspended task lights, and desktop task lights. For characterizing the light distribution of desktop task lights, depending on the details of the intended application, the illuminance on a desktop method (T.5.6) is generally more appropriate; the multi-plane and illuminance on a desktop methods may be used in conjunction to obtain both luminous flux and light distribution characteristics.

T.5.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Multi-plane test apparatus (described in Annex I).
- DC power supply.
- Illuminance meter.
- DC voltmeter or multimeter.
- DC ammeter.

T.5.3.3 Test prerequisites

The product specification may define the distance(s) at which the usable area, work surface illuminance, and radial distribution of illuminance are to be determined; if not otherwise specified, use a value of 0,75 m for the usable area and work surface illuminance measurements and 1 m for the radial distribution of illuminance. Distances shall be specified as the distance from the grid surface to the centre point of the light source. The DUT's battery voltage and current corresponding to the average light output over the L_{70} run time are required. The DUT shall be prepared for lighting evaluation as described in Annex G. Before measurement, the battery of the DUT shall be replaced by a DC power supply.

T.5.3.4 Apparatus

The multi-plane apparatus is described in I.4.4.

T.5.3.5 Procedure

The test procedures for determining the ambient light characterization are the same procedures as those used to determine total luminous flux and are described in I.4.4.5. This procedure needs only to be conducted once per test sample to gather all necessary information needed to calculate luminous flux (as detailed in Annex I), usable area, work surface illuminance, and FWHM angles.

T.5.3.6 Calculations

Since the multi-plane method requires the DUT to be positioned so that its centre point is at a distance of 0,5 m from the lighting distribution grid surface, the measurements shall be adjusted by performing the following calculations:

a) Correct for differences in measurement distance by adjusting the illuminance values to the desired distance for only the measurements on the first surface measured in the multi-plane method (i.e. the surface containing the point of maximum illuminance). Use the following formula:

$$E_{\text{v,adj}} = E_{\text{v,surf}} \left(\frac{y_{\text{surf}}}{y_{\text{spec}}} \right)^2$$

where

$E_{\text{v,adj}}$ is the illuminance adjusted for distance, in lux (lx);

$E_{\text{v,surf}}$ is the measured illuminance on the grid surface, in lux (lx);

y_{surf} is the distance between the centre of the grid surface and the DUT during the test (0,5 m), in metres (m);

y_{spec} is the distance at which usable area and work surface illuminance are to be determined (see T.5.3.3), in metres (m).

b) Calculate the average of the illuminance adjusted for distance ($E_{\text{v,adj}}$) over all possible regions of the first measured 1 m^2 grid surface that are composed of twelve illuminance values in a four by three configuration. The maximum of the calculated averages is the work surface illuminance.

NOTE 1 The work surface dimensions were selected to correspond to two adjacent sheets of A4 paper.

c) Count the number of illuminance values equal to or greater than the specified minimum illuminance (see T.5.3.3). Each value corresponds to 0,01 m^2. Multiply the number of values by 0,01 m^2 to obtain the total usable area. (A maximum usable area of 1,21 m^2 is achievable when taking 121 measurements.)

d) Repeat step c) for a range of minimum illuminance values. See Table T.3 for an example of determining the usable area for a range of minimum illuminance values.

e) Plot the usable area as a function of minimum illuminance. Plot the values for each of the tested settings on the same plot. The domain of the plot shall include the maximum illuminance value for the brightest setting. See Figure T.8 for an example of a plot showing usable area as a function of minimum illuminance.

f) Create a three-dimensional surface plot showing the illuminance values on the brightest surface of the 1 m^2 grid. See Figure T.9 for an example of a three-dimensional surface plot.

In order to generate polar plots of the distribution and to calculate FWHM angles, the data collected by the multi-plane method will need to be adjusted to estimate the illuminance on the inner surface of a virtual sphere centred on the DUT's light source. These calculations are only valid if the distance from the light source to the illuminance meter is at least five times the longest dimension of the emissive surface of the DUT. If this condition is not met, the polar plots shall be generated and FWHM angles determined using the goniophotometer (T.5.2) or turntable (T.5.5) method.

g) Correct the original, measured illuminance values ($E_{\text{v,surf}}$) for differences in measurement angle so that the illuminance values represent the illuminance on an imaginary surface normal to the line connecting the DUT and the illuminance meter:

$$E_{\text{v,rad}} = \frac{E_{\text{v,surf}}}{\cos\theta} = E_{\text{v,surf}} \frac{\sqrt{x^2 + z^2 + y_{\text{surf}}^2}}{y_{\text{surf}}}$$

where

$E_{v,rad}$ is the illuminance on a surface normal to the line connecting the DUT and the illuminance meter, in lux (lx);

$E_{v,surf}$ is the measured illuminance on the grid surface, in lux (lx);

θ is the angle between a line connecting the DUT and the illuminance meter and a line connecting the DUT and the centre of the grid;

x is the horizontal position of the illuminance meter relative to the centre of the grid, in metres (m);

z is the vertical position of the illuminance meter relative to the centre of the grid, in metres (m);

y_{surf} is the distance between the centre of the grid surface and the DUT during the test, in metres (m).

NOTE 2 The coordinate axes are oriented according to Figure I.1, with the origin at the DUT's light source; that is, at the centre of the grid, x = 0, z = 0, and $y = y_{surf}$.

Only those values that will be used in further calculations need to be corrected. Typically, this is the set of values lying in the horizontal and vertical planes, as described in steps i) and j) below.

h) Correct the angle-corrected illuminance values ($E_{v,rad}$) for differences in measurement distance, so that the illuminance values represent the illuminance on the inner surface of a sphere of radius R centred at the DUT's light source, by adjusting each measured illuminance value to a constant distance from the DUT using the following formula:

$$E_{v,sphere} = E_{v,rad} \frac{x^2 + z^2 + y_{surf}^2}{R^2}$$

where

$E_{v,sphere}$ is the illuminance on the virtual sphere, in lux (lx);

$E_{v,rad}$ is the illuminance on a surface normal to the line connecting the DUT and the illuminance meter, as calculated in g), in lux (lx);

x is the horizontal position of the illuminance meter relative to the centre of the grid, in metres (m);

z is the vertical position of the illuminance meter relative to the centre of the grid, in metres (m);

y_{surf} is the distance between the centre of the grid surface and the DUT during the test (0,5 m), in metres (m);

R is the distance at which the radial distribution of illuminance is to be determined (see T.5.3.3), in metres (m).

NOTE 3 The numerator of the fraction in the formula is the square of the distance, in metres, from the illuminance meter to the DUT.

i) Calculate the horizontal FWHM angle using the following steps.

1) Identify the illuminance values on the virtual sphere ($E_{v,sphere}$) that lie on the horizontal plane (as defined in T.5.1) that intersects the centre of the brightest surface of the 1 m^2 grid (Figure T.1 and Figure T.2). The point of maximum illuminance should fall on this plane.

2) For each illuminance value in the horizontal plane, calculate the angle between the Y axis (as defined in Figure I.1, with the origin of the coordinate system at the centre point of the light source) and the line connecting the centre point of the DUT's light source and the location of the illuminance measurement. Tabulate the illuminance ($E_{v,sphere}$) as a function of angle.

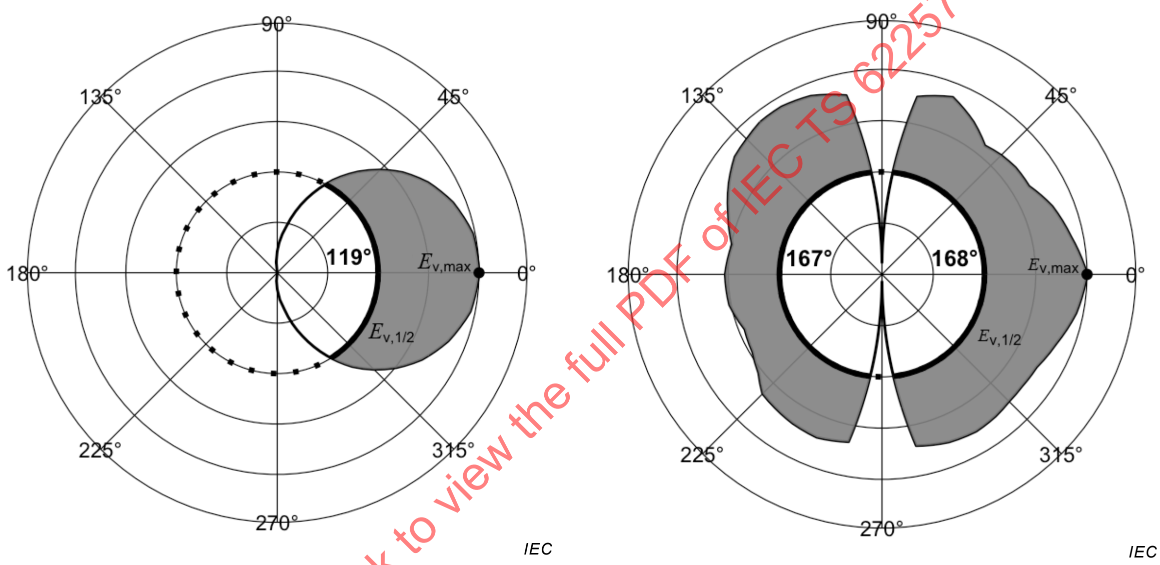
3) Calculate the half-maximum illuminance ($E_{v,1/2}$), which is half of the maximum value of $E_{v,sphere}$ in the plane identified in step 1).

4) Linearly interpolate between adjacent illuminance values (as a function of angle) to identify the regions over which the illuminance $E_{v,sphere}$ is greater than $E_{v,1/2}$.

5) Calculate the FWHM angle as the total angle subtended by the regions where $E_{v,sphere}$ is greater than $E_{v,1/2}$. If there are multiple regions over which the illuminance is greater than $E_{v,1/2}$, the FWHM angle is the sum of the angles subtended by all such regions. If there are no points where the illuminance is less than $E_{v,1/2}$, the FWHM angle is 360°. See Figure T.3 for examples.

j) To calculate the vertical FWHM angle, repeat the previous step using the vertical plane that intersects the centre of the brightest surface of the 1 m^2 grid, as defined in T.5.1. However, if the distribution in the vertical plane consists of multiple lobes, as in Figure T.4, the vertical FWHM angle is the average, not the sum, of the FWHM angles for all of the lobes. Report horizontal and vertical FWHM angles separately.

k) Plot the radial distribution of illuminance in the horizontal and vertical planes (as defined in T.5.1) on two separate polar plots. See Figure T.10 for an example of a polar plot.



a) Suspended task light with horizontal FWHM = 119°

b) Omnidirectional ambient light with horizontal FWHM = 335°

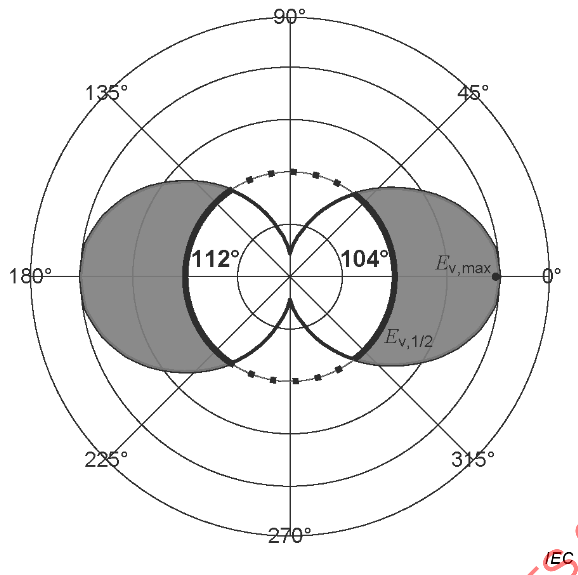
Key

$E_{v,max}$ Maximum illuminance (lx)

$E_{v,1/2}$ Half-maximum illuminance (lx)

NOTE The half-maximum illuminance ($E_{v,1/2}$) is indicated by the dotted line. The illuminance exceeds $E_{v,1/2}$ in the shaded areas. The sum of the angles subtended by the shaded areas is the FWHM angle.

Figure T.3 – Radial illuminance distributions in the horizontal plane for two example products, showing the calculation of the horizontal FWHM angle



Key

$E_{v,max}$ Maximum illuminance (lx)

$E_{v,1/2}$ Half-maximum illuminance (lx)

NOTE The half-maximum illuminance ($E_{v,1/2}$) is indicated by the dotted line. The illuminance exceeds $E_{v,1/2}$ in the shaded areas. The average of the angles subtended by the shaded areas is the vertical FWHM angle.

Figure T.4 – Radial illuminance distribution in the vertical plane for an example omnidirectional ambient light with vertical FWHM = 108°

T.5.4 Illuminance on a plane method

T.5.4.1 General

In this test, the illumination level is measured on a surface of 1 m^2. This test measures the usable area and work surface illuminance. If the DUT's light distribution is sufficiently narrow, the FWHM angles can also be measured using this method. To measure wider FWHM angles, or if plots of the radial illuminance distribution are desired, this method may be used in conjunction with the turntable method (T.5.5). This test is appropriate for ambient and suspended task lights; ambient lights with very wide-angle or omnidirectional output should be tested using the goniophotometer (T.5.2), multi-plane (T.5.3), or turntable (T.5.5) method.

T.5.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

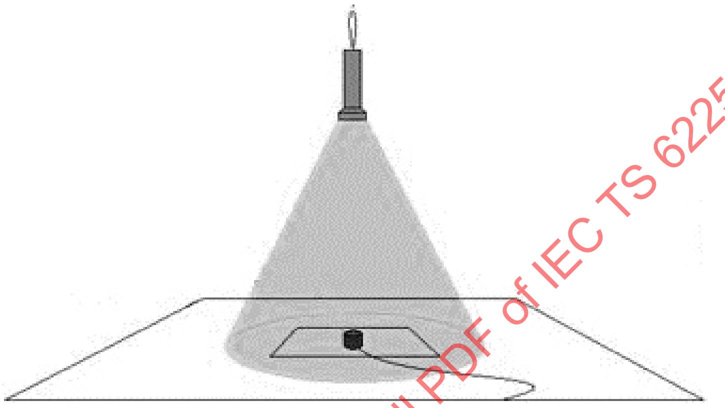
- DC power supply.
- DC voltmeter or multimeter.
- DC ammeter.
- Illuminance meter.
- Lighting distribution grid testing surface.

T.5.4.3 Test prerequisites

The product specification may define the distance(s) at which the usable area, work surface illuminance, and radial distribution of illuminance are to be determined and the minimum illuminance to be used in the usable area calculation; if not otherwise specified, use a value of 0,75 m for the usable area and work surface illuminance measurements and 1 m for the radial distribution of illuminance. The DUT's battery voltage and current corresponding to the average light output over the L_{70} run time are required. The DUT shall be prepared for lighting evaluation as described in Annex G. Before measurement, the battery of the DUT shall be replaced by a DC power supply. Measurements shall be taken in a conditioned space such that the air temperature is 22 °C ± 5 °C.

T.5.4.4 Apparatus

The apparatus for this test consists of a 1 m^2 measurement target with 121 evenly-spaced measurement points (10 cm apart), an illuminance meter, and a mechanism to mount the DUT at the specified distance from the measurement target (see Figure T.5). Testing shall be done in a completely dark space, except for illumination provided by the DUT. The test operator should wear all-black clothing if required to be near to the measurement surface.



IEC

Figure T.5 – Schematic of a task light suspended above an illuminance meter

T.5.4.5 Procedure

The following steps shall be followed.

a) Supply power to the DUT using a DC power supply as described in I.4.1. Follow power supply guidelines in the power supply set up procedure (Annex H).

b) If at the desired voltage the DUT will not operate in the desired setting, increase the power supply voltage by increments of 0,05 V until the DUT is able to operate in the desired setting, then attempt to reduce the voltage to the desired level.

c) Position the DUT as shown in Figure T.5 so that the point of maximum illuminance is in the centre of the grid. The distance from the DUT's light source to the grid shall be equal to the distance at which the usable area and work surface illuminance are to be determined (see T.5.4.3). The DUT need not be suspended vertically; the measurement grid may be on a horizontal or vertical surface.

d) Operate the DUT for at least 20 min at the desired setting before the first measurement is started.

e) Measure illuminance at each of the 121 measurement points on the test plane. However, illuminance need not be measured for the grid points at which the illuminance is less than the resolution of the illuminance meter or less than 0,2 % of the maximum illuminance reading on the grid.

T.5.4.6 Calculations

The following calculations shall be made.

a) Calculate the average illuminance over all possible regions of the 1 m^2 grid surface that are composed of twelve illuminance values in a four by three configuration. The maximum of the calculated averages is the work surface illuminance.

NOTE 1 The work surface dimensions were selected to correspond to two adjacent sheets of A4 paper.

b) Count the number of illuminance values equal to or greater than the specified minimum illuminance (see T.5.4.3). Each value corresponds to 0,01 m^2. Multiply the number of values by 0,01 m^2 to obtain the total usable area (a maximum usable area of 1,21 m^2 is achievable when taking 121 measurements).

c) Repeat step b) for a range of minimum illuminance values. See Table T.3 for an example of determining the usable area for a range of minimum illuminance values.

d) Plot the usable area as a function of minimum illuminance. Plot the values for each of the tested settings on the same plot. The domain of the plot shall include the maximum illuminance value for the brightest setting. See Figure T.8 for an example of a plot showing usable area as a function of minimum illuminance.

e) Create a three-dimensional surface plot showing the illuminance values on the entire grid. See Figure T.9 for an example of a three-dimensional surface plot.

For products with sufficiently narrow light distributions, FWHM angles can be determined from the illuminance on a plane method. In order to calculate FWHM angles, the data collected by the illuminance on a plane method will need to be adjusted to estimate the illuminance on the inner surface of a virtual sphere centred on the DUT's light source. These calculations are only valid if the distance from the light source to the illuminance meter is at least five times the longest dimension of the emissive surface of the DUT. If this condition is not met, the FWHM angles shall be determined using the goniophotometer (T.5.2) or turntable (T.5.5) method. If the FWHM angle cannot be determined because the distribution is too wide, the FWHM angles shall be determined using the goniophotometer (T.5.2), multi-plane (T.5.3), or turntable (T.5.5) method.

f) Using the formulas in T.5.3.6 g) and h), adjust the measured illuminance values to calculate the illuminance on the inner surface of a sphere of radius R centred at the DUT's light source.

g) Calculate the horizontal FWHM angle using the following steps:

   1) Identify the illuminance values on the virtual sphere ($E_{v,sphere}$) that lie on the horizontal plane (defined in T.5.1) that intersects the centre of the brightest surface of the 1 m^2 grid (Figure T.1 and Figure T.2). The point of maximum illuminance should fall on this plane.

   2) For each illuminance value on the horizontal plane, calculate the angle between the Y axis (as defined in Figure I.1, with the origin of the coordinate system at the DUT) and the line connecting the DUT's light source and the location of the illuminance measurement. Tabulate the illuminance ($E_{v,sphere}$) as a function of angle.

   3) Calculate the half-maximum illuminance ($E_{v,1/2}$), which is half of the maximum value of $E_{v,sphere}$ in the plane identified in step (1).

   4) Linearly interpolate between adjacent illuminance values (as a function of angle) to identify the regions over which the illuminance $E_{v,sphere}$ is greater than $E_{v,1/2}$.

   5) Calculate the FWHM angle as the total angle subtended by the regions where $E_{v,sphere}$ is greater than $E_{v,1/2}$. If there are multiple regions over which the illuminance is greater than $E_{v,1/2}$, the FWHM angle is the sum of the angles subtended by all such regions. If the illuminance at the leftmost or rightmost point is greater than $E_{v,1/2}$, the FWHM angle cannot be determined using the illuminance on a plane method. See Figure T.3 for examples.

   6) To calculate the vertical FWHM angle, repeat the previous step using the vertical plane that intersects the centre of the brightest surface of the 1 m^2 grid, as defined in T.5.1. However, if the distribution in the vertical plane consists of multiple lobes, as in Figure T.4, the vertical FWHM angle is the average, not the sum, of the FWHM angles for all of the lobes. Report horizontal and vertical FWHM angles separately.

NOTE 2 It is unlikely that the illuminance on a plane method would be appropriate for a product having a vertical-plane light distribution with multiple lobes.

T.5.5 Turntable method

T.5.5.1 General

This test measures the radial distribution of illuminance at a constant distance from the DUT. This method may be used in conjunction with the illuminance on a plane method to determine the FWHM angles, usable area, and work surface illuminance.

T.5.5.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Turntable (see Figure T.6) or equivalent apparatus as described in T.5.5.4.
- DC power supply.
- Illuminance meter.
- DC voltmeter or multimeter.

T.5.5.3 Test prerequisites

The product specification may define the distance at which the radial distribution of illuminance is to be determined; if not otherwise stated, use a value of 1 m. The DUT shall be prepared for lighting evaluation as described in Annex G. Before measurement, the battery of the DUT shall be replaced by a DC power supply. Measurements shall be taken in a conditioned space such that the air temperature is 22 °C ± 5 °C.

T.5.5.4 Apparatus

This test is performed using a turntable (see Figure T.6). The DUT is placed on the turntable and illuminance is measured at the distance determined in T.5.5.3 (from the centre of the DUT's light source to the illuminance meter sensor). Testing shall be done in a completely dark space, except for illumination provided by the DUT. The test operator should wear all-black clothing if required to be near to the measurement surface.

Ensure that the centre of the DUT's light source is at the same height as the illuminance meter during the test and that the illuminance meter is positioned at the point of maximum illuminance. If tilting the DUT to position the illuminance meter at the point of maximum illuminance would result in an inaccurate measurement of the FWHM angle and radial illuminance distribution (for example, if the DUT is an omnidirectional ambient light), the DUT or illuminance meter may be raised or lowered instead.

As an alternative to a turntable, an apparatus in which the illuminance meter is rotated or positioned at points at a constant distance around a stationary DUT may be used.

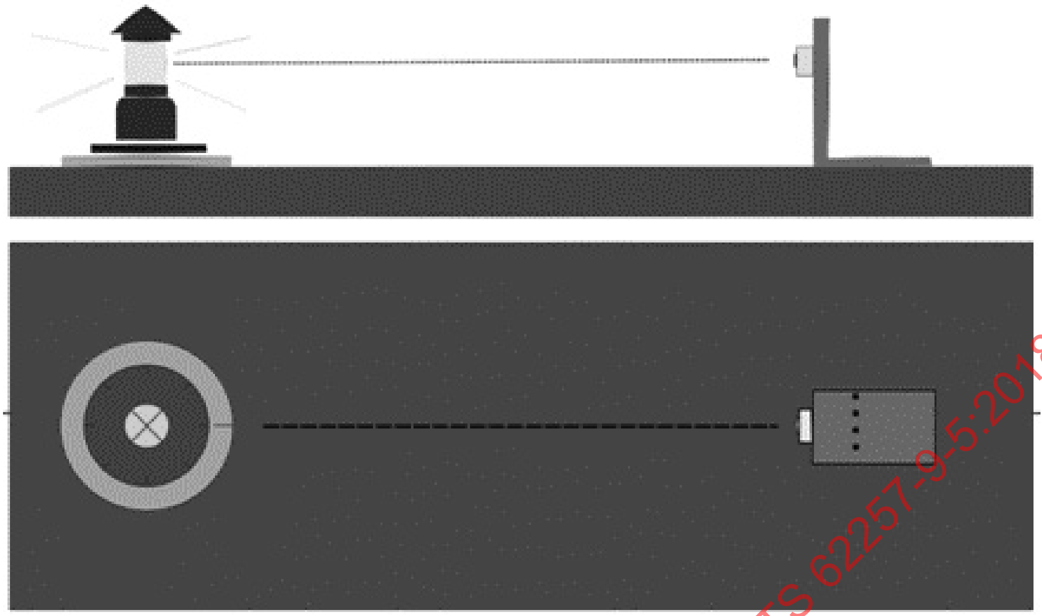


Figure T.6 – Schematic of turntable setup, with the DUT shown

T.5.5.5 Procedure

The following steps shall be followed.

a) Supply power to the DUT using a DC power supply as described in I.4.1. Follow power supply guidelines in the power supply setup procedure (Annex H). The distance from the centre of the DUT's light source to the illuminance meter should be equal to the distance at which the radial distribution of illuminance is to be measured (see T.5.5.3).

b) If at desired voltage the DUT will not operate at the desired setting, increase the power supply voltage by increments of 0,05 V until the DUT is able to operate at the desired setting, then attempt to reduce the voltage to the desired level.

c) Secure the DUT to the turntable so that the measured illuminance values lie in the horizontal plane shown in Figure T.1 and Figure T.2, with the illuminance meter at the point of maximum illuminance. Generally, omnidirectional lighting appliances such as lanterns can simply be set on the turntable and secured to prevent movement; for directed lighting appliances, a clamp or other special apparatus is often required to secure the DUT. Ensure that the DUT cannot move relative to the turntable.

d) Operate the DUT for at least 20 min at the desired setting before the first measurement is started.

e) Measure illuminance levels at least every 10° for the full 360° angle. However, measurements need not be taken for angles at which the illuminance value is known to be less than the resolution of the illuminance meter or less than 0,2 % of the illuminance at the brightest point. Further, if the FWHM angles are captured after measuring the illuminance levels over the brightest 180°, additional measurements need not be performed.

f) Repeat the procedure with the DUT resting at an orientation normal to the "horizontal" orientation, such that the measurement points lie in the vertical plane defined in T.5.1. A special apparatus may be required to secure the DUT in this orientation. Ensure that the DUT cannot move relative to the turntable.

T.5.5.6 Calculations

The following calculations shall be made.

a) Calculate the horizontal FWHM angle using the following steps.

1) Calculate the half-maximum illuminance ($E_{v,1/2}$), which is half of the maximum illuminance value from the horizontal sweep.
2) Identify the regions from the horizontal sweep over which the measured illuminance is greater than $E_{v,1/2}$. If the angular resolution of the measurements performed in T.5.5.5 is coarser than 2°, linearly interpolate between measurements (as a function of angle) to obtain finer resolution.
3) Calculate the FWHM angle as the total angle subtended by the regions where the measured illuminance is greater than $E_{v,1/2}$. If there are multiple regions over which the illuminance is greater than $E_{v,1/2}$, the FWHM angle is the sum of the angles subtended by all such regions. If there are no points where the illuminance is less than $E_{v,1/2}$, the FWHM angle is 360°. See Figure T.3 for examples.

b) To calculate the vertical FWHM angle, repeat the previous step using the measurements from the vertical sweep, except that if the distribution in the vertical plane consists of multiple lobes, as in Figure T.4, the vertical FWHM angle is the average, not the sum, of the FWHM angles for all of the lobes. Report horizontal and vertical FWHM angles separately.

c) Plot the illuminance values over the "horizontal" and "vertical" sweeps as two separate polar plots. See Figure T.10 for an example of a polar plot.

T.5.6 Illuminance on a desktop method

T.5.6.1 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

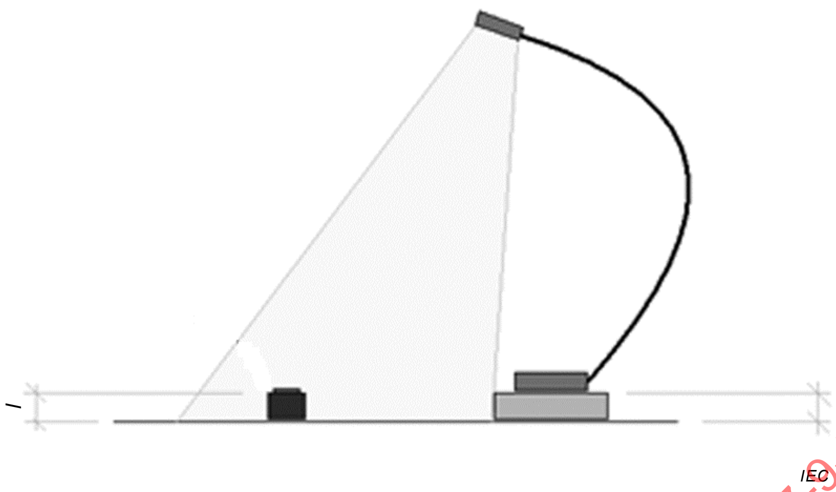
- DC power supply.
- Illuminance meter.
- Lighting distribution grid testing surface.

T.5.6.2 Test prerequisites

The DUT's battery voltage and current corresponding to the average light output over the L_{70} run time is required. The DUT shall be prepared for lighting evaluation as described in Annex G. Before measurement, the battery of the DUT shall be replaced by a DC power supply. Measurements shall be taken in a conditioned space such that the air temperature is 22 °C ± 5 °C.

T.5.6.3 Apparatus

Figure T.7 shows a side view of the desktop light measuring setup. The test operator should wear all-black clothing if required to be near to the measurement surface. Testing shall be done in a completely dark space, except for illumination provided by the DUT.



Key

l Height of illuminance meter head and desktop light spacer

Figure T.7 – Side view of desktop light measuring setup

T.5.6.4 Procedure

The following steps shall be followed.

a) Supply power to the DUT using a DC power supply as described in I.4.1. Follow power supply guidelines in the power supply set up procedure (Annex H).

b) If at the desired voltage the DUT will not operate at the desired setting, increase the power supply voltage by increments of 0,05 V until the DUT is able to operate at the desired setting, then attempt to reduce the voltage to the desired level (Annex M).

c) Operate the DUT at least for 20 min at the desired setting before the first measurement is taken.

d) Place the DUT on the surface using a spacer to compensate for the height of the illuminance meter head. The height of the spacer shall be equal to the height of the measurement plane of the illuminance meter (see Figure T.7). The DUT shall be oriented in the manner that it would be used by the consumer, to the best of the tester's ability, using the provided stand or mounting mechanism, if any. The DUT shall be located at the position that the tester estimates will maximize the usable area that falls on the grid (as defined in T.5.4.6 step b)).

e) Measure the illuminance at 121 evenly spaced points, 10 cm apart, on a 1 m × 1 m horizontal grid surface. Measure illuminance levels for the grid points that read an illuminance value greater than the resolution of the illuminance meter and greater than 0,2 % of the maximum illuminance reading.

T.5.6.5 Calculations

The calculations for the illuminance on a desktop method are identical to the calculations for the illuminance on a plane method (refer to T.5.4.6). Omit steps f) and g). (Do not calculate FWHM angles or generate polar plots.)

T.6 Reporting

Report the following in the light distribution test report.

- Metadata:
  - report name;
  - procedure(s) used;

- DUT manufacturer;
- DUT name;
- DUT model number;
- DUT setting;
- test room temperature (°C);
- name of test laboratory;
- approving person;
- date of report approval.

• Results for tested DUT aspects for samples 1 through n:
  - drive current (A);
  - drive voltage at product (V);
  - waiting time (min);
  - vertical FWHM angle (°);
  - horizontal FWHM angle (°);
  - average usable area through L_{70} (m^2);
  - work surface illuminance (lux).

• Average of n sample results for each DUT aspect tested.

• Coefficient of variation of n sample results for each DUT aspect tested (%).

• Comments:
  - individual comments, as necessary, for samples 1 through n;
  - overall comments, as necessary, for collective set of samples 1 through n.

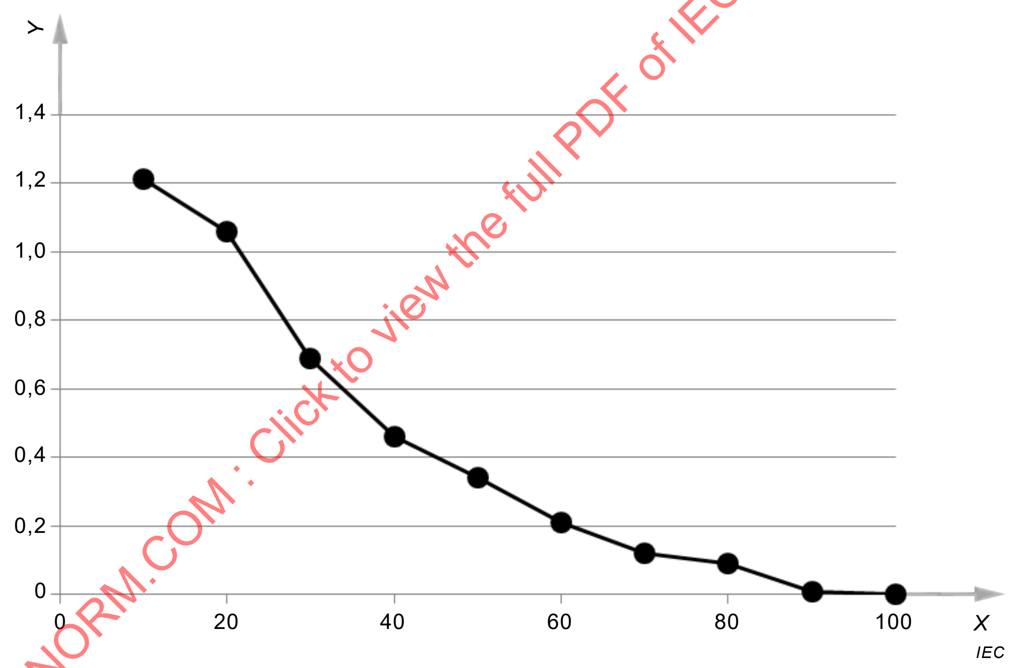
• Tables:
  - table of illuminance values on the brightest "face" of the 1 m^2 grid (see Table T.3 for an example).

• Figures:
  - plot of illuminated area vs. minimum illuminance (see Figure T.8 for an example);
  - surface plots of illuminance on a plane and/or polar plots of the radial illuminance distribution (see Figure T.9 and Figure T.10 for examples).

Table T.3 – Table of example illuminance measurements on the brightest "face" of the 1 m^2 grid and usable area as a function of minimum illuminance

Illuminance measurements lx										
13,6	17,3	21,0	24,5	26,6	27,8	26,6	22,7	19,7	16,5	13,5
16,9	22,1	28,0	33,5	38,5	41,1	38,1	33,2	27,7	21,5	16,6
20,6	27,1	35,8	44,4	52,7	54,7	51,6	43,0	34,7	26,9	20,0
24,1	32,4	44,3	57,4	69,3	74,3	68,4	55,9	42,5	32,0	23,3
26,4	36,8	52,1	66,9	82,7	88,7	81,9	66,1	49,1	35,4	25,1
27,4	38,2	54,5	71,1	88,1	95,0	87,0	69,5	52,1	36,9	26,2
27,0	36,7	51,2	66,7	81,8	87,4	80,8	64,9	49,4	34,9	24,3
24,0	32,2	43,4	56,5	66,7	70,5	66,2	55,4	41,6	30,0	22,0
20,8	26,8	35,7	43,7	49,6	52,2	50,3	41,6	32,7	25,1	18,4
17,3	21,9	27,6	32,6	36,9	38,1	35,9	31,4	25,6	20,2	15,4
13,8	17,0	20,3	23,3	25,6	26,1	25,4	22,6	18,9	15,2	12,3

Minimum illuminance lx	Usable area m^2
10	1,21
20	1,06
30	0,69
40	0,46
50	0,34
60	0,21
70	0,12
80	0,09
90	0,01
100	0,00

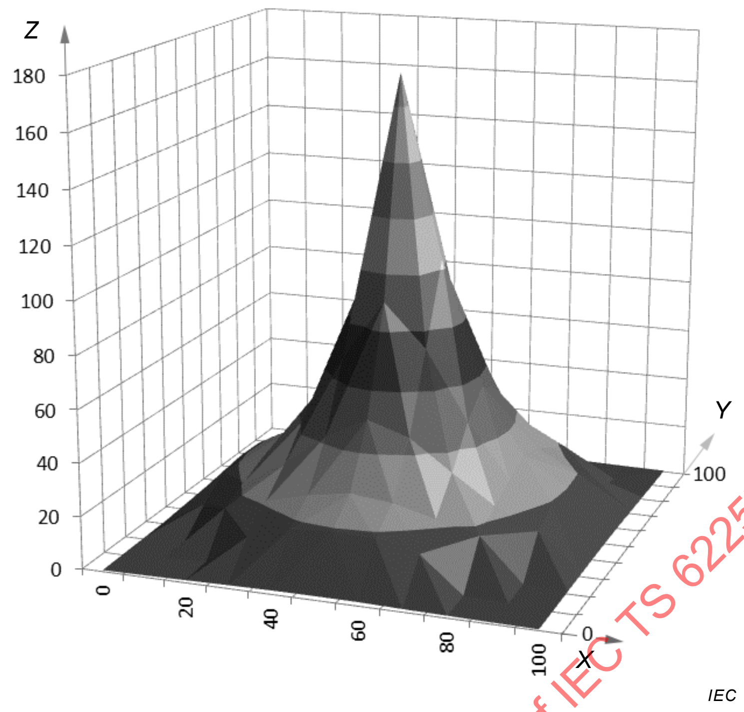


Key

X Minimum illuminance (lx)

Y Usable area (m^2)

Figure T.8 – Example plot of usable area as a function of minimum illuminance



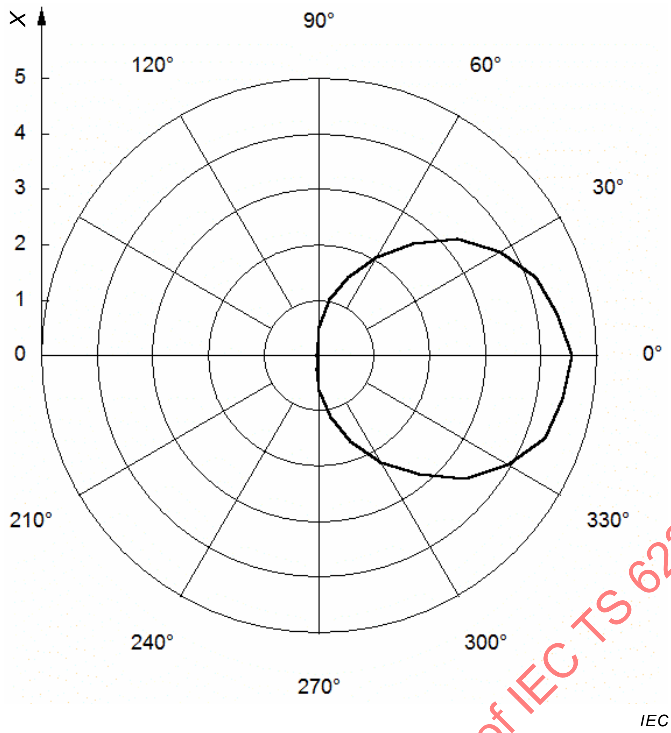
Key

X Horizontal position (cm)

Y Vertical position (cm)

Z Illuminance (lx)

Figure T.9 – Example of resulting surface plot of light distribution from the brightest "face" of the multi-plane method or illuminance on a plane method



Key

X Illuminance (lx)

Figure T.10 – Example of a polar plot of the radial illuminance distribution

Annex U
(normative)

Physical and water ingress protection test

U.1 Background

Ingress protection (IP) testing determines the degrees of protection provided by the enclosures of a product's components. The IP rating uses two numerals to define the degrees of protection. The first numeral identifies the degree the DUT has protection against solid foreign objects. The second numeral identifies the degree the DUT has protection against ingress of water with harmful effects.

This test applies to any components of the DUT that contain electronics or electrical connections, including the primary components of the DUT, the PV module, and any appliances included with the DUT. Note that the test requirements for components may be specified based on the component category (fixed outdoor, portable integrated, portable separate, fixed indoor or PV module) as described in 4.1.2. If more than one identical component or appliance is included with the product, only one of each set of identical appliances should be tested.

U.2 Test outcomes

The water exposure and physical ingress protection test outcomes are listed in Table U.1.

Table U.1 – Water exposure and physical ingress protection test outcomes

Metric	Reporting units	Related aspects	Notes
IP2x	Pass/fail	4.2.3.5 Physical ingress protection 4.2.3.6 Physical ingress protection – solar module	12,5 mm diameter probe
IP3x	Pass/fail	4.2.3.5 Physical ingress protection 4.2.3.6 Physical ingress protection – solar module	2,5 mm diameter probe
IP4x	Pass/fail	4.2.3.5 Physical ingress protection 4.2.3.6 Physical ingress protection – solar module	1 mm diameter probe
IP5x	Pass/fail	4.2.3.5 Physical ingress protection 4.2.3.6 Physical ingress protection – solar module	No ingress of dust Shall be tested by a laboratory that has been accredited to test according to IEC 60529. Laboratories shall use the procedure in IEC 60529; no simplified alternative is acceptable.
IPx1	Pass/fail	4.2.3.1 Water protection – enclosure 4.2.3.2 Water protection – circuit protection and drainage	Vertically dripping water

Metric	Reporting units	Related aspects	Notes
IPx3	Pass/fail	4.2.3.1 Water protection – enclosure 4.2.3.2 Water protection – circuit protection and drainage	Direct sprays of water from within 60° of vertical
Modified IPx4	Pass/fail	4.2.3.4 Water protection – solar module	Splashes of water from any direction
IPx5	Pass/fail	4.2.3.1 Water protection – enclosure 4.2.3.2 Water protection – circuit protection and drainage	Water projected in jets Shall be tested by a laboratory that has been accredited to test according to IEC 60529. Laboratories shall use the procedure in IEC 60529; no simplified alternative is acceptable.

U.3 Related tests

Annex U is related to the level of water protection annex (Annex V).

For lighting appliances without batteries, the physical ingress and water protection test of IEC TS 62257-12-1 may be used in place of Annex U, provided that the IEC TS 62257-12-1 test method defines procedures for estimating or testing the IP classes for which testing is needed according to the product specification and/or the assessment of level of water protection (Annex V).

U.4 Procedure

U.4.1 General

The IP class may be assessed either by sending samples of the DUT component to a laboratory that has been accredited to test according to IEC 60529 or by estimating the IP class according to the methods below, except that in the case of testing for IPx5 or IP5x, the DUT component shall be tested by a laboratory that has been accredited to test according to IEC 60529. When testing for IPx5 or IP5x, laboratories shall use the procedure in IEC 60529; no simplified alternative is acceptable.

U.4.2 IP testing at a laboratory that has been accredited to test according to IEC 60529

U.4.2.1 General

Samples are sent to a laboratory that has been accredited to test according to IEC 60529 to determine the passing or failing for the desired IP requirements.

U.4.2.2 Guidance on working with external IP testing laboratory

Many international IP testing laboratories will require two samples for testing. These should be samples that have not been altered in any way.

This test is destructive. Do not perform any additional tests on the samples after testing.

For water ingress testing, specify to the laboratory that has been accredited to test according to IEC 60529 how the DUT component shall be oriented during testing. It shall be oriented in the way that the DUT component is most likely to be used.

NOTE The test used to assess solar modules for ingress of water with harmful effects is modified from the test described in IEC 60529. The modified IPx4 assessment for water ingress protection follows the same procedure to test for IPx4 as described in IEC 60529 with the exception of the angle of spray. In IEC 60529, the solar module is sprayed at angles ± 180° from vertical, while in the modified method described below the solar module is sprayed at angles ± 90° from vertical.

U.4.3 Simplified IP inspection for ingress of solid foreign objects

U.4.3.1 General

The DUT component is visually inspected for protection against ingress of solid foreign objects to determine the passing or failing result for the desired IP requirement. This method may be performed to estimate IP ratings IP2x, IP3x, and IP4x.

U.4.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- 1 mm, 2,5 mm, or 12,5 mm diameter rigid probe.
- Camera.

U.4.3.3 Test prerequisites

The sample tested should have not been altered in any way.

U.4.3.4 Apparatus

No apparatus is required for this test.

U.4.3.5 Procedure

U.4.3.5.1 Procedure for testing DUT component enclosures

Perform the following steps.

a) Before the measurement, be sure that the DUT component is properly functioning and that it is sufficiently charged to check for functionality during the test.

b) If the DUT component is required to pass IP2x, select the 12,5 mm probe. If the DUT component is required to pass IP3x, select the 2,5 mm probe. If the DUT component is required to pass IP4x, select the 1 mm probe.

c) Explore the DUT component's entire surface to test for penetration with the selected probe.

d) If the 12,5 mm probe can enter a part of the DUT component's enclosure that contains electronic components, electrical connections or circuits, with minimal force, the DUT component is estimated to fail the IP2x assessment.

e) If the 2,5 mm probe can enter a part of the DUT component's enclosure that contains electronic components, electrical connections or circuits, with minimal force, the DUT component is estimated to fail the IP3x assessment.

f) If the 1 mm probe can enter a part of the DUT component's enclosure that contains electronic components, electrical connections or circuits, with minimal force, the DUT component is estimated to fail the IP4x assessment.

g) If the probe can enter an external jack, this is not considered a failure, unless it can enter the DUT's enclosure through the external jack. Document any failures with photographs and text.

U.4.3.5.2 Procedure for testing a product's external solar module (if applicable)

PV modules that have been tested according to and meet all requirements of the IEC 61215 series need not be tested using this procedure. Test results provided by the manufacturer of the DUT may be accepted if the tests were performed at a laboratory accredited to perform the tests by a recognized accrediting body (e.g. an ILAC MRA signatory, to ISO/IEC 17025).

Integrated solar modules that were tested as part of the DUT need not undergo this test, except in cases similar to the roof light described in c).

a) Before the measurement, be sure that the solar module is properly functioning and that the enclosure and/or junction box has never been opened previously.
b) Most solar modules need only to be assessed for IP3x; however, if the module fails the IP3x assessment, it should also be assessed for IP2x. To estimate IP3x, select the 2,5 mm probe; to estimate IP2x, select the 12,5 mm probe.
c) Explore the solar module's entire surface to test for penetration with the selected probe. For a product that is designed to be installed on the roof with the main unit attached inside the structure directly below, the portion of the product that is designed to be outside shall be assessed for IP3X, while the portion of the product designed to be inside shall be assessed for IP2X.
d) If the 12,5 mm probe can enter a part of the solar module's enclosure that contains electronic components, electrical connections or circuits, with minimal force, the solar module is estimated to fail the IP2x assessment.
e) If the 2,5 mm probe can enter a part of the solar module's enclosure that contains electronic components, electrical connections or circuits, the solar module is estimated to fail the IP3x assessment for ingress of solid foreign objects.
f) If the probe can enter an external jack, this is not considered a failure, unless it can enter the solar module's enclosure through the external jack. Document any failures with photographs and text.

NOTE Since the solar module junction box is not opened until the enclosure inspection steps below, it is not always possible to determine whether the DUT passes or fails this test until after the enclosure inspection steps are performed.

g) Enclosure inspection: Open the junction box or PV enclosure of the solar module to determine if a circuit board or other sensitive electronics are present. (This can be destructive.) If no circuit boards or sensitive electronics are present or if the junction box or PV enclosure is completely potted with silicone or similar sealant, the solar module is estimated to pass for protection from water ingress and the tester does not need to assess the solar module for water ingress. Simple screw terminals or a single diode, not soldered to a circuit board, need not be considered "sensitive electronic components". Any printed circuit board shall be considered "sensitive".
h) If a circuit board or other sensitive electronic components are present within the junction box or PV enclosure, the water ingress test should be conducted on a new solar module sample that has not been opened.

U.4.3.6 Calculations

No calculations are made for the ingress of solid foreign objects IP test performed through visual inspection.

U.4.4 Simplified IP preliminary inspection for ingress of water with harmful effects

U.4.4.1 General

The DUT component is visually inspected for protection against ingress of water with harmful effects to determine if it is likely to pass or fail with respect to the desired IP requirement. This method may be performed to estimate IP ratings IPx1, IPx3 and a modified IPx4.

NOTE The test used to assess solar modules for ingress of water with harmful effects is modified from the test described in IEC 60529. The modified IPx4 assessment for water ingress protection follows the same procedure to test for IPx4 as described in IEC 60529 with the exception of the angle of spray. In IEC 60529, the DUT is sprayed at angles ±180° from vertical, while in the modified method described below the DUT is sprayed at angles ±90° from vertical.

U.4.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Controlled water source.
- Camera.

U.4.4.3 Test prerequisites

This test is destructive. Do not perform any additional tests on the sample after testing. The sample tested should have not been altered in any way.

U.4.4.4 Apparatus

No apparatus is required for this test.

U.4.4.5 Procedure

U.4.4.5.1 Procedure for testing DUT component enclosures

a) Before the measurement, be sure that the DUT component is properly functioning and that it is sufficiently charged to check for functionality during the test.

b) The DUT component should be oriented in the way that it is most likely to be used. Reference the product's packaging, user's manual, and/or website to determine the orientation in which the DUT component is most likely to be used. Record the selected orientation.

c) If the DUT component requires passing IPx1, sprinkle water from the controlled water source over the DUT component so that the water drops are vertical to the DUT component. The water flow rate should be close to 1 mm/min. Let the water drip over the DUT component for 10 min while rotating the DUT component at approximately 1 rpm about its vertical axis. The distance between the water source and DUT component should be approximately 0,2 m.

d) If the DUT component requires passing IPx3, spray water from the controlled water source over the DUT component in all practical directions at an angle less than or equal to 60° from vertical. The water flow rate should be close to 10 l/min. Spray the water over the DUT component for approximately 1 min per square metre of enclosure surface area for a minimum of 5 min. The distance between the water source and the DUT should be between 0,3 m and 0,5 m.

e) After sprinkling or spraying water over the DUT component, dry the enclosure's exterior with a towel without moving the DUT component from its orientation during testing.

f) Enclosure inspection: While keeping the product in the same orientation from testing, open the enclosure with the proper screwdriver(s) or other devices. If any water is found within any compartment holding electronic components inside the enclosure, the DUT component does not pass the required IP class for ingress of water with harmful effects. Document with photographs and text.

U.4.4.5.2 Procedure for testing a product's external solar module (if applicable)

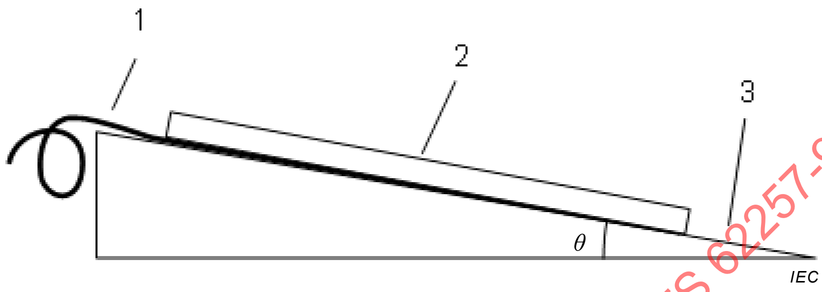
PV modules that have been tested according to and meet all requirements of IEC 61215 (all parts) need not be tested using this procedure. Test results provided by the manufacturer of the DUT may be accepted if the tests were performed at a laboratory accredited to perform the tests by a recognized accrediting body (e.g. an ILAC MRA signatory, an ILAC MRA signatory, to ISO/IEC 17025). Integrated solar modules that were tested as part of the DUT need not undergo this test, except in cases similar to the roof light described in c).

a) Be sure that before the measurement, the junction box of another sample's external solar module has already been opened to determine if a circuit board or other sensitive electronics are present. (This can be destructive.) If no circuit boards or sensitive electronics are present or if the junction box is completely potted with silicone or similar sealant, the solar module passes for protection from water ingress with harmful effects and the tester does not need to further assess the solar module for water ingress.

b) Before the measurement, be sure that the solar module is properly functioning and that the enclosure and/or junction box has never been opened previously.

c) Place the solar module with the active PV area facing up on a smooth, solid, flat surface that is tilted at a 10° angle from the horizontal (Figure U.1). The DUT should be placed in the least favourable orientation on the surface. The placement is intended to resemble common rooftop installations and allow for the possibility that water would run behind the module. This will typically be accomplished by allowing the PV cord to rest under the frame as could occur when installed. For a product that is designed for its solar module to be installed on the roof with the main unit attached inside the structure directly below, install the unit as per the product's instructions on a smooth, solid, flat surface.

NOTE 1 The least favourable orientation is typically the one in which the cable exits the junction box on the upslope side.



Key

1 Solar module cable

2 Solar module

3 Flat surface

θ 10° incline

Figure U.1 – Side view of the apparatus for testing an external solar module for protection against water ingress

d) Spray water from the controlled water source over the solar module in all practical directions (at angles up to 90° from vertical). The water flow rate should be close to 10 l/min. Spray the water over the solar module for approximately 1 min per square metre of enclosure surface area for a minimum of 5 min. The distance between the water source and the solar module should be between 0,3 m and 0,5 m.

e) After spraying water over the solar module, dry the solar module's exterior on all sides with a towel without tilting the solar module.

f) Open the junction box or the solar module's enclosure protecting its electronic components with the proper screwdriver(s) or other devices. (This can be destructive.)

NOTE 2 Some external solar modules do not have a typical junction box, but rather the connections are within an enclosure around the module itself.

g) After opening the solar module's junction box or enclosure, note if there are any unsealed penetrations around the solar module's frame through which water reaches the active material of the solar module.

h) If no water is found inside the junction box, enclosures or any unsealed penetrations, the solar module is estimated to pass for modified IPx4 protection from water ingress with harmful effects.

i) If any water is found on electronic components inside the junction box, enclosures or any unsealed penetrations, document with photographs and text. For the DUT to pass, electronic components and the active material of the PV module shall be adequately protected according to the technical aspects outlined in Annex V. Adequate protection is evaluated by an organization with expertise in product design, failure analysis, energy systems, and general engineering practices. This requirement cannot be met through labelling or consumer-facing documentation.

U.4.4.6 Calculations

No calculations are made for the ingress of water with harmful effects IP test performed through visual inspection.

U.5 Reporting

Report the following in the water exposure and physical ingress protection test report.

- Metadata:
  – report name;
  – procedure(s) used;
  – DUT manufacturer;
  – DUT name;
  – DUT model number;
  – name of test laboratory;
  – approving person;
  – date of report approval;
  – component name.
- Results for tested DUT aspects for samples 1 through n:
  – IP levels tested and ratings for the ingress of solid foreign objects;
  – IP levels tested and ratings for the ingress of water with harmful effects;
  – Result of enclosure inspection of PV module junction box; specify if a circuit board or other sensitive electronics are present and if junction box is completely potted with silicone or similar sealant.
  – pass/fail for the IP rating for the ingress of solid foreign objects, if applicable;
  – pass/fail for the IP rating for the ingress of water with harmful effects, if applicable.
- Comments:
  – individual comments, as necessary, for samples 1 through n;
  – overall comments, as necessary, for collective set of samples 1 through n.
- Figures:
  – photographs to evidence the ingress of solid foreign objects or water, as necessary.

Annex V
(normative)

Level of water protection

V.1 Background

The enclosure of a solar lighting product can prevent water and solid foreign particles from coming in contact with internal electronic circuits, components, wires, and battery components (electronic components). The degree of protection provided by the enclosure is determined through ingress protection (IP) as outlined in Annex U. IP testing does not, however, assess the actual or potential damage caused to electronic components by water exposure.

Alternate means of protection exist for electronic components exposed to water. These alternate means can allow manufactures to reduce the cost of their product(s) to the consumer, thereby increasing consumer access to modern lighting technology. Annex V outlines procedures for assessing overall water exposure protection based on IP test results combined with alternate protection means.

Annex V does not attempt to characterize the damage caused by water exposure to sensitive electronic components. Rather, Annex V provides a framework to assess the likelihood, during the service life of a product, that unprotected internal electronic components will be exposed to water that could negatively affect product operation.

V.2 Test outcomes

The procedures in Annex V may be used to establish a DUT component's water exposure protection level. The five levels are:

a) No protection – The product has no water protection and could be damaged by any water exposure.
b) Occasional rain – The product can be exposed to occasional light rain without damage.
c) Frequent rain – The product can be exposed to frequent rain without damage.
d) Permanent rooftop installation for PV modules – (solar modules only) when installed on a roof, the product's solar module can be exposed to frequent heavy rain without damage.
e) Permanent outdoor exposure – The product can be exposed to frequent heavy rain without damage.

The water exposure and physical ingress protection test outcomes are listed in Table V.1.

Table V.1 – Water exposure and physical ingress protection test outcomes

Metric	Reporting units	Related aspects	Notes
Overall level of water protection	Qualitative (from list above)	4.2.3.1 Water protection – enclosure 4.2.3.2 Water protection – circuit protection and drainage 4.2.10.1 Product and manufacturer information 4.2.2.7 Packaging and user's manual information	This is the level of water protection that is achieved when considering user instructions and labels in addition to the technical elements of the product.
Technical level of water protection	Qualitative (from list above)	4.2.3.1 Water protection – enclosure 4.2.3.2 Water protection – circuit protection and drainage 4.2.3.4 Water protection – solar module 4.2.10.1 Product and manufacturer information	This is the level of water protection provided by only the technical elements of the product – the enclosure, circuits, and other physical aspects.
Enclosure-only level of water protection	Qualitative (from list above)	4.2.3.1 Water protection – enclosure 4.2.3.4 Water protection – solar module	This only refers to the IP rating of the enclosure.

V.3 Related tests

Annex V is related to the water exposure and physical ingress protection test (Annex U) and visual screening (Annex F).

V.4 Laboratory requirements

The assessments in Annex V are typically done by an organization with broad experience in the off-grid lighting sector, including technical and field experience.

Assessments regarding the technical level of water protection should be completed by an organization with expertise in product design, failure analysis, energy systems, and general engineering practices.

Assessments of the overall level of water protection (incorporating consumer labelling information) should be completed by a committee with expertise in communication and end user behaviour in the off-grid lighting market.

V.5 Procedure

V.5.1 General

The following procedures establish a product's level of water protection. All of the procedures in Annex V require an IP test result as specified in Annex U. Additional factors, such as product labelling or specific product design features, may also be considered when determining the level of water protection.

V.5.2 Level of water protection for enclosure only

This procedure uses a product's IP rating, and only its IP rating, to determine the level of water protection. No other tests are required. The level of water protection by IP rating is determined according to Table V.2.

Table V.2 – Enclosure-only level of water protection requirements

Enclosure level of water protection	IP rating requirement
No protection	IPx0
Occasional rain	IPx1
Frequent rain	IPx3
Permanent rooftop installation for PV modules	Modified IPx4
Permanent outdoor exposure	IPx5
NOTE The modified IPx4 assessment for water ingress protection follows the same procedure to test for IPx4 as described in IEC 60529 with the exception of the angle of spray. IEC 60529 requires that the DUT be sprayed at angles ±180° from vertical, while the modified method described below requires that the DUT be sprayed at angles ±90° from vertical.	

V.5.3 Level of water protection from technical aspects

V.5.3.1 General

This procedure describes an assessment of the technical aspects of a product to establish the level of water protection that is achieved by a product from an engineering design standpoint. The aspects included in this holistic assessment are:

- the enclosure,
- circuit design and protection,
- internal draining,
- manufacturing processes, and
- other innovative approaches.

The overall product design shall be assessed on a case-by-case basis to determine the technical level of water protection. The assessment includes information from lab tests, field experience, and statements supplied by the manufacturer.

The manufacturer is responsible for providing information about product design and manufacture that is part of a water protection strategy. This information is used to establish a technical level of water protection for the product. Manufacturers that successfully demonstrate additional water protection may have the enclosure-only level of water protection category (Table V.2) increased by one level. For example, a product may move from "no protection" to "occasional rain," from "occasional rain" to "frequent rain," or from "frequent rain" to "permanent outdoor exposure" (Table V.3).

Solar modules that fail the modified IPx4 test (U.4.4.5.2) may also achieve the permanent rooftop installation for PV modules category if the manufacturer successfully demonstrates that the sensitive electronic components (as defined in U.4.3.5.2) have additional water protection.

Table V.3 – Adjusted level of water protection for products with additional technical water protection

Enclosure-only level of water protection	Technical level of water protection	Requirement
No protection (IPx0)	Occasional rain	Assessment indicates the enclosure and other technical aspects will protect from occasional rain, equivalent to IPx1 protection.
Occasional rain (IPx1)	Frequent rain	Assessment indicates the enclosure and other technical aspects will protect from frequent rain, equivalent to IPx3 protection.
Frequent rain (IPx3)	Permanent outdoor exposure	Assessment indicates the enclosure and other technical aspects will protect from permanent outdoor exposure, typically requiring an enclosure with at least IPx3 protection and additional circuit protection.
The solar module failed the modified IPx4 test (U.4.4.5.2)	Permanent rooftop installation for PV modules (Modified IPx4)	Assessment indicates the enclosure and other technical aspects will protect the module from permanent outdoor exposure in the context of a rooftop installation, equivalent to a modified IPx4 protection.

V.5.3.2 Gathering product design information from lab testing

Results and observations from the following tests are relevant for this assessment:

- Annex U (physical and water ingress protection test);
- Annex F (visual screening).

V.5.3.3 Gathering field and experiential information

Information from field trials and using samples of the product in a variety of environmental conditions may supplement other information and provide unique, targeted insights.

V.5.3.4 Gathering product design information from the manufacturer

V.5.3.4.1 General

The manufacturer is responsible for providing information about product design and manufacturing that is part of a water protection strategy.

Ask the manufacturer to provide product design data and explanations justifying a technical level of water protection. This data should include the following.

a) Written descriptions of the product design elements and materials that will protect the circuit components from water exposure damage.
b) Photographs or video clips showing the relevant design features.
c) Specification sheets for materials used for protection.
d) Written descriptions of protection for each circuit component in V.5.3.4.2.
e) Written descriptions of relevant manufacturing processes employed for circuit component protection.
f) Written descriptions of quality control processes relevant to circuit component protection.
g) Descriptions of tests performed by the manufacturer to demonstrate protection of circuit components from damage caused by water exposure.

V.5.3.4.2 Circuit design information

The relevant circuit components to provide information about include:

a) printed circuit boards,
b) component solder joints,
c) wire to board solder joints,
d) wire to board connectors,
e) wire to battery terminal solder joints,
f) wire to battery terminal connectors,
g) LED components, and
h) switch components.

V.5.3.4.3 Manufacturing quality control information

The manufacturer should describe quality control processes that are in place to ensure consistent application of coatings, use of gaskets, etc.

V.5.3.4.4 Water resistant coatings

Polymer coatings on printed circuit boards, wire solder joints, connectors, and electronic components have been shown to reduce or eliminate the negative effects of water exposure to live electronic circuit elements. In order to be effective, these coatings shall be properly applied to clean substrates in a quality controlled manufacturing process.

V.5.3.4.5 Novel design approaches

Other means are available to protect electronic components from water exposure damage. For example, the product could be designed to allow water to drain from the case and not collect on circuit components. These novel approaches shall be outlined and explained by the manufacturer with supporting documentation justifying a level of water protection as outlined in Table V.3.

V.5.3.5 Assessment of technical level of water protection

The final assessment of the technical level of water protection should include information from each of the sources listed above.

The assessment details should include an evaluation of protection for critical components on a piece by piece basis. Reference should be provided where appropriate to the manufacturer supplied data. See Table V.4 for an example product where the manufacturer is using conformal coatings and silicone sealants to protect internal circuit components:

Table V.4 – Example detailed assessment supporting technical level of water protection

Circuit component	Method of protection	Manufacturer reference material	Notes
Printed circuit boards	Conformal coating	Pcb_coating1.jpg	
Component solder joints	Conformal coating	Pcb_coating2.jpg	
Wire to board solder joints	None		Wire to board solder joints are not sealed or encapsulated
Wire to board connectors	N/A		None used
Wire to wire connectors	N/A		None used
Wire to battery terminal solder joints	Silicone encapsulant	Battery_coating1.jpg	
Wire to battery terminal connectors	N/A		None used
LED components	Case design	LED_lens1.jpg	Manufacturer statement
Switch components	None		Switch is not sealed

V.5.4 Overall level of water protection

V.5.4.1 General

The overall level of water protection assessment accounts for consumer labelling and instructions in combination with either the technical or enclosure-only level of water protection.

If appropriate consumer information is provided, the level of water protection is increased relative to the technical or enclosure-only findings.

This assessment shall not result in an increase to the permanent outdoor exposure level, since products that are permanently mounted outdoors are not protected from water by the end user.

Table V.5 lists the requirements for assessing the overall level of water protection.

Table V.5 – Overall level of water protection requirements

Technical level of water protection or Enclosure-only level of water protection	Overall level of water protection without consumer labelling	Overall level of water protection with consumer labelling
No protection	Same	Occasional rain
Occasional rain	Same	Frequent rain
Frequent rain	Same	Same
Permanent rooftop installation for PV modules	Same	Same
Permanent outdoor exposure	Same	Same

V.5.4.2 Assessing consumer labels and information

V.5.4.2.1 General

Subclause V.5.4.2 describes a framework for assessing consumer labels and instructions for appropriateness.

The overall requirement for consumer labels and instructions is that the communication strategy should be designed and implemented so that a typical user understands both the degree of protection from water for the product and what they should do to maintain the product in an instance of water exposure.

The factors to consider are:

- language and literacy of expected end users,
- prominence of information, and
- clarity of presentation.

V.5.4.2.2 Gathering information on water protection messages

Information from visual screening (Annex F) and additional inspection of the packaging should be used to establish the messages to buyers and end users concerning water protection.

Potential locations (not inclusive) of information:

- Labels and pictograms on packaging.
- Instructions in the users manual.
- Information on the warranty card.
- Advertising and media.

V.6 Reporting

Report the following in the equivalent IP water exposure protection report.

- Metadata:
  - name of test;
  - procedures used to qualify for level of water protection (IP rating, labelling and/or product design);
  - DUT manufacturer;
  - DUT name;
  - DUT model number;
  - name of test laboratory;
  - approving person;
  - date of report approval.
- Main findings:
  - overall level of water protection;
  - technical level of water protection;
  - enclosure-only level of water protection.
- Supporting information:
  - IP rating for enclosure;
  - description of other technical approaches (if applicable);
  - suitability of consumer labelling for communicating level of technical water protection and steps to protect the product.
- Manufacturer supplied data (Include all manufacturer supplied data in the test report).
- Assessment of manufacturer supplied data.

- Comments:
  - individual comments, as necessary, on the specific material provided by the manufacturer demonstrating an equivalent IP level protection;
  - overall comments, as necessary, for the collective set of materials provided by the manufacturer demonstrating an equivalent level of IP protection.

Annex W
(normative)

Mechanical durability test

W.1 Background

The mechanical durability test captures the DUT's robustness in withstanding the rigors of expected daily usage. The mechanical durability test includes the drop test, the switch and connector test, the gooseneck and moving part test (if applicable), and the strain relief test (if applicable). This test should be conducted on all appliances included with the DUT, in addition to the primary components of the DUT.

During the drop test, the DUT is dropped from a height of 1 m onto a concrete surface. The number of times each sample is dropped depends on the type of component and number of samples required for testing. During the switch and connector test, each switch and/or connector of the DUT sample is cycled. The gooseneck and moving part test is only conducted on DUT samples with goosenecks or moving parts, and it requires the gooseneck or other moving part of the DUT sample to be bent through its feasible range of usage. Switches, connectors, goosenecks and moving parts that are intended for regular use are cycled 1 000 times, while any of these mechanisms that are expected to be used primarily during installation are cycled only 100 times. (Product specifications may require additional cycles.) The strain relief test involves attaching a 2 kg weight onto any permanently attached cable ends (i.e. cable ends without connectors) for 60 s at three different strain angles. Throughout all four tests, the DUT sample is examined for functionality, damage, and the presence of user safety hazards.

W.2 Test outcomes

The test outcomes of the mechanical durability test are listed in Table W.1.

Table W.1 – Mechanical durability test outcomes

Metric	Reporting units	Related aspects	Notes
Drop test sample functionality	Yes/no	4.2.3.7 Drop resistance	--
Drop test user safety hazard(s) present	Yes/no, description	4.2.3.7 Drop resistance	--
Drop test sample damage	Yes/no, description	4.2.3.7 Drop resistance	--
Switch and connector test cycles achieved	Cycles	4.2.3.9 Connector durability 4.2.3.10 Switch durability	--
Switch and connector test sample functionality	Yes/no	4.2.3.9 Connector durability 4.2.3.10 Switch durability	--
Switch and connector test user safety hazard(s) present	Yes/no, description	4.2.3.9 Connector durability 4.2.3.10 Switch durability	--
Switch and connector test sample damage	Yes/no, description	4.2.3.9 Connector durability 4.2.3.10 Switch durability	--
Gooseneck/moving part test cycles achieved	Cycles	4.2.3.8 Gooseneck and moving part durability	
Gooseneck/moving part test sample functionality	Yes/no	4.2.3.8 Gooseneck and moving part durability	--
Gooseneck/moving part test user safety hazard(s) present	Yes/no, description	4.2.3.8 Gooseneck and moving part durability	--

Metric	Reporting units	Related aspects	Notes
Gooseneck/moving part test sample damage	Yes/no, description	4.2.3.8 Gooseneck and moving part durability	--
Strain relief time achieved for each weight and strain angle	Seconds (s)	4.2.3.11 Strain relief durability	--
Strain relief test sample functionality	Yes/no	4.2.3.11 Strain relief durability	--
Strain relief test user safety hazard(s) present	Yes/no, description	4.2.3.11 Strain relief durability	--
Strain relief test sample damage	Yes/no, description	4.2.3.11 Strain relief durability	--

W.3 Related tests

Annex W is not related to any of the other annexes.

For lighting appliances without batteries, the mechanical durability tests of IEC TS 62257-12-1 may be used in place of Annex W.

W.4 Procedures

W.4.1 Drop test

W.4.1.1 General

The DUT sample is dropped on six different sides from a height of 1 m onto a level concrete surface and examined for functionality, user safety hazards, and damage. The number of times each sample is dropped depends on the type of component and number of samples required for testing.

W.4.1.2 Equipment requirements

The camera is required.

W.4.1.3 Test prerequisites

At the start of the drop test, the DUT samples shall be minimally altered (ideally unaltered), fully functional, and have sufficient charge to check for functionality throughout the test.

If the DUT samples have multiple units or components, determine an appropriate order to test the parts that need to undergo the drop test. Portable DUT samples or sample components (e.g., torches, lanterns, desktop lamps, etc.) shall be drop tested. DUT samples or sample parts that are portable but are expected to meet less rigorous durability standards (non-lighting appliances such as radios, razors, portable fans, etc.) should be drop tested under less rigorous criteria as outlined in the following sections.

DUT samples or sample parts that are intended to be stationary (e.g. separate control boxes, lamp units intended to be mounted) and PV modules do not need to be drop tested. Portable appliances that are not typically expected to meet the same durability standards, such as TVs, do not need to be drop tested.

This test is destructive. Do not carry out additional tests with the tested samples.

W.4.1.4 Apparatus

The drop test should be performed in a location with a smooth, level concrete surface with ample space to avoid personal injury from a DUT projectile (e.g. glass or plastic shards). A height of 1 m shall be established from the ground to begin the drop.

W.4.1.5 Procedure

The following steps shall be followed.

a) Drop the DUT sample from a height of 1 m as indicated below:

   1) For testing portable lighting components, drop the DUT sample six times – once on each of the six "faces" of the product, taking care to drop the DUT sample on parts deemed mechanically weak (e.g. handles, loose parts). Using the three-dimensional system shown in Figure W.1, the DUT should be rotated after each drop as follows: The DUT sample is rotated by 90° along the x-axis following each of the first three drops, rotated by 90° along the y-axis from its initial drop orientation for the fifth drop, and rotated 180° along the y-axis from its fifth drop orientation for the sixth drop.

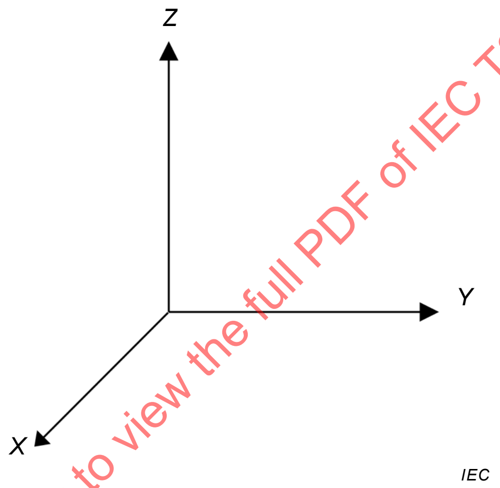


Figure W.1 – Three-dimensional Cartesian coordinate system for drop test reference

   2) For testing non-lighting portable appliances (radios, razors, etc.):

      i) If the product specification requires testing six samples, drop each sample two times—once on each of two of the six "faces,", taking care to drop the sample on parts deemed mechanically weak (e.g., handles, loose parts, etc.). Rotate the angle of drop between samples so that after the sixth sample, all six sides have been tested twice.

      ii) If the product specification requires testing four samples:

         – Drop each sample two times—once on each of two of the six "faces" of the product, taking care to drop the sample on parts deemed mechanically weak (e.g., handles, loose parts, etc.). Rotate the angle of drop between samples so that after the third sample, all six sides have been tested once.

         – The fourth sample should be used for verification. If any of the first three samples sustained major damage during drop testing, the sides on which they were dropped should be re-tested with the fourth sample. If none of the first three samples sustained major damage, the fourth sample may be dropped on two sides with parts deemed mechanically weak.

      iii) If the product specification requires testing two samples (e.g. when conducting two concurrent ISM tests or an AVM test), drop each sample two times—once on each of two of the six "faces," taking care to drop the sample on parts deemed mechanically weak (e.g., handles, loose parts, etc.). Rotate the angle of drop between samples so that after the second sample, four of the six sides are tested.

iv) If the product specification requires testing only one sample (such as for the ISM), drop the sample six times—once on each of the six "faces," taking care to drop the sample on parts deemed mechanically weak (e.g., handles, loose parts, etc.).

It is recommended to drop the non-lighting appliance sample six times during a one-sample test for informative purposes only. If the test is being used for other purposes, such as program entry or qualification for subsidies, it may be more appropriate to only consider the results from the first two drops.

For radios, the antenna should not be extended.

b) After each of the drops, examine the DUT for functionality, the presence of user safety hazards (e.g. glass shards, short circuits), and damage and record the observations with descriptions and photographs. Superficial damage (minor scrapes or "popped off" components that can easily be put back in place) shall not be noted; only note damage that is permanent and non-superficial. Similarly, if only simple repairs are required to maintain the functionality of the product (a broken casing can be taped or a component can easily be put back into place), then the sample shall still be considered functional.

W.4.1.6 Calculations

No calculations are made for the drop test.

W.4.2 Switch and connector test

W.4.2.1 General

Each DUT sample switch and/or connector intended for regular use is cycled 1 000 times (unless otherwise specified in the product specification) and examined for functionality, user safety hazards, and damage. Each DUT sample switch and/or connector that is expected to be used primarily during installation is cycled 100 times (unless otherwise specified in the product specification) and examined for functionality, user safety hazards, and damage.

The following examples may be used as guidelines to determine which category applies to each switch and/or connector.

- Switches/connectors used primarily during installation:
  - A safety disconnect switch or circuit breaker that is turned on during installation and only turned off for maintenance
  - Connectors dedicated to light points that are specifically designed and explicitly stated to be for permanent installation and are not intended to be relocated after installation
  - Connections between a light point and an extension cable.
- Switches/connectors intended for regular use:
  - Connectors to be used in USB ports
  - Switches for light points or ports
  - Main power switches if unit is intended to be regularly turned off and on.

W.4.2.2 Equipment requirements

A camera is required.

W.4.2.3 Test prerequisites

At the start of the switch and connector test, the DUT samples shall be fully functional and have sufficient battery charge to check for functionality throughout the test.

This test is destructive. Do not carry out additional tests with the tested samples, with the exception of the gooseneck and moving parts test, the strain relief test, and the drop test (if the DUT samples are still functional after the switch and connector test).

W.4.2.4 Apparatus

No apparatus is required for the switch and connector test.

W.4.2.5 Procedure

The following steps shall be followed.

a) Cycle each of the DUT sample's unique switch(es) and/or connector(s) 1 000 times or 100 times, or as specified in the product specification, depending on the expected use of the switch or connector. This test can be done manually or by using a mechanical device. A unique switch or connector is one that is not identical to any other switch or connector of the DUT. If the DUT has two or more identical switches or connectors, only one of those identical switches is considered unique and shall be cycled. A cycle consists of actuating a switch through all possible positions or mechanical states or fully inserting and removing a connector; at the end of the cycle, the switch or connector should be in the same mechanical state as at the start of the cycle. For example:
   - For a slide, rocker, rotary, or toggle switch with three positions, a cycle could start in position 1 and cycle through positions 2, 3, 2, and back to 1;
   - For a momentary pushbutton switch, a cycle consists of pressing and releasing the button once, even if the product changes state (e.g., brightness setting);
   - For a mechanically latching (push-on-push-off) switch, a cycle consists of pressing and releasing the button twice to return the switch to its initial mechanical state.

b) If the DUT has at least two identical switches or connectors and more than one DUT is being tested (e.g. six DUTs are tested using the QTM), the selection of the unique switch or connector to be tested within the set of identical switches or connectors on any single DUT shall rotate between the identical switches or connectors (e.g. if a product has six identical barrel plug sockets and the product is undergoing QTM testing, each DUT should have a different barrel plug socket tested).

c) If damage is observed during the testing, record the observations with descriptions and photographs. Superficial damage (minor scrapes or "popped off" components that can easily be put back in place) shall not be noted; only note damage that is permanent and non-superficial.

d) Continue testing until the product fails to function, a user safety hazard develops (e.g. short circuit), or targeted number of cycles are achieved. If potential damage cannot instantly be observed during testing (e.g. damage to a PV module or mobile device connector), check for DUT sample functionality after every 100 cycles.

W.4.2.6 Calculations

No calculations are made for the switch and connector test.

W.4.3 Gooseneck and moving part test

W.4.3.1 General

If applicable, each DUT sample's gooseneck or other moving part intended for regular use is bent 1 000 times (unless otherwise specified in the product specification) through its feasible range of usage. Each DUT sample's gooseneck or other moving part that is expected to be used primarily during installation is bent 100 times (unless otherwise specified in the product specification) through its feasible range of usage.

The following examples may be used as guidelines to determine which category applies to each gooseneck or moving part.

- Moving parts used primarily during installation:
   - Parts that are not critical to the function of the product
   - Hinged joints adjusted only during installation.

- Moving parts intended for regular use:
  - Hinges and goosenecks that include wires
  - Parts that are intended to be adjusted regularly
  - Radio dials and dials for dimming lights.

W.4.3.2 Equipment requirements

A camera is required.

W.4.3.3 Test prerequisites

At the start of the gooseneck and moving part test, the DUT samples shall be fully functional and have sufficient battery charge to check for functionality throughout the test.

This test is destructive. Do not carry out additional tests with the tested samples, with the exception of the switch and connector test, the drop test, and the strain relief test (if the DUT samples and PV modules are still functional after the gooseneck and moving parts test).

W.4.3.4 Apparatus

No apparatus is required for the gooseneck and moving part test.

W.4.3.5 Procedure

The steps shall be followed.

a) Bend the DUT sample’s gooseneck or moving part 1 000 times through its feasible range of usage 1 000 times or 100 times, or as required by the product specification, depending on the expected use of the gooseneck or moving part. This can be done manually or by using a mechanical device.

b) If damage is observed during the testing, record the observations with descriptions and photographs. Superficial damage (minor scrapes or "popped off" components that can easily be put back in place) shall not be noted; only note damage that is permanent and non-superficial.

c) Continue testing until the product fails to function, a user safety hazard develops (e.g. short circuit), or the targeted number of bends is achieved.

W.4.3.6 Calculations

No calculations are made for the gooseneck and moving part test.

W.4.4 Strain relief test

W.4.4.1 General

If applicable, each DUT samples’ permanent cable ends (i.e. cable ends without connectors) are subjected to a 2 kg weight for 60 s at various strain angles.

PV modules that have been tested according to and met all requirements of the robustness of terminations test for type A (wire or flying lead) terminations (10.14) of IEC 61215, whichever is applicable, need not be tested using this procedure, provided that the junction box or cable entry has not been modified from the version that was tested. Test results provided by the manufacturer of the DUT may be accepted if the tests were performed at a laboratory accredited to perform the tests by a recognized accrediting body (e.g. an ILAC MRA signatory, to ISO/IEC 17025).

W.4.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Camera.
- Clamp or other means of holding DUT components in place.
- Calibrated 2 kg weight.
- Protractor or other means of determining the strain angle.
- Stopwatch.

W.4.4.3 Test prerequisites

At the start of the strain relief test the DUT samples and their PV modules should be fully functional and have sufficient battery charge to check for functionality throughout the test.

This test is destructive. Do not carry out additional tests with the tested samples, with the exception of the switch and connector test, the drop test, and the gooseneck and moving part test (if the DUT samples and PV modules are still functional after the strain relief test).

W.4.4.4 Apparatus

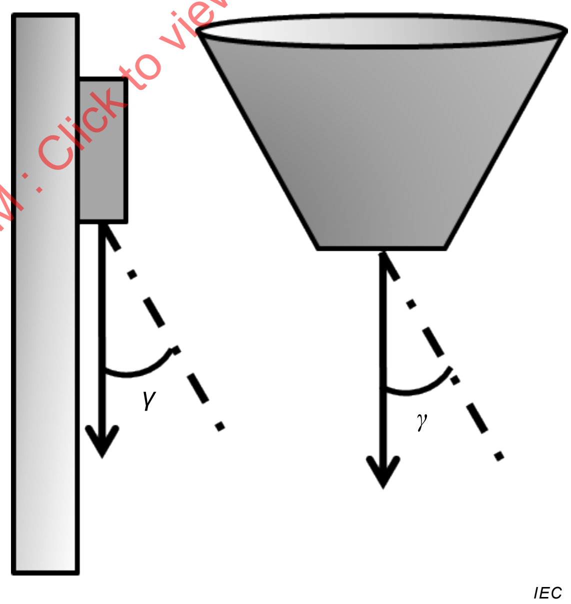
A clamp or other means of securely holding a 2 kg weight and the DUT and/or the DUT's PV module in place is required.

W.4.4.5 Procedure

The following steps shall be followed.

a) Determine which DUT cable ends are permanently attached (i.e., do not have a connector end) to the DUT and/or PV module.

b) Clamp the DUT, DUT component, or PV module in place and attach the 2 kg weight to the cable so that the strain angle (γ) is 0° relative to the direction from which the cable protrudes from the DUT, DUT component, or PV module (see Figure W.2).



Key

γ Cable strain angle (°)

Figure W.2 – Cable strain angle (γ) schematics for a PV module junction box (left) and a separate light point (right)

c) Observe the DUT, DUT component, or PV module for 60 s. After 60 s, record the DUT's, DUT component's, or PV module's functionality, any physical damage, and the presence of safety hazards. Superficial damage (minor scrapes or "popped off" components that can easily be put back in place) should not be noted; only note damage that is permanent and non-superficial.

d) Repeat steps b) and c) for strain angles of 45° and 90°.

e) Repeat step b) through step d) for each permanently-attached cable end found in step a).

W.4.4.6 Calculations

No calculations are made for the strain relief test.

W.5 Reporting

Report the following in the mechanical durability test report.

- Metadata:
  - report name;
  - procedure(s) used;
  - DUT manufacturer;
  - DUT name;
  - DUT model number;
  - name of test laboratory;
  - approving person;
  - date of report approval.
- Results for tested DUT aspects for samples 1 through n:
  - drop tests:
    a) functions after each drop (pass/fail);
    b) no damage present after each drop (pass/fail);
    c) no user safety hazard present after each drop (pass/fail).
  - switch/connector tests:
    a) cycles achieved for each switch and/or connector;
    b) functions after test (pass/fail);
    c) no damage present after test (pass/fail);
    d) no user safety hazard present after test (pass/fail).
  - gooseneck and moving part test:
    a) cycles achieved for the gooseneck/moving part;
    b) functions after test (pass/fail);
    c) no damage present after test (pass/fail);
    d) no user safety hazard present after test (pass/fail).
  - strain relief test:
    a) time achieved for each strain angle (s);
    b) functions after test (pass/fail);
    c) no damage present after test (pass/fail);
    d) no user safety hazard present after test (pass/fail).
- Comments:
  - individual comments, as necessary, for samples 1 through n for each test;
  - overall comments, as necessary, for collective set of samples 1 through n for each test.

- Figures:
  – photographs of observed user safety hazards and/or DUT sample damage.

Annex X
(informative)

Reserved

Annex X is reserved as a placeholder.

Annex Y
(informative)

Photometer box for relative luminous flux measurements

Y.1 Background

Annex Y includes plans and instructions for building a photometer box (Figure Y.1 and Figure Y.2) – an optical cavity for relative luminous flux measurements that can be used to measure the run time or lumen maintenance of lighting products, but not the absolute luminous flux of lighting products. Photometer boxes can be built for much lower cost than integrating spheres or similar equipment.

The box is a cube that is painted with high-reflectivity, matte white paint inside. The DUT is placed in the centre of the box either by hanging from the top or on a stand. An illuminance meter is placed in one of the corners or sides with a baffle blocking direct light from the DUT. Because the illuminance meter only "sees" reflected light, the measurements of relative illuminance in time are less sensitive to the arrangement of the lighting device and therefore more robust.

For a given product in a fixed orientation, the reading from the illuminance meter is directly proportional to the luminous flux of the DUT but does not represent the absolute luminous flux. The same photometer box and illuminance meter shall be used for any given test, since different boxes and illuminance meters will result in different relative light outputs.

IEC

The photometer box depicted here has two screens (baffles); only one screen, in front of the illuminance meter head, is required per Clause Y.3, step y). In this example, the required screen is in the lower left corner of the image.

Figure Y.1 – Interior view of a completed photometer box

IEC

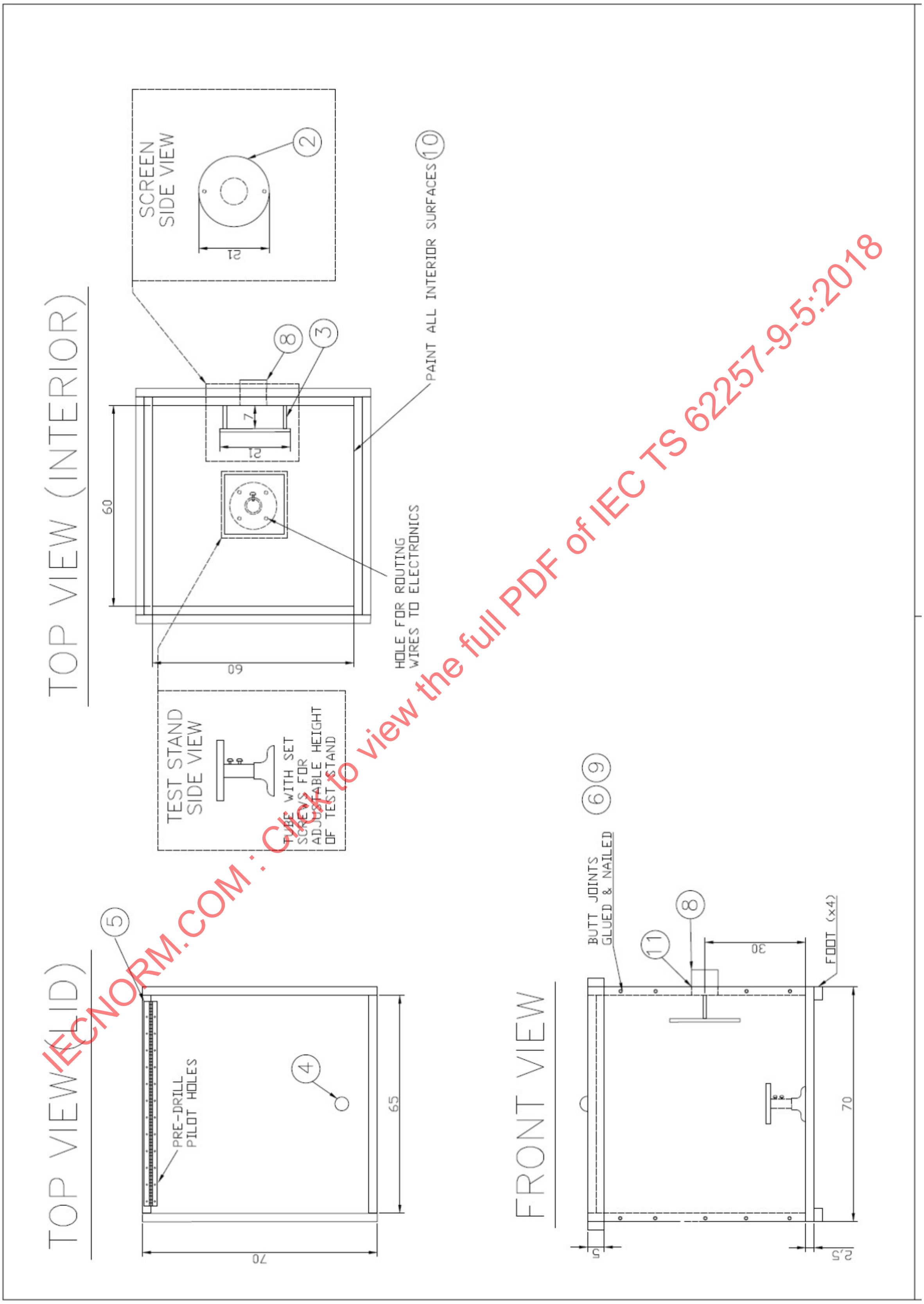
In this example, the illuminance meter head is located in the corner of the box. The illuminance meter head can also be placed on the side of the box to simplify construction.

Figure Y.2 – Exterior view of completed photometer box

Y.2 Plans

Plans for a photometer box are given in Figure Y.3 and Figure Y.4.

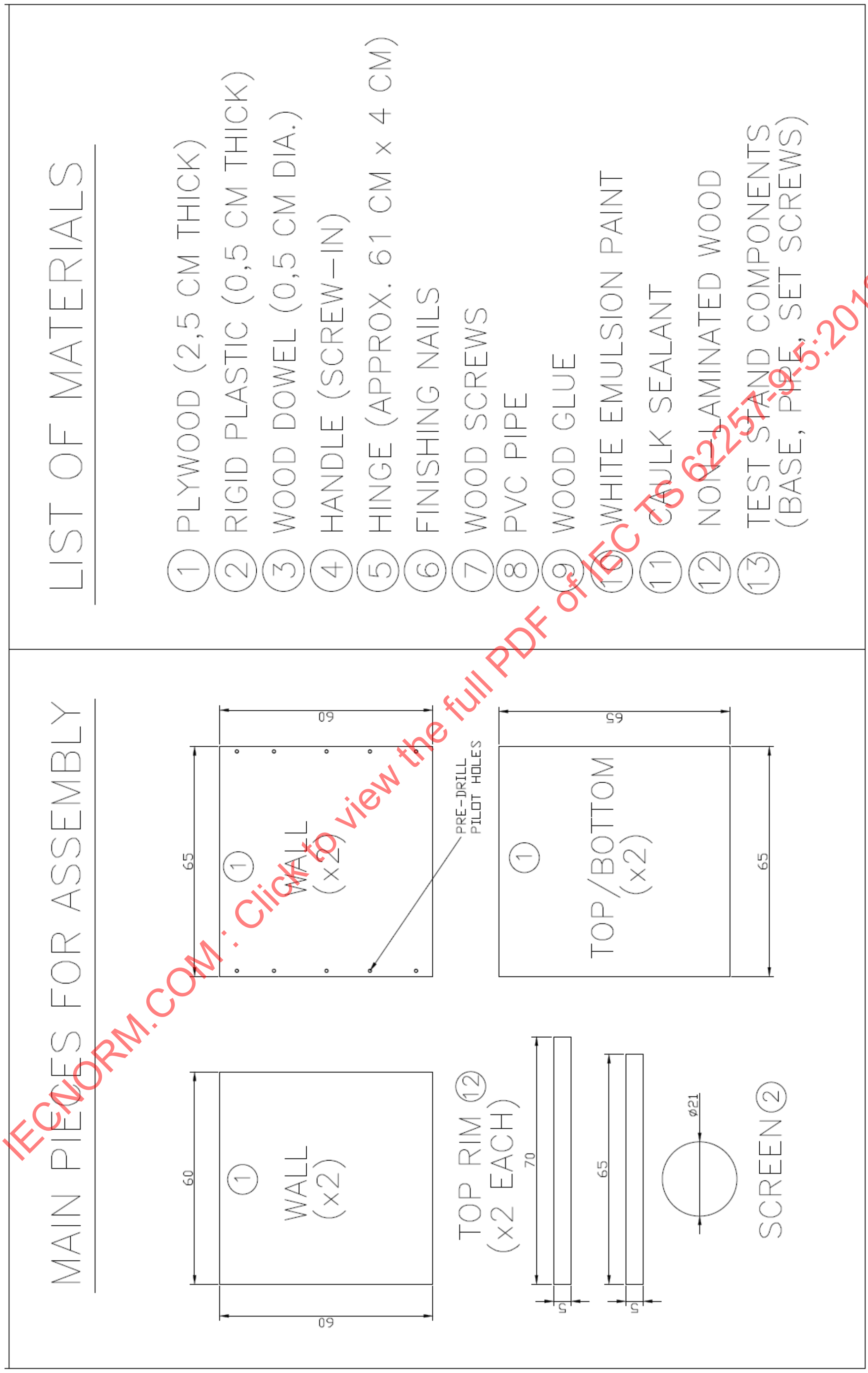
Dimensions in centimetres



IEC

Figure Y.3 – Photometer box dimensions

Dimensions in centimetres



IEC

Figure Y.4 – Photometer box assembly pieces and list of materials

Y.3 Instructions for construction

The following steps shall be followed.

a) Cut the pieces in Figure Y.4 to the dimensions shown in Figure Y.3 – Use a table saw if available.

b) Pre-drill pilot holes on 65 cm × 60 cm wall pieces.

c) Apply glue along 2,5 cm × 60 cm area of wall pieces with pilot holes.

d) Use four clamps (one at top, one at bottom for each side) to hold the four walls together as shown on in the top view of Figure Y.3.

e) Drive finish nails into pre-drilled pilot holes.

f) Allow 12 h for glue to cure.

g) Remove clamps.

h) Check butt joints for structural integrity.

i) Apply glue to bottom edges of walls.

j) Align and clamp bottom piece to walls.

k) Allow 12 h for glue to cure.

l) Remove clamps.

m) Check for structural integrity.

n) Cut 4 cm × 4 cm feet (as shown in front view of Figure Y.3) and glue to four exterior corners of bottom piece. The weight of the photometer box will hold the feet in place while the glue cures.

o) Apply glue to 2,5 cm width of "top rim" pieces along top outside perimeter of walls.

p) Place "top rim" pieces on outside walls as shown in Figure Y.3 and clamp in place.

q) Allow 12 h for glue to cure.

r) Remove clamps.

s) Check for structural integrity.

t) Drill hole in corner or side of photometer box for placement of PVC section – Use a hole saw if available.

u) Cut PVC pipe to appropriate length and mitre cut if necessary to tightly fit against hole in photometer box.

v) Affix PVC section to photometer box with caulk sealant, making sure to seal against all possible light intrusion at joint.

w) Assemble test stand and attach with wood screws to centre bottom of photometer box as shown in top view.

x) Cut plastic screens and drill holes for insertion of dowels.

y) Drill holes at appropriate angles and locations for screen dowels, refer to top view (interior). Only one screen is required, between the DUT and the illuminance meter head.

z) Insert screen dowels into holes in photometer box walls. No glue should be required.

aa) Place top lid piece onto photometer box.

bb) Align hinge as shown in top view (lid).

cc) Pre-drill pilot holes and attach hinge with wood screws.

dd) Pre-drill hole for handle (as shown in top view) and attach to lid.

ee) Paint all interior surfaces of photometer box with white emulsion paint, matte finish. Several light coats are recommended (at least five coats).

Annex Z
(informative)

Reserved

Annex Z is reserved as a placeholder.

Annex AA
(informative)

Reserved

Annex AA is reserved as a placeholder.

Annex BB
(normative)

Battery durability test

BB.1 Background

The battery durability test aims to identify batteries unsuitable for the application in stand-alone renewable energy products. The procedures are related to storage of the stand-alone renewable energy products.

In general terms, the storage procedures use methods to accelerate the ageing mechanisms occurring during storage. This method enables the identification of batteries which age prematurely and are therefore unsuitable for use in stand-alone renewable energy products.

BB.2 Test outcomes

The test outcomes of the battery durability test are listed in Table BB.1.

Table BB.1 – Battery durability test outcomes

Metric	Reporting units	Related aspects	Notes
Capacity loss from storage (δC)	Percentage (%)	4.2.5.3 Battery storage durability	

BB.3 Related tests

The battery durability test is related to the battery test (Annex K).

BB.4 Procedure

BB.4.1 Durability storage test for valve-regulated lead-acid batteries

BB.4.1.1 General

The DUT's valve-regulated lead-acid battery is stored for 360 h connected to a resistance corresponding to a current of 2 I_t A (where I_t A is defined in K.4.1), which causes a deep discharge.

BB.4.1.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Battery analyser.
- Wire cutters.
- Wire strippers.
- Soldering iron and solder.
- Heat-shrink tubing and heat gun, or electrical tape.
- Resistor with resistance corresponding to a current of 2 I_t A ± 10 % and a power rating that is greater than the maximum power dissipated during the test, as specified in IEC 61056-1:2012, 7.9.2.

BB.4.1.3 Test prerequisites

The DUT's battery shall be recently received and fully charged. The battery capacity shall have been determined using the valve-regulated lead-acid battery test (K.4.2). The product shall have been cycled no more than two times and shall have been stored for no more than 1 week since undergoing the battery capacity test. The battery shall be removed from the DUT.

BB.4.1.4 Procedure

Perform the charge acceptance after the deep discharge test from IEC 61056-1:2012, 7.9, with the following modifications:

- the requirements of IEC 61056-1:2012, 7.9.1 need not be met;
- capacity before and after storage shall be measured using the method defined in K.4.2. The same channel of the battery analyser should be used for both the before and after capacity tests;
- the battery shall be stored at an ambient temperature of 22 °C ± 5 K. Temporary excursions from this range, e.g. due to power outages, are permitted, but the cumulative duration of all such excursions shall not exceed 1 % of the storage period.

BB.4.1.5 Calculations

Determine the capacity loss using the following formula:

$$\delta C = \left(1 - \frac{C_A}{C_B}\right) \times 100\,\%$$

where

δC is the percent capacity loss experienced by the battery after storage (%);

C_A is the battery capacity measured after the storage, in ampere-hours (Ah);

C_B is the battery capacity measured before the storage, in ampere-hours (Ah).

BB.4.2 Durability storage test for flooded lead-acid batteries

BB.4.2.1 General

The DUT's flooded lead-acid battery is stored for 7 days connected to a resistance corresponding to a current of 0,01 I_t A (where I_t A is the current corresponding to a 1 h discharge in amperes), which causes a deep discharge. The storage test for flooded lead-acid batteries is based on VW 75073 and AS 4086.

BB.4.2.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Battery analyser
- Wire cutters
- Wire strippers
- Soldering iron and solder
- Heat-shrink tubing and heat gun, or electrical tape
- Resistors with resistance corresponding to a current of 0,1 I_t A and 0,01 I_t A, and a power rating that is greater than the maximum power dissipated during the test. The tolerance of the resistor itself shall be at least 5 %; a 20 % range within the calculated resistance value of the resistor is adequate.

BB.4.2.3 Test prerequisites

The DUT's battery shall be recently received and fully charged. If testing a flooded lead-acid battery that was shipped dry, the battery shall have been filled with battery acid according to instructions in K.4.2.1.

The battery capacity shall have been determined using the lead-acid battery test (K.4.2). The product shall have been cycled no more than two times and shall have been stored for no more than 1 week since undergoing the battery capacity test. The battery shall be removed from the DUT. The storage test shall be carried out at 30 °C ± 5 °C.

BB.4.2.4 Procedure

The following steps shall be followed, starting with a fully charged battery:

a) Discharge the battery at a rate of 0,1 I_t A until a voltage of 1,8 V/cell is reached. The value of I_t shall be determined using the battery capacity measured in the battery test (Annex K).

b) Connect across the battery terminals a resistor with resistance and power rating calculated using the following formulas, respectively:

$$R = \frac{V_{nom}}{0{,}01 \times I_t}$$

where

R is the resistance corresponding to a current of 0,01 I_t A, in ohms (Ω);

V_{nom} is the battery's nominal voltage, in volts (V);

I_t is the current corresponding to a 1 h discharge, in amperes (A).

$$P \geq \frac{V_{initial}^2}{R}$$

where

P is the resistor's power rating, in watts (W);

$V_{initial}$ is the battery voltage when the resistor is first connected, in volts (V);

R is the resistance of the selected resistor, in ohms (Ω);

c) Store the battery for 7 days at 30 °C ± 5 °C. Temporary excursions from this range, e.g. due to power outages, are permitted, but the cumulative duration of all such excursions shall not exceed 1 % of the storage period.

d) Determine the battery capacity according to the lead-acid battery test (K.4.2). The same channel of the battery analyser should be used for both the before and after capacity tests.

BB.4.2.5 Calculations

The calculations required for the storage test for flooded lead-acid batteries are identical to those for valve-regulated lead-acid batteries (BB.4.1.5).

BB.4.3 Durability storage test for nickel-metal hydride batteries

BB.4.3.1 General

The DUT's nickel-metal hydride battery is stored for 30 days at 60 °C ± 5 °C connected to a resistance corresponding to a current of 0,2 I_t A (where I_t A is the current corresponding to a 1 h discharge in amperes), which causes a deep discharge in the battery.

BB.4.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Battery analyser.
- Wire cutters.
- Wire strippers.
- Soldering iron and solder.
- Heat-shrink tubing and heat gun, or electrical tape.
- Oven, environmental chamber, or other apparatus capable of maintaining temperature in the required range.
- Resistor with resistance corresponding to a current of 0,2 I_t A and a power rating that is greater than the maximum power dissipated during the test. The tolerance of the resistor shall be no more than 5 % and the nominal value of the resistor shall be within 20 % of the calculated resistance.

BB.4.3.3 Test prerequisites

The battery shall be recently received and fully charged. The battery capacity shall have been determined using the nickel-metal hydride battery test (K.4.3). The product shall have been cycled no more than two times and shall have been stored for no more than 1 week since undergoing the battery capacity test. The battery shall be taken out of the DUT. The storage test shall be carried out at 60 °C ± 5 °C.

BB.4.3.4 Procedure

The following steps shall be followed, starting with a fully charged battery.

a) Discharge the battery at a rate of 0,2 I_t A until a voltage of 1,0 V/cell is reached. The value of I_t shall be determined using the battery capacity measured in the battery test (Annex K).
b) Connect across the battery terminals a resistor with resistance and power rating as specified in BB.4.3.2.
c) Store the battery for 30 days at 60 °C ± 5 °C. Temporary excursions from this range, e.g. due to power outages, are permitted, but the cumulative duration of all such excursions shall not exceed 1 % of the storage period.
d) Determine the battery capacity according to the nickel-metal hydride battery test (K.4.3). The same channel of the battery analyser should be used for both the before and after capacity tests.

BB.4.3.5 Calculations

The calculations required for the storage test for nickel-metal hydride batteries are identical to those for valve-regulated lead-acid batteries (BB.4.1.5).

BB.4.4 Durability storage test for lithium-ion batteries

BB.4.4.1 General

The DUT’s lithium-ion battery is stored for 30 days at 60 °C ± 5 °C at a state of charge of 50 %. The storage test for lithium-ion batteries is an accelerated version of the charge (capacity) recovery after long term storage test from IEC 61960-3:2017, 7.5.

BB.4.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Battery analyser.
- Oven, environmental chamber, or other apparatus capable of maintaining temperature in the required range.

BB.4.4.3 Test prerequisites

The battery shall be recently received and fully charged. The battery capacity shall have been determined using the lithium-ion battery test (K.4.4). The product shall have been cycled no more than two times and shall have been stored for no more than 1 week since undergoing the battery capacity test. The battery shall be taken out of the DUT. The storage shall be carried out at 60 °C ± 5 °C.

BB.4.4.4 Procedure

The following steps shall be followed, starting with a fully charged battery.

a) Discharge the battery at a rate of 0,2 I_t A for 2 h and 30 min. The battery is then at a state-of-charge of 50 %. The value of I_t shall be determined using the battery capacity measured in the battery test (Annex K).

b) Store the battery for 30 days at 60 °C ± 5 °C. Temporary excursions from this range, e.g. due to power outages, are permitted, but the cumulative duration of all such excursions shall not exceed 1 % of the storage period.

c) If the battery has multiple cells (or parallel cellblocks) in series, charge according to G.4.4 a).

d) Determine the battery capacity according to the lithium-ion battery test (K.4.4). The same channel of the battery analyser should be used for both the before and after capacity tests

BB.4.4.5 Calculations

The calculations required for the storage test for lithium-ion batteries are identical to those for valve-regulated lead-acid batteries (BB.4.1.5).

BB.4.5 Durability storage test for lithium iron phosphate batteries

BB.4.5.1 General

The DUT's lithium iron phosphate battery is stored for 30 days at 60 °C ± 5 °C at a state of charge of 50 %. The storage test for lithium iron phosphate batteries is an accelerated version of the charge (capacity) recovery after long term storage test from IEC 61960-3:2017, 7.5.

BB.4.5.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Battery analyser.
- Oven, environmental chamber, or other apparatus capable of maintaining temperature in the required range.

BB.4.5.3 Test prerequisites

The battery shall be recently received and fully charged before undertaking the procedure. The battery capacity shall have been determined using the lithium iron phosphate battery test (K.4.5). The battery shall be taken out of the DUT. The product shall have been cycled no more than two times and shall have been stored for no more than 1 week since the undergoing the battery capacity test. The storage shall be carried out at 60 °C ± 5 °C.

BB.4.5.4 Procedure

The following steps shall be followed, starting with a fully charged battery.

a) Discharge the battery at a rate of 0,2 I_t A for 2,5 h. The battery is then at a state of charge of 50 %. The value of I_t shall be determined using the battery capacity measured in the battery test.

b) Store the battery for 30 days at 60 °C ± 5 °C. Temporary excursions from this range, e.g. due to power outages, are permitted, but the cumulative duration of all such excursions shall not exceed 1 % of the storage period.

c) If the battery has multiple cells (or parallel cellblocks) in series, charge according to G.4.4 a).

d) Determine the battery capacity according to the lithium iron phosphate battery test (K.4.5). The same channel of the battery analyser should be used for both the before and after capacity tests.

BB.4.5.5 Calculations

The calculations required for the storage test for lithium-ion batteries are identical to those for valve-regulated lead-acid batteries (BB.4.1.5).

BB.5 Reporting

Report the following in the battery test report.

- Metadata:
  - report name;
  - procedure(s) used;
  - DUT manufacturer;
  - DUT name;
  - DUT model number;
  - battery manufacturer, if available;
  - battery name, if available;
  - battery model number, if available;
  - name of test laboratory;
  - approving person;
  - date of report approval.
- Results for tested DUT aspects for samples 1 through n:
  - capacity loss from storage (%).
- Average of n sample results for each DUT aspect tested.
- Coefficient of variation of n sample results for each DUT aspect tested (%).
- DUT's rating for aspects tested, if available.
- Deviation of the average result from the DUT's rating for each aspect tested, if available (%).
- Comments:
  - individual and overall comments, as necessary.

Annex CC
(normative)

Equipment requirements

CC.1 Overview

Annex CC gives requirements and recommendations for the equipment and materials needed for the test methods described in this document. These provisions are stated in tabular form in Clause CC.2.

Several test methods in this document involve the calculation of electrical power or energy, which can be complicated by the presence of time-varying voltage or current waveforms. Issues relating to power measurement are discussed in Clause CC.3.

CC.2 Requirements and recommendations for equipment and materials

Table CC.2 gives requirements and recommendations for the laboratory instruments, apparatus, and materials needed to perform the tests in this document. Many pieces of equipment can be used for multiple tests; the right side of the table shows which test methods require each item. The symbols used in these columns of Table CC.2 are defined in Table CC.1.

All equipment and materials shall meet the specifications given in the "requirements" column of Table CC.2 and should conform with the recommendations given in the "recommendations" column.

Table CC.1 – Symbols used in test method column of Table CC.2

Symbol	Meaning
No symbol	Equipment is not used for this test.
●	Equipment is required for this test. (Some equipment marked ● is required only for certain types of products or appliances.)
○	Equipment is optional for this test. (For tests with multiple procedure alternatives, some of the optional equipment could be required for some of the alternatives.)
A, B, C	Letters indicate alternative sets of equipment to perform the test. For example, the test can be performed using all of the items marked A, or all of the items marked B, but it is not necessary to use both sets of items. The order of the letters is arbitrary and does not indicate an order of preference or ranking of accuracy.

Table CC.2 – Specifications for all required test equipment

Equipment	Recommendations	Requirements	Test method																		
			Visual screening	Sample preparation	Photovoltaic module IV characteristics test	Light output test	Light distribution test	Battery test	Full battery run time	Full discharge preparation	Solar charge test	Grid charge test	Electromechanical charge test	Charge controller behaviour test	Protection tests	Assessment of DC ports	Appliance tests	Lumen maintenance test	Physical and water ingress protection test	Mechanical durability test	Battery durability
Computer	Depends on equipment that needs to be connected; typically good to have multiple RS-232 serial ports and USB ports for test equipment I/O. Test equipment often requires Windows®.	Depends on equipment	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Callipers and/or ruler	--	--	•																		
Balance (scale)	--	≤ 0,1 g resolution; ≤ 1 % accuracy	•																		
Bright task light with good colour rendering	≥ 700 lux and ≥ 85 CRI	--	•																		
Camera	--	--	•																•	•	
DC voltmeters or multimeters	--	≤ 0,5 % accuracy Two meters required for several tests Functionality may be incorporated into other equipment (e.g. power supply, electronic load)	•		B	•	•							•	•	•	•	•			
Wire stripper	--	--		•																	•
Wire cutter	--	--		•																	•

Equipment	Recommendations	Requirements	Test method																		
			Visual screening	Sample preparation	Photovoltaic module IV characteristics test	Light output test	Light distribution test	Battery test	Full battery run time	Full discharge preparation	Solar charge test	Grid charge test	Electromechanical charge test	Charge controller behaviour test	Protection tests	Assessment of DC ports	Appliance tests	Lumen maintenance test	Physical and water ingress protection test	Mechanical durability test	Battery durability
Soldering iron and solder	--	--		•																	•
Heat-shrink tubing and heat gun	--	--		•																	•
Screwdrivers	--	--		•																	
Power drill with drill bits	--	--		•																	
Wire	4 different colours (e.g. red, black, white, green) See recommendations on wire size in Table G.1.	See G.4.2.		•																	
Connectors	--	--		○																	
Solar simulator	--	Meets the requirements of IEC 60904-1:2006			A																
PV reference cell	Calibration should be traceable to applicable national or international standards.	Matched to DUT spectral response (see Q.4.2.1) unless spectral mismatch correction is used			A																
Outdoor I-V curve analyser	Current range up to 10 A; voltage range up to 2 times maximum nominal voltage of modules to be tested.	≤ 1 % accuracy for currents > 0,1 A and voltages > 2,5 V			B																
Indoor I-V curve analyser, source-measure unit, or similar	Same as for outdoor, unless limited by solar simulator dimensions.	Same as outdoor I-V curve analyser			A																

Equipment	Recommendations	Requirements	Test method: Visual screening	Sample preparation	Photovoltaic module IV characteristics test	Light output test	Light distribution test	Battery test	Full battery run time	Full discharge preparation	Solar charge test	Grid charge test	Electromechanical charge test	Charge controller behaviour test	Protection tests	Assessment of DC ports	Appliance tests	Lumen maintenance test	Physical and water ingress protection test	Mechanical durability test	Battery durability
Fast-response pyranometer	Silicon PV- or photodiode-based	≤ 5 % accuracy Response time ≤ 1 s			B																
Thermocouple meter or other suitable thermometer with surface-mountable sensors	Thermocouple meter and fast-response thermocouples For Clause J.6: type T thermocouple, diameter ≤ 0,13 mm	± 2 °C or better accuracy			●						○	○		○				○			
Integrating sphere	--	≥ 1 m diameter with auxiliary lamp; set of 3 calibrated lamp standards; spectroradiometer detector with range containing 380 nm to 780 nm				A			A									○			
Goniophotometer	--	See I.4.3.				B	○[b]														
Multi-plane test apparatus	Black matte paint minimizes surface reflectance. An array of clamp types is useful to hold DUTs in place.	See I.4.4.4.				C	○[b]														
Turntable ("rotary disk")	--	--					○[b]														
Lighting distribution grid testing surface	Black matte paint minimizes surface reflectance. An array of clamp types is useful to hold DUTs in place.	--					○[b]														

Equipment	Recommendations	Requirements	Test method: Visual screening	Sample preparation	Photovoltaic module IV characteristics test	Light output test	Light distribution test	Battery test	Full battery run time	Full discharge preparation	Solar charge test	Grid charge test	Electromechanical charge test	Charge controller behaviour test	Protection tests	Assessment of DC ports	Appliance tests	Lumen maintenance test	Physical and water ingress protection test	Mechanical durability test	Battery durability
Illuminance meter May be the same instrument as the data-logging illuminance meter below.	--	Cosine-corrected; ≤ 0,1 lux precision; V(λ) corrected				B	○[b]										•				
Illuminance meter with data-logging capability	Sufficient memory for 3 days at ≤ 1 min time resolution	Cosine-corrected; ≤ 0,1 lux precision; V(λ) corrected;							•												
DC power supply	≤ 0,001 A current resolution Be sure the power supply can supply high enough current and voltage values for the products tested. For the protection tests and assessment of DC ports, some ports require up to 20 A at 30 V. Multiple units may be paralleled to meet requirement.	≤ 0,01 V voltage resolution[a]; ≤ 0,2 % load regulation				•	•							○	•	•	•				
DC power supply, with programmable capability	Be sure the power supply can supply high enough current and voltage values for the products tested.	≤ 0,01 V voltage resolution; ≤ 0,001 A current resolution; programming accuracy of ±0,05 V or better for voltage, ± (0,5% + 5 mA) or better for current									B										

Equipment	Recommendations	Requirements	Test method																		
			Visual screening	Sample preparation	Photovoltaic module IV characteristics test	Light output test	Light distribution test	Battery test	Full battery run time	Full discharge preparation	Solar charge test	Grid charge test	Electromechanical charge test	Charge controller behaviour test	Protection tests	Assessment of DC ports	Appliance tests	Lumen maintenance test	Physical and water ingress protection test	Mechanical durability test	Battery durability
Battery simulator	Apparatus from IEC 62509:2010, 5.1.6.2; 2- or 4-quadrant power supply or power amplifier; or DC power supply and load	--													○		○				
Pulsed load (electronic load or fixed and/or variable resistors and switching element)	5 A current capability at approximately 5 V	5 % current accuracy; can alternate between two current values at < 5 Hz														•					
Electronic load or variable and fixed resistors May be same device as the pulsed load	≥ 20 A current limit ≥ 20 V voltage limit ≥ 250 W power limit constant-current mode	Capable of meeting required steady-state current values within 5 %													•	•					
Two DC ammeters or multimeters	≥ 10 A current limit Can use DC voltmeter and current shunt resistor if higher currents are needed.	≤ 1 % accuracy Functionality may be incorporated into other device (e.g. power supply, load)													•	•	•				
Digital oscilloscope	--	Minimum sampling interval of 1 ms Sufficient bandwidth to record voltage transients < 10 ms														•	•				

Equipment	Recommendations	Requirements	Test method																		
			Visual screening	Sample preparation	Photovoltaic module IV characteristics test	Light output test	Light distribution test	Battery test	Full battery run time	Full discharge preparation	Solar charge test	Grid charge test	Electromechanical charge test	Charge controller behaviour test	Protection tests	Assessment of DC ports	Appliance tests	Lumen maintenance test	Physical and water ingress protection test	Mechanical durability test	Battery durability
Power measuring instrument	See Clause CC.3.	DC accuracy of ≤ 2 % of reading, or ≤ 0,01 W for values less than 0,05 W.	See Clause CC.3.																		
Audio/video signal generation equipment	--	Meets requirements of IEC 62087-2:2015, 6.1, 6.2, 6.3															•				
Dynamic broadcast-content video signal media	--	Provided with IEC 62087-2:2015, 4.1.3															•				
Sound pressure level (SPL) meter	--	Class 2 certified meter; A-weighting[c]															•				
Sine wave audio signal media (e.g. IEC 62087-2:2015, 4.3.1)	--	1 kHz															•				
RF/FM transmitter	--	Able to accept the sine wave signal from the computer or hardware device															•				
Tachometer	Non-contact tachometer or stroboscope	≤ 1 % accuracy															A				
Anemometer	--	Measurement range includes 0,5 m/s. ≤ 0,2 m/s accuracy															B				

Equipment	Recommendations	Requirements	Test method																		
			Visual screening	Sample preparation	Photovoltaic module IV characteristics test	Light output test	Light distribution test	Battery test	Full battery run time	Full discharge preparation	Solar charge test	Grid charge test	Electromechanical charge test	Charge controller behaviour test	Protection tests	Assessment of DC ports	Appliance tests	Lumen maintenance test	Physical and water ingress protection test	Mechanical durability test	Battery durability
Solar array simulator	--	≤ 5 % current accuracy at half the module's maximum-power current[d]									A			A							
Series and parallel resistors (not required if a solar array simulator is used)	R_p: up to 1 000 Ω at up to 0,5 A or 30 V. R_s: up to 6 Ω at 10 A and 50 Ω at 1,25 A. A combination of fixed and variable resistors can be more economical than a single variable resistor.	Difference between calculated and measured resistance not exceeding the largest of: • 1 % of the calculated value; • 0,02 Ω; or • half the ohmmeter resolution									B			B							
Resistance meter or multimeter	--	≤ (1% + 0,1 Ω) accuracy Resolution of 0,01 Ω or 1 % of the measured value, whichever is greater									B										
DC ammeter	--	≤ 1 % accuracy				•															
DC power supply	≤ 0,001 A current resolution	≤ 0,01 V voltage resolution[a]; ≤ 3 % load regulation For Clause J.6: ≤ 0,2 % load regulation																•			

Equipment	Recommendations	Requirements	Test method																		
			Visual screening	Sample preparation	Photovoltaic module IV characteristics test	Light output test	Light distribution test	Battery test	Full battery run time	Full discharge preparation	Solar charge test	Grid charge test	Electromechanical charge test	Charge controller behaviour test	Protection tests	Assessment of DC ports	Appliance tests	Lumen maintenance test	Physical and water ingress protection test	Mechanical durability test	Battery durability
DC ammeter or current shunt and voltmeter	Current-sensing shunt resistor (one for each DUT) and voltmeter ≤ 1 % accuracy	≤ 1 % accuracy for Clause J.6 only					•											•			
DC ammeter or multimeter	--	≤ 0,01 mA precision												•							
Stopwatch	--	≤ 1 second resolution											•	•						•	
Capacitor filter	Capacitor filter should be soldered on perforated prototyping board or equivalent, or on a printed circuit board (PCB).	1 µF, 10 µF, and 100 µF (± 20 %) capacitors in parallel (ceramic or tantalum)				•												•			
Battery analyser	Accuracy of ±1 % for voltage, current, and capacity.	Accuracy of ± 2 % for total energy over full charge or discharge cycle.						•	•	○											
Low-voltage disconnect device	--	≤ 2,5 % accuracy							○	○											
Timer disconnect device	Combine digital timer with relay	≤ 2 min precision								○		•									
AC power supply	Utility (mains) if compatible with DUT, or true sine wave inverter, frequency converter, uninterruptible power supply, or AC power supply with voltage total harmonic distortion (THD) ≤ 5 %.	--										•									

Equipment	Recommendations	Requirements	Test method																		
			Visual screening	Sample preparation	Photovoltaic module IV characteristics test	Light output test	Light distribution test	Battery test	Full battery run time	Full discharge preparation	Solar charge test	Grid charge test	Electromechanical charge test	Charge controller behaviour test	Protection tests	Assessment of DC ports	Appliance tests	Lumen maintenance test	Physical and water ingress protection test	Mechanical durability test	Battery durability
Appropriate optical cavity or dark room/closet	Photometer box (Annex Y)	Magnitude of stray light's influence on absolute light output measurements at most 0,5 % of the minimum light output magnitude being measured.							B									•			
Voltage data logger	Sufficient memory for 3 days at ≤ 1 min intervals	≤ 1 mV resolution; ≤ (2,5 % + 2 mV) accuracy							•		•	•	•	•							
Current data logger, or voltage data logger plus current shunt or transducer	Sufficient memory for 3 days at ≤ 1 min intervals	≤ 1 mA resolution; ≤ 3 % accuracy							•		•	•	•	•							
Overcharge disconnect device	Temperature and/or voltage sensing; operating voltage range sufficient for highest expected battery voltage (typically < 20 V).	≤ 0,01 V resolution and ≤ 1 % accuracy for voltage									•	•		•							
Controlled water source	--	rotating head ± 60°																	•		
Rigid probes	--	diameters $1^{+0,05}_{0}$ mm, $2,5^{+0,05}_{0}$ mm, and $12,5^{+0,2}_{0}$ mm																	•		

Equipment	Recommendations	Requirements	Test method																		
			Visual screening	Sample preparation	Photovoltaic module IV characteristics test	Light output test	Light distribution test	Battery test	Full battery run time	Full discharge preparation	Solar charge test	Grid charge test	Electromechanical charge test	Charge controller behaviour test	Protection tests	Assessment of DC ports	Appliance tests	Lumen maintenance test	Physical and water ingress protection test	Mechanical durability test	Battery durability
Tape measure or ruler	--	≥ 1 m																		•	
Weight	--	2 kg																		•	
Protractor	--	--																		•	
Clamp	--	--																		•	
45 degree angle	Wooden block	--																		•	
Resistor	--	≤ 5 % tolerance; size and power rating dependent on DUT's battery																			•
Oven or environmental chamber	--	Able to maintain 60 °C ± 5 °C and 30 °C ± 5 °C																		•	•

[a] If voltage and current measurements are made using multimeters or voltmeters/ammeters, there is no requirement for voltage and current readout accuracy or resolution for the power supply. If voltage and/or current measurements are made using the power supply, the readout accuracy shall meet the requirement for multimeters or voltmeters/ammeters.

[b] The light distribution test includes multiple test methods, which produce different sets of outcomes and apply to different categories of products. See Annex T for the list of equipment required for each test method, the outcomes generated, and the applicability to different product categories.

[c] Sound pressure level meter accuracy classes are specified in IEC 61672 and weightings are specified in IEC 60268-1.

[d] Some commercial solar array simulators are designed for large modules and are not accurate at the low currents typically seen with small stand-alone renewable energy products. For example, an SAS with a rated accuracy of ± (0,2 % + 20 mA) would not necessarily be appropriate to simulate a module with a maximum power point current of 100 mA. If the rated accuracy is insufficient to meet this requirement, the instrument may be used if the simulated I-V curve is measured to verify that the current values are within 5 % of the actual I-V curve at all points where the actual current is greater than half the maximum power point current. This test shall be performed each time the SAS is set up to test a new DUT.

CC.3 Guidelines for electrical power measurements

CC.3.1 Background

In several test procedures in this document, it is necessary to measure voltage and current in order to calculate a power value. These test procedures include:

- the full-battery run time test (Annex M) and appliance full-battery run time test (Clause FF.9),
- the grid charge test (Annex O),
- the electromechanical charge test (Annex P),
- the solar charge test (Annex R),
- the measurement of steady-state port characteristics (EE.4.2),
- the appliance power consumption test (Clause FF.6), and
- the appliance charging efficiency test (Clause FF.7).

In addition, while this is not required, the power during the light output test (Annex I) is often calculated in order to determine luminous efficacy.

NOTE The photovoltaic module I-V characteristics test (Annex Q) also involves a measurement of power, but the information in Clause CC.3 is generally not applicable.

The best way to perform this measurement is with a power meter (wattmeter) capable of both AC and DC measurements. However, these instruments are expensive, and as a result it can be more convenient for some laboratories to use separate instruments, such as multimeters or a custom data acquisition system, to measure voltage and current and then multiply the resulting values. However, unless appropriate precautions and corrective measures, if applicable, are taken, this method can result in significant measurement error when the current is varying with time. Therefore, the use of separate current and voltage measurements is permitted only if the resulting error is kept to an acceptable level.

CC.3.2 defines a metric to quantify the error associated with the calculation of power from separate measurements of DC current and voltage. A recommended limit for this metric is stated in CC.3.3 and additional recommendations are given in CC.3.4. Due to limited laboratory experience with these methods, Clause CC.3 does not presently give requirements.

CC.3.2 Overview of DC power measurement

When set to measure DC voltage or current, a multimeter displays the average value of the quantity being measured. (Some multimeters also have the ability to display the value of the DC component and the rms value of the AC components.) The power calculated by multiplying the current and voltage readings of two multimeters is given by:

$$P_{\text{mm}} = I_{\text{avg}} \cdot V_{\text{avg}} = \frac{1}{T^2} \int_0^T I(t)dt \cdot \int_0^T V(t)dt$$

where

P_{mm} is the power measured using two multimeters or other DC measuring instruments;

T is the averaging period;

$I(t)$ is the instantaneous current at time t;

$V(t)$ is the instantaneous voltage at time t;

I_{avg} is the average current;

V_{avg} is the average voltage.

This is in contrast to the correct expression for the average power, which is:

$$P_{avg} = I_{avg} \cdot V_{avg} = \frac{1}{T}\int_0^T I(t) \cdot V(t)dt$$

where

P_{avg} is the average power;

T is the averaging period;

$I(t)$ is the instantaneous current at time t;

$V(t)$ is the instantaneous voltage at time t.

These two quantities are identical if either current or voltage is constant with respect to time. Otherwise, the difference between P_{mm} and P_{avg} will contribute to the overall error in the power measurement. It is useful to quantify the contribution to relative error in power due to the current and voltage waveforms:

$$\delta P = \frac{P_{mm} - P_{avg}}{P_{avg}}$$

where

δP is the relative error in average power due to the current and voltage waveforms;

P_{avg} is the average power;

P_{mm} is the power measured using two multimeters or other DC measuring instruments.

In the case where the power is being measured across a load that uses pulse-width modulation (PWM), the load current will be a pulse train varying between zero and a constant nonzero value. If the load being measured is supplied with power by a voltage source with nonzero output resistance, such as a PV simulator or a DC power supply with a current shunt in series, it can be shown that the value of δP can also be expressed in terms of the voltages during the on and off periods:

$$\delta P_{PWM} = (1 - D) \cdot \frac{V_{off} - V_{on}}{V_{on}}$$

where

δP_{PWM} is the relative error in average power due to the current and voltage waveforms, when the current waveform is PWM;

D is the duty cycle (the fraction of time when the load is drawing current);

V_{off} is the load voltage when the load is not drawing current;

V_{on} is the load voltage when the load is drawing current.

NOTE V_{on} is less than V_{off}.

This form can be more convenient to use since it is not necessary to measure the current waveform quantitatively.

When multiple power measurements are being averaged together, δP may be calculated as a weighted average, using either the general or PWM forms:

$$\delta P = \frac{\sum_i \left(\Delta t_i \cdot \frac{P_{\mathrm{mm},i} - P_{\mathrm{avg},i}}{P_{\mathrm{avg},i}} \right)}{\sum_i \Delta t_i}$$

where

δP is the relative error in average power due to the current and voltage waveforms;

Δt_i is the time interval corresponding to measurement i;

$P_{\mathrm{avg},i}$ is the average power at measurement i;

$P_{\mathrm{mm},i}$ is the power measured using two multimeters or other DC measuring instruments at measurement i.

$$\delta P_{\mathrm{PWM}} = \frac{\sum_i \left(\Delta t_i \cdot (1 - D) \cdot \frac{V_{\mathrm{off,i}} - V_{\mathrm{on,i}}}{V_{\mathrm{on},i}} \right)}{\sum_i \Delta t_i}$$

where

δP_{PWM} is the relative error in average power due to the current and voltage waveforms;

Δt_i is the time interval corresponding to measurement i;

D is the duty cycle (the fraction of time when the load is drawing current) at measurement i;

$V_{\mathrm{off},i}$ is the load voltage when the load is not drawing current, at measurement i;

$V_{\mathrm{on},i}$ is the load voltage when the load is drawing current, at measurement i;

$P_{\mathrm{mm},i}$ is the power measured using two multimeters or other DC measuring instruments at measurement i.

Since accurately calculating δP requires an accurate measurement or calculation of the average power, it is generally not beneficial to calculate δP in order to apply a correction to measured data. However, a calculation of δP can be used to determine whether it is acceptable to use lower-cost measuring instruments for a given product. For example, a laboratory could test one sample using a power meter and use the result to determine whether the remaining samples could be tested simultaneously using low-cost instruments. Alternatively, the laboratory could test the samples using the low-cost instruments while observing one sample with an oscilloscope, and use the results to determine whether to repeat the test, one sample at a time, using a power meter.

CC.3.3 Power measurement accuracy recommendations

Power measurements should be performed using a power-measuring instrument meeting the requirements of Table CC.2, except that two multimeters (or a DC voltmeter and DC ammeter, or a data-logging or data-acquisition system with equivalent functionality) may be used if the relative error contribution (δP) defined in CC.3.2 does not exceed 1 %. If the current and voltage waveforms are not known with sufficient accuracy to enable a direct calculation of δP, the current waveform may be assumed to be PWM with a duty cycle of 10 %; the δP criterion can then be assessed by inspection of the voltage waveform with an oscilloscope. For very low frequencies, a multimeter with pulse width and minimum/maximum voltage features can be used if the response time of this feature is sufficient to meet the accuracy requirement.

Many power meters can calculate DC voltage and DC current in addition to the rms values, so the same instrument can be used to measure both P_{mm} and P_{avg} simultaneously. This is the recommended method. If δP is determined by comparison between two measurements with different instruments (e.g. a power meter and two multimeters), the comparison is valid only for simultaneous measurements of a single DUT. In addition, the use of different instruments introduces another source of measurement uncertainty.

If a power-measuring instrument is used in test procedures that calculate average power or cumulative energy over a period of time (e.g. the solar charge test), the internal averaging or integration function of the power meter, if present, should be used rather than calculating and integrating the power at each sampling interval, since the power meter uses a high internal sampling rate resulting in a more accurate total or average.

Whenever separate current and voltage measurements are used, any time offset between the two measurements should be taken into account in the calculation of measurement error.

When the voltage and current waveforms are not constant or sinusoidal, many factors can contribute to the total uncertainty of a power measurement. The accuracy requirement in Table CC.2 applies to DC conditions only.

CC.3.4 Additional guidelines and corrective measures

The following items provide additional guidance on the measurement of power in the test procedures defined in this document. In all cases, the recommendation in CC.3.3 is the definitive criterion for whether a given test method should be considered appropriate.

- It is always acceptable to use a power-measuring instrument meeting the requirements of Table CC.2.
- If the current is known to be approximately constant (e.g. through observation with an oscilloscope), the criterion in CC.3.3 is likely to be met, so separate current and voltage measurements may be used. This is likely to be the case for most steady-state measurements of appliance power consumption, since even appliances that use PWM internally often include bypass capacitors.
- If the current is not constant, but the voltage is approximately constant, the criterion in CC.3.3 can be met in some cases. It is important to consider the effect of the voltage drop across the ammeter or current shunt when determining whether the voltage remains constant, since the current is varying, the voltage drop will also vary. Using a higher current range can reduce the voltage drop, but can increase the measurement uncertainty.
- If the current and voltage are not constant, but it is desired to use separate voltage and current measurements, the following corrective measures can be attempted to reduce the measurement error to an acceptable level (as specified in CC.3.3):
  - If the appliance is being driven from a power supply and the power measurement is at the power input to the appliance, a power supply with remote sensing may be used to compensate for the varying voltage drop across the current-sensing element. This method is unlikely to be effective at high frequencies and is most suitable for appliances where the change in current is gradual, such as television sets.
  - Current and voltage data loggers or a data acquisition system may be used to record the values of current and power over the averaging period. The instantaneous power is then calculated and the values are averaged. This method can be effective if the change in current is gradual, as with television sets, or if the current is relatively constant for most of the averaging period. The weighted-average form of the δP calculation should be used.

For the measurement of appliance power, a capacitor may be connected across the appliance plug (i.e. in parallel with the voltmeter). The required capacitor value depends on the current waveform, the average values of current and voltage, and the resistance of the ammeter. The value should be chosen based on a circuit model or comparison with a power meter or observation with an oscilloscope. This option shall not be used for the solar charge test or if the capacitor influences the behaviour of the DUT.

Annex DD
(normative)

Protection tests

DD.1 Background

Annex DD contains test methods to assess the robustness of the stand-alone renewable energy product to faults, including incorrect wiring and a disconnected battery. To meet the requirements of these tests, the product shall withstand the fault condition without being damaged or presenting a safety hazard.

DD.2 Test outcomes

The test outcomes of the protection tests are listed in Table DD.1.

Table DD.1 – Protection test outcomes

Metric	Reporting units	Related aspects	Remarks
Presence of sufficient miswiring protection	pass/fail	4.2.7.3 Circuit and overload protection	Overall pass/fail result for entire DUT
Miswiring protection test damage	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every tested configuration
Miswiring protection test safety hazard	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every tested configuration
Miswiring protection test fault indication	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every tested configuration
Miswiring protection test repairs needed	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port
Presence of sufficient output overload protection	pass/fail	4.2.7.3 Circuit and overload protection	One result for every port
Output overload protection test damage	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port
Output overload protection test safety hazard	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port
Output overload protection test fault indication	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port
Output overload protection test repairs needed	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port
Output overload protection test maximum sustained current	Amperes (A)	4.2.7.3 Circuit and overload protection	One result for every port
Presence of sufficient PV overvoltage protection	pass/fail	4.2.7.3 Circuit and overload protection	Overall pass/fail result for entire DUT
PV overvoltage protection test damage	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port or built-in appliance
PV overvoltage protection test safety hazard	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port or built-in appliance
PV overvoltage protection test port allowable voltage limit	Voltage (V)	4.2.7.3 Circuit and overload protection	One result for every port
PV overvoltage protection test port voltage	Voltage (V)	4.2.7.3 Circuit and overload protection	One result for every port
PV overvoltage protection fault indication	Yes/no, description	4.2.7.3 Circuit and overload protection	Single result for entire DUT

DD.3 Related tests

The protection tests use results from the photovoltaic module I-V performance test (Annex Q). The maximum sustained current calculated in the output overload protection test (DD.4.2) is used in the assessment of DC ports (Annex EE).

DD.4 Procedure

DD.4.1 Miswiring protection test

DD.4.1.1 General

This test assesses whether the DUT is protected against improper wiring and system component connections. In many cases, it is infeasible to test every possible combination of incorrect connections, so this procedure attempts to identify and test configurations that are likely to occur during installation, operation, and routine maintenance.

DD.4.1.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- DC power supply
- Battery simulator (optional), which, if used, may be one of the following:
  - The battery simulator circuit defined in IEC 62509:2010, Figure 1, with parameters from IEC 62509:2010, 5.1.6.2.
  - A two- or four-quadrant (bipolar) power supply or power amplifier.
  - A commercially available battery simulator.
  - A power supply in constant-current mode placed in parallel with an electronic load in constant-voltage mode. (The power supply current is set to a value greater than the current drawn by the DUT.)

The use of a battery simulator can provide more stable and controllable operating conditions, improving repeatability, but the use of the DUT's battery is permitted as a low-cost option.

DD.4.1.3 Test prerequisites

The visual screening (Annex F) and photovoltaic module I-V performance test (Annex Q) shall be performed before performing the miswiring protection test.

If a battery simulator is not used, the DUT's battery shall be partially charged so that the battery will accept charge from the PV input and supply power to the ports and any built-in appliances for the duration of the test. (That is, neither the deep discharge protection limit nor the overcharge protection limit shall be reached during the test. If one of these limits is reached, the battery may be charged or discharged as needed and the test continued.)

DD.4.1.4 Procedure

Perform the following steps.

a) Identify the connectors subject to the miswiring protection test. A connector shall be tested if both of the following are true.
   - The connector is accessible to the user or installer during normal installation, operation, and routine maintenance. (A compartment or enclosure is considered "accessible" if it can be opened without the use of any tools, or if it is opened at any time during the normal processes of installation, operation, or routine maintenance.)
   - The connector can be inserted, assembled, or mated incorrectly (for example, backwards) without excessive force or modification, and/or the connector can be

inserted into or mated with a receptacle or connector other than those with which it is intended to be used.

Examples of situations requiring testing:

EXAMPLE 1 The PV module and lighting appliances have the same type of plug, so one can be inserted into the socket intended for the other.

EXAMPLE 2 The battery, mounted in a user-accessible enclosure (as defined above), is connected to the charge controller using quick-disconnect lugs, and the positive and negative leads are physically interchangeable.

Examples of situations not requiring testing:

EXAMPLE 3 The battery is mounted in an enclosure that is not intended to be accessed by the user or installer. In this case, the battery connector does not require testing.

EXAMPLE 4 The product includes several different appliances with USB plugs and four USB sockets intended for connecting appliances. Although a given appliance could be connected to any of the four sockets, this would not be an incorrect connection, so it does not require testing.

EXAMPLE 5 The product includes a non-polarized connector that is designed to function correctly when connected in either direction. (For example, a plug with a symmetrical arrangement of contacts.)

b) Identify each incorrect configuration to be tested, using the following rules.

- In these rules, a pair is defined as a positive and negative lead from the same circuit.
- The following configurations shall be tested.
  - The conductors making up a single pair are swapped (e.g. the battery is connected in reverse polarity).
  - A single connector or pair of conductors is matched with the wrong mating connector, and all other connections are made correctly (e.g. the PV module is connected to an appliance port).
  - Two connectors or pairs of conductors are swapped (e.g. the battery is connected to the PV input and the PV module is connected to the battery input).
  - A single connector is inserted in the wrong orientation (e.g. the battery connector is inserted backwards).
- Combinations of the above situations (e.g. both battery and PV module are connected in reverse polarity) need not be tested.
- If multiple connectors are functionally identical, only one connector is required to be tested. For example, if the DUT includes four identical sockets for connecting appliances, and a PV connector that fits in the appliance sockets, the PV connector shall be tested in one of the four appliance sockets. Testing of the other three sockets is optional.
- All required configurations shall be tested prior to testing any optional configurations, since the test can be destructive.
- In addition to the configurations tested above, the test laboratory should test any additional configurations if, in the tester's judgment, the configuration is likely to occur during installation, use, or routine maintenance.
- If the testing laboratory determines that a configuration will result in a safety hazard to property or personnel, the laboratory should not test that configuration. If this is a required configuration, the DUT fails the test. (For example, if reversing a connector would result in a short-circuit path across the battery with no overcurrent protection, the configuration should not be tested.)
- It is not necessary to test configurations in which excessive force or modifications to the DUT would be required to make connections, provided that no electrical contact occurs unless excessive force is applied or modifications are performed. (For example, if the battery and PV module use connectors of different sizes or shapes, a configuration in which these connectors are swapped need not be tested.) "Excessive force" is defined as sufficient force to physically damage the DUT in a way that would

be apparent to a typical user. If a connector can be forced into a socket without causing obvious damage, even if non-obvious damage (e.g. bent pins or contacts) occurs, this configuration shall be tested.

c) If a PV module input is required for the wiring configuration under test, use a DC power supply set to the maximum power voltage (V_{mpp}) and maximum power point current (I_{mpp}) of the PV module at typical module operating temperature (TMOT). If the PV module of the DUT has not undergone the photovoltaic module I-V characteristics test (Annex Q), the average values of the samples that underwent the photovoltaic module I-V characteristics test (Annex Q) shall be used. Prior to testing, connect the power supply to the PV input and verify that the DUT charges correctly.

d) For each incorrect wiring configuration identified in b), perform the following steps:

   1) Configure the DUT according to the incorrect wiring configuration under test. (If necessary for safety, disconnect the battery and/or PV input before making wiring configuration changes.)

   2) Reconnect and turn on the power supply simulating the PV module.

   3) Allow the DUT to remain connected for 20 min, unless a safety hazard develops (e.g., smoke or a burning smell). The DUT is not required to function correctly while configured incorrectly.

   4) If the DUT provides an indication of the fault condition (for example, a warning light, error code, or audible alarm), note the type of indication.

   5) Restore the DUT to the correct wiring configuration. (If necessary for safety, disconnect the battery and/or PV input before making wiring configuration changes.)

   6) If a safety hazard develops, disconnect the battery and PV input from the DUT and discontinue the test.

   7) Test the functionality of the DUT. If the DUT no longer functions:

      i) If the problem can be identified and repaired by following instructions in the user documentation (e.g., replacing a blown fuse or resetting a tripped circuit breaker), using no tools except a screwdriver used to remove and insert screws, without creating a safety hazard, repair the fault. Only spare parts included with DUT (or their equivalent, in case the supply of included spare parts is exhausted through repeated testing) may be used. (For example, if a fuse is blown, and the manufacturer did not supply replacement fuses, the DUT fails the test.) If the DUT is functional after the repair, and the repair can be conducted without exposing the person conducting the repair to a safety hazard, the DUT does not fail the test.

      ii) If the problem can be easily identified and repaired by the test laboratory, but requires steps not documented in the user documentation, tools other than a screwdriver used to remove and insert screws, or spare parts not included with the DUT, the DUT fails the test. However, the test laboratory may, at its discretion, repair the fault and continue the test. (For example, if a replacement fuse is required, the test laboratory may replace the fuse, continue the test, and state in the report that the DUT failed the test, but would have passed the test had spare fuses been included).

      iii) In the test report, describe any repairs made.

   8) Record whether the DUT remains functional at the end of the test, whether any damage occurred, and whether any user safety hazard is present. Describe any failures and take photographs of any visible damage or safety hazards.

The DUT passes the miswiring protection test if it remains functional after the final incorrect configuration is tested and no safety hazards developed during the test. The DUT is not required to function normally during the test, although any abnormal operation should be noted in the test report. The DUT is not required to provide indication of the fault condition (for example, a warning light, error code, or audible alarm), but any such indication should be noted and described.

DD.4.2 Output overload protection test

DD.4.2.1 General

This test assesses whether the DUT is protected against excessive load or short circuits applied to the appliance ports.

NOTE This test can be conducted using the same apparatus as the assessment of DC ports (Annex EE).

DD.4.2.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- DC power supply.
- Two DC ammeters or multimeters.
- Two DC voltmeters or multimeters.
- Electronic load or fixed and variable resistors as described below.

In some cases, it can be necessary to use multiple laboratory power supplies in parallel to achieve the required current. Unless otherwise specified by the power supply manufacturer, a diode should be used at the output of each power supply to prevent backfeeding. If the power supplies do not include current-sharing functionality, set one power supply to constant-voltage mode to control the voltage and set the remaining power supplies to constant-current mode with a voltage limit not exceeding the battery's overcharge protection voltage threshold, as determined in the charge controller behaviour test (Annex S).

If the optional battery simulator specified in DD.4.3.2 can supply sufficient current and meet the voltage regulation requirements for the DC power supply in Table CC.2, it may be used instead of the DC power supply, allowing Procedure A of the PV overvoltage protection test (DD.4.3.4) to be performed concurrently; see DD.4.3.4 for details.

The currents required in this test can exceed the maximum range of many multimeters. In this case, a current transducer or current sense resistor and voltmeter may be used instead of an ammeter or multimeter. The voltage should be measured at the DUT to compensate for the voltage drop across the ammeter or current sense resistor.

In this test, a variable load is applied to each port. This variable load may be an electronic load or fixed and variable resistors. The load should be capable of sinking 125 % of the rated current for the port (see DD.4.2.4 a)) at the nominal port voltage. (Since port voltage can drop under load, and the maximum sustained current determined by this test can be less than 125 % of the rated current, it is sometimes possible to use a load with lower limits if care is taken not to exceed the limits during the test.)

If an electronic load is used, and the electronic load contains current and voltage measurement functionality that meets the requirements for DC ammeters and voltmeters in Table CC.2 after accounting for any voltage drop between the port and the load, this functionality may be used instead of an ammeter and/or voltmeter at the port.

The electronic load shall be galvanically isolated from the power supply if this is necessary in order to avoid altering the behaviour of the DUT.

DD.4.2.3 Test prerequisites

The visual screening (Annex F) and photovoltaic module I-V performance test (Annex Q) shall be performed before performing the output overload protection test.

DD.4.2.4 Procedure

Perform the following steps for each port under test. If the DUT has multiple identical ports, or multiple ports that are known (e.g. through visual inspection) to share the same overload protection device, it is only necessary to test one port from each such set of ports. In the following procedure, the term "overload protection device" refers to a fuse, circuit breaker, PTC device, other overcurrent protection device, thermal fuse, thermal switch, or other thermal protection device).

a) Determine the maximum testing current for each port, using the following rules.

   1) If the manufacturer supplied a maximum current rating or overcurrent protection limit for the port, the maximum testing current is 125 % of the manufacturer-provided value. If more than one value was given by the manufacturer (for example, a nominal current value and an overcurrent protection limit), use the largest value.

   2) If a current rating or overcurrent protection limit for the port is given in the user documentation or product packaging or marked on the product or on an internal component (such as a fuse or circuit breaker), the maximum testing current is 125 % of the value given in the documentation or marked on the product or component.

   3) If no rating was given and no markings can be found, calculate the highest power consumption that could be achieved using a combination of the included and advertised appliances that can be powered simultaneously using the port and all identical ports, plus any splitters or similar components that are included or advertised for use with the port. Use Annex HH to determine the power consumption of appliances not included in the product. Divide the total power consumption by the nominal port voltage (Annex EE) and multiply by 1,25 to calculate the maximum testing current.

b) Use a laboratory power supply to power the DUT power control unit according to Annex H. Set the power supply to the DUT standard operating voltage as described in H.5.2. Measure the voltage as close to the DUT as possible and adjust the power supply to compensate for voltage drop in the wires, ammeter, and paralleling diodes if used.

c) Turn on the power supply and verify that the DUT is functional.

d) Connect an adjustable load to the port under test. The load should have a current and power ratings sufficient to achieve the maximum testing current at the port's output voltage. The load should be used in constant-current mode if available.

e) Adjust the load in order to find the largest current, less than or equal to the maximum testing current, that does not result in the trigger of an overload protection device after 20 min of operation. This is the maximum sustained current. It is only necessary to test multiples of 1 % of the rated current. The test laboratory may use any algorithm to identify the maximum sustained current, including the following.

   – Starting at a low value and slowly increasing the current until the overload protection device is triggered. This method can be preferable if the overload protection device is a fuse that needs to be replaced after each operation, or if the overload protection device requires a long cool-down period to reset.

   – Starting at a high value and slowly decreasing the current until the overload protection device does not trigger. This method can give faster results but could result in excessive operation of the overload protection device or could damage the DUT.

   – Performing a binary search, as follows:

      1) Define I_L to be equal to zero and I_H to be equal to the maximum testing current.

      2) Calculate the test current I_{test}, as follows:

$$I_{test} = \frac{I_L + I_H}{2}$$

      3) Round the value of I_{test} to the nearest multiple of 1 % of the rated current.

      4) Apply a current of I_{test} for 20 min.

5) If an overcurrent protection device operates, set I_H equal to I_{test}. Otherwise, set I_L equal to I_{test}.

6) If the difference between I_H and I_L is less than 1 % of the rated current, stop the procedure. Otherwise, go to step 2.

– Using a combination of these methods. For example, one or two steps of a binary search could be performed to get a coarse estimate of the maximum sustained current, followed by a slow ramp-up to find the precise value without excessive operation of the overload protection device.

– Regardless of the specific method used, an initial search using a larger step size, such as 5 % of the rated current, followed by fine-tuning using a step size of 1 % of the rated current, can reduce testing time for some products.

For some types of overload protection, it is necessary to allow the DUT to cool before repeating the test. When possible, the test laboratory should avoid unnecessary operation of the overload protection device, especially if the type of device is not known.

Some ports are unable to maintain a stable voltage even at loads that do not trigger the overload protection device. For example, the load voltage can oscillate between a value within the normal operating voltage range of the port and a very low value, even though a constant current is maintained. In this case, the maximum sustained current is the highest current at which a stable voltage is supplied by the port after 20 min. The laboratory should record both the maximum sustained current and the minimum current at which the overload protection device activates.

f) If an overload protection device operates, record the type of overload protection device, the tools required to reset it, and whether the user documentation (including the user's manual and any labels on the product) contains sufficient instructions to carry out the procedure. If the overload protection device is a non-resettable fuse, record whether the product includes spare fuses.

g) If no overload protection device operates when the device is operated at the maximum testing current for 20 min, no overload protection is detected and the maximum sustained current cannot be determined. The test laboratory may consult with the DUT manufacturer to determine whether a higher value for the maximum sustained current should be used; if so, the test should be repeated.

h) If the port driver circuitry limits the current such that even when the load resistance is decreased, the current remains below the maximum testing current, the maximum sustained current is the maximum current measured during the test.

i) Note the functionality of the DUT after operating at the maximum sustained current for 20 min. Be sure to turn off or disconnect the load before checking for functionality.

j) Record the following.

1) Record whether an overload protection device operated during the test.

2) Record whether the DUT remains functional after the test is completed. Describe any abnormal operation during or after the test. (If abnormal operation occurred during the test, note whether the behaviour returned to normal when the overload condition was removed.)

3) Record whether the DUT was damaged during the test. Describe and photograph any damage.

4) Record whether any safety hazards developed during the test. Describe and document with photographs where applicable.

5) If the DUT provides indication of the overload condition (for example, a warning light, error code, or audible alarm), describe the indication.

6) Record whether the DUT provides adequate protection against PV overvoltage, if applicable.

The DUT is considered to have adequate output overload protection if all of the following are true.

- The maximum sustained current is less than or equal to the maximum testing current.
- The DUT remains functional after the test. (The DUT is not required to operate normally while the overload condition exists, but shall return to normal operation after the overload is removed.)
- No damage occurred and no safety hazards developed when the DUT was operated at the maximum sustained current for 20 min.

DD.4.3 PV overvoltage protection test

DD.4.3.1 General

The open-circuit voltage of a PV module can be significantly higher than the normal operating voltage of the system when a battery is connected. If not properly regulated, this has the potential to cause damage if applied to system components. Additionally, if a port voltage exceeds a certain value above the nominal design voltage for that port, appliances connected to that port can be damaged. This voltage is defined here as the allowable port voltage limit.

The PV overvoltage protection test assesses whether the DUT

- can withstand a PV overvoltage condition,
- provides sufficient protection to appliances if the system battery is disconnected, and
- provides a mechanism for alerting the user to the fault condition.

The PV overvoltage protection test includes two procedures. The purpose of procedure A (DD.4.3.4) is to determine whether an overcurrent protection device can isolate the battery from the system and result in an overvoltage condition at one or more ports. The purpose of procedure B (DD.4.3.5) is to determine whether such an overvoltage condition occurs when the battery is manually removed from the system.

Procedure A shall be conducted if both of the following are true.

- The battery cannot be isolated from the system by the user or installing technician without opening an enclosure that is not intended to be opened during installation, operation, or maintenance.
- The battery is connected to the system in such a way that it is unlikely to become disconnected during shipping, installation, or normal operation and maintenance. (The battery may be replaceable by a technician using ordinary tools, as long as the connector or other means of disconnecting the battery is not accessible to the user during ordinary use.)

Generally, these conditions are met if the battery is enclosed in a part of the product enclosure that is screwed or glued closed so that tools are required to open it, provided that the battery is adequately fixed in place and all connections are secure. Procedure B is expected to be used primarily in cases where the battery is external to the system or can be removed without the use of tools. (Exception: if the battery is enclosed but the enclosure is opened during installation, operation, or routine maintenance, by following instructions provided by the manufacturer to the user, procedure A should be used.)

DD.4.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- DC power supply.
- DC voltmeter or multimeter.
- resistor(s) selected to draw 0,1 mA ± 10 % at the nominal port voltage for each port.

NOTE For voltages of 5 V, 6 V, and 12 V, this requirement can be met using standard resistor values of 51 kΩ, 62 kΩ, and 120 kΩ, respectively, with 5 % tolerance.

If procedure A (DD.4.3.4) is to be used, the following additional equipment, meeting the requirements in Table CC.2, is required:

- electronic load or fixed and variable resistors as described in DD.4.2.2.
- (optional) battery simulator, as described in DD.4.1.2.

If used, the battery simulator shall have sufficient current capacity to trigger the overload protection identified in the output overload protection test (DD.4.2).

DD.4.3.3 Test prerequisites

The visual screening (Annex F) and photovoltaic module I-V performance test (Annex Q) shall be performed before performing the PV overvoltage protection test. For procedure A (DD.4.3.4), the output overload protection test (DD.4.2) is also a prerequisite; it is likely to be most convenient to perform procedure A immediately after the output overload protection test.

For procedure A (DD.4.3.4), unless a battery simulator is used, the battery shall be at a state of charge sufficient to trigger the overload protection identified in the output overload protection test (DD.4.2). If no overcurrent protection was detected for any port in DD.4.2, this test cannot be performed.

DD.4.3.4 Procedure A

This procedure is for products that meet both of the conditions in DD.4.3.1. If either condition is not met, procedure B (DD.4.3.5) shall be performed instead.

If the battery simulator used for this test can sink and source sufficient current while maintaining a regulated voltage, the test may be performed concurrently with the output overload protection test (DD.4.2) by performing the procedure after DD.4.2 f), while the overload protection device is in the tripped state.

If the overload protection device that disconnected the load in the output overload test (DD.4.2) can be identified from visual inspection, and if it can be determined with certainty through visual inspection of the circuit that this device cannot isolate the battery from the system in a way that would expose any appliance to the unregulated PV module voltage, then this procedure may be omitted. The process used to make this determination shall be documented. Otherwise, perform the following steps.

a) Determine the allowable port voltage limit for each port, using the following procedure.
   1) If the nominal voltage of the port (from Annex EE) is listed in Table DD.2, use the allowable port voltage limit from Table DD.2.
   2) If the nominal voltage of the port is not listed in Table DD.2, determine an appropriate voltage limit using any available information about the loads intended or expected to be connected to the port, taking into account any existing conventions or standards as well as any markings on or documentation provided with the product.

Table DD.2 – Allowable port voltage limit by nominal voltage

Nominal port voltage V	Allowable port voltage limit V
5	5,50
6	7,90
12	15,8

b) Calculate the maximum open-circuit voltage of the PV module using the following formula:

$$V_{oc,max} = 2 \times V_{oc,STC} - V_{oc,TMOT}$$

where

$V_{oc,max}$ is the maximum open-circuit voltage for the PV overvoltage protection test, in volts (V);

$V_{oc,STC}$ is the measured open-circuit voltage at STC, in volts (V);

$V_{oc,TMOT}$ is the measured open-circuit voltage at TMOT, in volts (V).

NOTE This is an estimate of the open-circuit voltage at 0 °C.

If the PV module of the DUT has not undergone the photovoltaic module I-V characteristics test (Annex Q), the average values of the samples that underwent the photovoltaic module I-V characteristics test (Annex Q) shall be used.

c) Disconnect all removable appliances from the DUT.

d) If using a battery simulator, connect the simulator in place of the DUT's battery and set the output voltage to the standard operating voltage (H.5.2). (Omit this step if performing the test concurrently with DD.4.2.)

e) Apply a load to one port of the DUT sufficient to activate (trip) the overcurrent protection for that port identified in the output overload protection test. The exact value of the load current is not critical for this test as long as it activates the overcurrent protection. Alternatively, if the overload protection device that operated in the output overload protection test can be manually activated (e.g., by turning off a circuit breaker or removing a fuse), this may be done instead of activating the overload protection device by applying an excess current.

f) Connect a DC power supply to the PV input connector of the DUT.

g) Apply a voltage equal to the maximum open-circuit voltage calculated in step b). Set the current limit to the short-circuit current of the PV module measured at STC.

h) Disconnect the load from the port.

i) Perform the following steps for one port from each set of identical ports of the DUT.

   1) Select a resistor to draw 0,1 mA at the nominal port voltage. (See DD.4.3.2.)

   2) Connect the resistor to the port.

   3) Perform any actions necessary to turn on the port. (For example, if a DC socket is controlled by a switch, turn the switch on.)

   4) Measure and record the voltage at the port.

j) Turn on any power switches for any built-in appliances, as identified in F.4.1.5 c) 9).

k) Allow the built-in appliances to remain turned on with the power supply applied for 20 min, regardless of whether the appliance functions, unless a safety hazard develops (e.g., smoke or a burning smell). Record any abnormal operation.

l) Reset the overcurrent protection device.

m) Test the functionality of the DUT. The DUT no longer functions if:

   1) If the problem can be identified and repaired by following instructions in the user documentation (e.g., replacing a blown fuse or resetting a tripped circuit breaker), using no tools except a screwdriver used to remove and insert screws, without creating a safety hazard, repair the fault. Only spare parts included with the DUT (or their equivalent, in case the supply of included spare parts is exhausted through repeated testing) may be used. (For example, if a fuse is blown, and the manufacturer did not supply replacement fuses, the DUT fails the test.) If the DUT is functional after the repair, and the repair can be conducted without exposing the person conducting the repair to a safety hazard, the DUT does not fail the test.

   2) If the problem can be easily identified and repaired by the test laboratory, but requires steps not documented in the user documentation, tools other than a screwdriver used to remove and insert screws, or spare parts not included with the DUT, the DUT fails the test. However, the test laboratory may, at its discretion, repair the fault and continue the test.

   3) In the test report, describe any repairs made.

n) Record whether the DUT remains functional at the end of the test, whether any damage occurred, and whether any user safety hazard is present. Describe any failures and take photographs of any visible damage or safety hazards.

o) If the DUT has multiple port types, repeat steps e) through n) with the load connected to one port of each type. (Exception: if two port types are protected by the same overcurrent protection device, the test need not be repeated with the load applied to both port types. This exception only applies if the test lab can determine with certainty the overcurrent protection device that operates in each case.) Note that this procedure can result in multiple voltage values for each port type; report the maximum voltage measured at each port.

The DUT is considered to have sufficient protection from PV overvoltage if all of the following are true.

- All features of the DUT, including built-in appliances, remain functional at the end of the test.
- No safety hazard developed during or after the test.
- The highest voltage measured at each port did not exceed the allowable voltage limit calculated in step a) above.

If the overload protection test failed to detect any overload protection for any port, this procedure cannot be performed. This should be considered a passing result for this test, since it is not possible for an overcurrent protection device to disconnect the battery from the circuit in this situation. (However, the DUT would fail the output overload protection test.)

DD.4.3.5 Procedure B

This procedure is for products that do not meet both of the conditions in DD.4.3.1. If both conditions are met, procedure A (DD.4.3.4) shall be performed instead.

Perform the following steps:

a) Calculate the allowable port voltage limit according to DD.4.3.4 a).

b) Calculate the maximum open-circuit voltage of the PV module according to DD.4.3.4 b).

c) Disconnect all removable appliances from the DUT.

d) Disconnect the battery from the DUT.

e) Connect a DC power supply to the PV input connector of the DUT.

f) Apply a voltage equal to the maximum open-circuit voltage calculated in b). Set the current limit to the short-circuit current of the PV module measured at STC.

g) If the DUT provides an indication of the fault condition (for example, a warning light, error code, or audible alarm), note the type of indication.

h) Perform the following steps for one port from each set of identical ports of the DUT.

   1) Select a resistor to draw 0,1 mA from the port at the nominal port voltage. (See DD.4.3.2.)

   2) Connect the resistor to the port.

   3) Perform any actions necessary to turn on the port. (For example, if a DC socket is controlled by a switch, turn the switch on.)

   4) Measure and record the voltage at the port.

i) Turn on any power switches for any built-in appliances, as identified in F.4.1.5 c) 9).

j) Allow the built-in appliances to remain turned on with the power supply applied for 20 min, regardless of whether the appliance functions, unless a safety hazard develops (e.g., smoke or a burning smell). Record any abnormal operation.

k) Turn off the power supply.

l) Reconnect the battery to the DUT.

m) Test the functionality of the DUT. If the DUT no longer functions, perform the following steps.

   1) If the problem can be identified and repaired by following instructions in the user documentation (e.g. replacing a blown fuse or resetting a tripped circuit breaker), using no tools except a screwdriver used to remove and insert screws, without creating a safety hazard, repair the fault. Only spare parts included with DUT (or their equivalent, in case the supply of included spare parts is exhausted through repeated testing) may be used. (For example, if a fuse is blown, and the manufacturer did not supply replacement fuses, the DUT fails the test.) If the DUT is functional after the repair, and the repair can be conducted without exposing the person conducting the repair to a safety hazard, the DUT does not fail the test.

   2) If the problem can be easily identified and repaired by the test laboratory, but requires steps not documented in the user documentation, tools other than a screwdriver used to remove and insert screws, or spare parts not included with the DUT, the DUT fails the test. However, the test laboratory may, at its discretion, repair the fault and continue the test.

   3) In the test report, describe any repairs made.

n) Record whether the DUT remains functional at the end of the test, whether any damage occurred, and whether any user safety hazard is present. Describe any failures and take photographs of any visible damage or safety hazards.

o) The DUT is considered to have sufficient protection from PV overvoltage if all of the following are true.

   – All features of the DUT, including built-in appliances, remain functional at the end of the test.

   – No safety hazard developed during or after the test.

   – The voltage measured at each port did not exceed the allowable voltage limit calculated in step a) above.

The DUT is not required to function normally during the test, although any abnormal operation should be noted in the test report. The DUT is not required to provide indication of the fault condition (for example, a warning light, error code, or audible alarm), but any such indication should be noted and described.

DD.5 Reporting

Report the following in the protection test report.

- Metadata:
  - report name;
  - procedure(s) used;
  - DUT manufacturer;
  - DUT name;
  - DUT model number;
  - DUT setting;
  - DUT orientation;
  - test room temperature (°C);
  - name of test laboratory;
  - approving person;
  - date of report approval.
- Results for tested DUT aspects for samples 1 through n:

- presence of sufficient protection against miswiring (pass/fail);
- damage present after miswiring protection test (pass/fail);
- user safety hazard present after miswiring protection test (pass/fail);
- fault indication for miswiring (yes/no, description);
- repairs needed after miswiring protection test (yes/no, description);
- presence of sufficient protection against output overload (pass/fail);
- functionality after output overload protection test (yes/no);
- damage present after output overload protection test (yes/no);
- user safety hazard present after miswiring protection test (yes/no);
- fault indication for output overload (yes/no, description);
- repairs needed after output overload protection test (yes/no, description);
- maximum testing current for each port (A);
- maximum sustained current for each port (A);
- presence of sufficient PV overvoltage protection (pass/fail);
- functionality after PV overvoltage protection test (yes/no);
- damage present after PV overvoltage protection test (yes/no);
- user safety hazard present after PV overvoltage protection test (yes/no);
- fault indication for PV overvoltage (yes/no, description).

• Tables:
  - table of results from miswiring protection test including configuration description, description of fault indication, damage, safety hazard, functionality, and overall pass/fail result after test for each configuration (see Table DD.3 for an example).
  - table of nominal voltage, voltage limit, measured voltage, functionality, and pass/fail result during PV overvoltage test for each port and built-in appliance (see Table DD.4 for an example);

• Comments:
  - individual comments, as necessary, for samples 1 through n;
  - overall comments, as necessary, for collective set of samples 1 through n.

Table DD.3 – Example table of miswiring protection test results

Configuration	Sample ID	Fault indication	Damage?	Safety hazard?	Functional ?	Pass/fail	Remarks
PV reverse polarity	1	Warning light	No	No	Yes	Pass	PV fuse replaced with included spare.
	2	Warning light	No	No	Yes	Pass	PV fuse replaced with included spare.
	3	Warning light	No	No	Yes	Pass	PV fuse replaced with included spare.
	4	Warning light	No	No	Yes	Pass	PV fuse replaced with included spare.
Battery reverse polarity	1	Warning light	Yes	Yes	N/A	Fail	Control box emitted smoke. Test was discontinued.
	2	Warning light	No	No	Yes	Pass	
	3	Warning light	No	No	Yes	Pass	
	4	Warning light	No	No	Yes	Pass	
PV/battery plugs swapped	1	--	--	--	--	--	Test not performed due to prior failure.
	2	None	No	Yes	No	Fail	
	3	None	No	Yes	No	Fail	
	4	None	No	Yes	No	Fail	

Table DD.4 – Example table of PV overvoltage test results

Port or built-in appliance	Nominal voltage V	Voltage limit V	Sample ID	Measured voltage V	Functional after test?	Pass/fail
USB port	5	5,50	1	5,09	Yes	Pass
			2	5,08	Yes	Pass
			3	5,19	Yes	Pass
			4	5,36	Yes	Fail
Cigarette lighter port	12	15,8	1	21,3	Yes	Fail
			2	21,3	Yes	Fail
			3	21,7	Yes	Fail
			4	20,9	Yes	Fail
5 mm barrel plug	12	15,8	1	21,4	Yes	Fail
			2	21,4	Yes	Fail
			3	21,5	Yes	Fail
			4	21,0	Yes	Fail
Integrated light	--	--	1	--	Yes	Pass
			2	--	No	Fail
			3	--	Yes	Pass
			4	--	Yes	Pass

Annex EE
(normative)

Assessment of DC ports

EE.1 Background

DC ports (also called receptacles or outlets) are a key component of many stand-alone renewable energy products; the specifications of the DC ports determine what appliances can be powered by the product. Annex EE contains test procedures to determine the following properties of DC ports:

- the output voltage range and current-voltage relationship over a variety of operating conditions;
- the efficiency of the path from the DUT's battery to the port;
- the ability of included appliances to function at the voltage supplied by the port over a variety of operating conditions.

Universal serial bus (USB), a standard defined by the USB Implementers Forum, is a common port format for charging mobile phones and other portable devices, as well as providing power to small electronic appliances. Annex EE contains additional procedures to evaluate the performance of USB ports, including undershoot and overshoot during step increases and decreases in current, to ensure that these ports can safely power mobile phones and other portable devices. These test methods are derived from the *USB Battery Charging Specification*, revision 1.2, and the *USB Battery Charging 1.2 Compliance Plan*, revision 1.0, published by the USB Implementers Forum.

EE.2 Test outcomes

The test outcomes of the DC ports assessment are listed in Table EE.1.

Table EE.1 – DC ports assessment outcomes.

Metric	Reporting units	Related aspects	Remarks
Minimum port voltage for each port	Volts (V)	4.2.7.5 DC ports	One value for each port
Maximum port voltage for each port	Volts (V)	4.2.7.5 DC ports	One value for each port
Plots of output voltage vs. output current, and associated data, for each port and each simulated battery voltage	Volts (V), amperes (A)	4.2.7.5 DC ports	Three or four plots for each tested port, and associated tabular data.
Plots of output voltage vs. output power, and associated data, for each port and each simulated battery voltage	Volts (V), watts (W)	4.2.7.5 DC ports	Three or four plots for each tested port, and associated tabular data
Plots of battery-to-port efficiency vs. output current, and associated data, for each port and each simulated battery voltage	Percentage, amperes (A)	4.2.7.5 DC ports	Three or four plots for each tested port, and associated tabular data
Plots of battery-to-port efficiency vs. output power, and associated data, for each port and each simulated battery voltage	Percentage, watts (W)	4.2.7.5 DC ports	Three or four plots for each tested port, and associated tabular data
Shared and individual resistances for each set of multiple identical ports	Ohms (Ω)	4.2.7.5 DC ports	These values are used to adjust appliance power consumption and battery-to-appliance efficiency to account for the simultaneous use of multiple appliances.

Metric	Reporting units	Related aspects	Remarks
Power consumption values for each built-in appliance	Watts (W)	4.2.7.2 Power consumption	One value for each built-in appliance
Functionality of each appliance for each simulated battery voltage	Yes/no	4.2.7.1 Appliance voltage compatibility	Three values for each tested appliance
Tables of peak overshoot voltages, minimum undershoot voltages, and undershoot times for each port and each voltage tested.	Volts (V), milliseconds (ms)	4.2.7.5 DC ports	Three tables for each port, showing values for each current transition.
Maximum power for each port	Watts (W)	4.2.7.5 DC ports	One value for each port
Pass/fail for functionality for each port	Yes/no	4.2.7.5 DC ports	One value for each port
Pass/fail for truth in advertising for each port	Yes/no	4.2.7.5 DC ports	One value for each port
Data line resistance for each USB port	Ohms (Ω)	4.2.7.5 DC ports	One value for each USB port
Voltage on D- line for each USB port	Volts (V)	4.2.7.5 DC ports	One value for each applicable USB port
Voltage on D+ line for each USB port	Volts (V)	4.2.7.5 DC ports	One value for each applicable USB port

EE.3 Related tests

The tests in Annex EE use some of the same equipment as the protection tests (Annex DD), particularly the output overload protection test (DD.4.2), which is a prerequisite. Test laboratories may perform the DC ports tests immediately after the protection tests to take advantage of equipment commonalities. However, since the protection tests are potentially destructive, they are generally not performed on the same samples.

Several other tests, including the visual screening (Annex F), the charge controller behaviour test (Annex S), the solar charge test (Annex R), and the full-battery run time test (Annex M), are used to derive operating parameters for the ports tests.

The efficiencies measured in EE.4.2 are used in the energy service calculations (Annex GG). The voltage vs. current and power data measured in Annex EE are used in the appliance tests (Annex FF), including the determination of appliance operating voltage (Clause FF.5).

EE.4 Procedure

EE.4.1 Preparation

Perform the following steps.

a) Identify the ports to be tested. All ports capable of supplying power, including mobile device charging ports, shall be tested, except that if the DUT has multiple identical ports only one port need be tested from each group of identical ports. Ports shall be considered identical only if they have identical driver circuitry and identical voltage and current limits.

b) If multiple samples of the product are being tested, the selected port from each group shall rotate between samples.

EXAMPLE Six samples of a product with three USB ports are to be tested. Port 1 would be tested on samples 1 and 4, port 2 on samples 2 and 5, and port 3 on samples 3 and 6.

c) If a port has multiple selectable voltage settings, each setting shall be considered a separate "port" for the purposes of testing.

d) Identify the maximum current for each port, using the following procedure.

1) Use the maximum sustained current, measured in the output overload protection test (DD.4.2), if the value could be determined and no damage or safety hazard occurred at a current less than or equal to the maximum sustained current.
2) If, during the output overload protection test, damage or a safety hazard was noted when a current less than or equal to the maximum sustained current was applied to the port, the maximum current for this test is the highest possible current that does not result in damage or a safety hazard.
3) If the maximum sustained current could not be determined during the output overload protection test, the advertised or rated maximum current should be used. If there is no advertised or rated maximum current, the test laboratory should request this information from the manufacturer. If the manufacturer is unable to provide the rated maximum current, the test laboratory should determine an appropriate maximum value. If possible, the value chosen should be at least the maximum current drawn by the advertised or included appliances. The following procedure can be used, if necessary, to determine the current required by an included or advertised appliance:
   i) Set up the DUT according to EE.4.2.6 a) through c).
   ii) For included appliances, connect the appliance to the port at the highest setting that will be measured (see Clause FF.6). For advertised appliances, connect an electronic load set to constant-power mode, with the power setpoint determined following the procedure in HH.5.2. If an electronic load with this feature is not available, use constant-current or constant-resistance mode, or use a variable resistor, and adjust the load until the desired power value is achieved.
   iii) Vary the power supply voltage (simulated battery voltage) between the values specified in EE.4.2.6 c) and i) through k).
   iv) Record the highest value of port current measured in steps ii) and iii).

   A maximum current value of 2,5 A is generally appropriate for USB ports that can be used to charge mobile phones or tablet computers. The method used to determine the appropriate maximum current value shall be documented and reported.

e) Identify any special procedures required to enable the output on each port. For example, some USB ports require an attached device to be enumerated and negotiate to receive power in excess of a certain limit, and some products use proprietary tamper-proofing strategies to supply power only to authorized appliances. If any such requirements exist, the manufacturer of the DUT should be consulted to develop a plan to test the port.
f) Determine whether the port should be treated as a USB port for the purposes of this test. A port shall be considered a USB port if any of the following is true:
   – the port accepts a standard USB connector;
   – the DUT includes an adapter that allows a USB connector to be connected to the port;
   – the port is intended or expected to be used for charging mobile devices with a nominal DC input voltage of 5 V.

EE.4.2 Measurement of steady-state port characteristics

EE.4.2.1 Overview

EE.4.2.1.1 General

This test measures the relationship of output voltage and steady-state battery-to-port efficiency to load current at three or four simulated battery voltages, defined in EE.4.2.6:

a) the typical battery discharge voltage (Clause M.8), corresponding to typical operation during discharge;
b) a voltage corresponding to operation in a deeply discharged state;
c) (optional) the average charging voltage measured during the solar charge test (Annex R), corresponding to typical operation during solar charging;
d) a voltage corresponding to operation during solar charging with a nearly full battery.

In addition, several other parameters not directly related to port performance are measured at the time of this test. These measurements are described in EE.4.2.1.2 through EE.4.2.1.4.

EE.4.2.1.2 Voltage droop measurement

For products with multiple identical ports, a load connected to one port can cause voltage droop at the other ports. This can in turn affect the power consumption of appliances connected to the other ports. The combined load can also affect the efficiency of the port's voltage regulator or DC-DC converter, if present. To measure these effects, the open-circuit voltage of an unloaded port is measured.

EE.4.2.1.3 Appliance voltage compatibility

This test also assesses the ability of built-in and removable appliances to function normally and without damage at the voltage levels supplied by the product's ports under these usage conditions, and measures the power consumption of built-in appliances. These tests are carried out in EE.4.2.6 f) through h). The number of appliance samples used in steps EE.4.2.6 g) and EE.4.2.6 h) should be the same as the number of samples required for the appliance operating voltage range test. This may be different from the sample size for the assessment of DC ports. If the product specification requires a sample size greater than one, each combination of product sample and appliance sample shall be tested. The specifying organization should consider the added cost of testing multiple combinations of product and appliance when defining the sample size for the appliance operating voltage range test.

EXAMPLE 1 The product specification requires a sample size of 1 for the appliance operating voltage range test and a sample size of 4 for the assessment of DC ports. The product includes a main power control unit and a fan without internal battery. Step EE.4.2.6 g) would be carried out 16 times: once for each voltage level and each power control unit sample, using the same fan sample for each test.

EXAMPLE 2 The product specification requires a sample size of 4 for both the appliance operating voltage range test and the assessment of DC ports; the other product details are the same as Example 1. Step EE.4.2.6 g) would be carried out 64 times: once for each combination of voltage level, power control unit sample, and fan sample.

The laboratory may choose to perform the appliance operating voltage test (Clause FF.8) instead of steps EE.4.2.6 g) and EE.4.2.6 h) for some or all appliances included with the product. The use of Clause FF.8 can be advantageous in the following circumstances:

- One or more appliances are used with more than one product under test. In some circumstances, described in FF.8.4, the results from a single test may be used for multiple products with identical appliances.
- One or more lighting appliances without batteries have been previously tested according to the input voltage range test of IEC TS 62257-12-1.
- The laboratory testing the appliances does not possess samples of the full product.
- The product specification requires a sample size greater than 1 for the appliance operating voltage range test.

In cases where, as identified in F.4.1.5 a) 19) and F.4.1.5 b) 1), multiple appliances without internal batteries that provide the same type of service, e.g. lighting, can be connected to a single port, these appliances may be treated as a single appliance or as individual appliances. The product specification may provide further guidance on treatment of these appliances.

EE.4.2.1.4 Built-in appliance power consumption

The test procedure includes an evaluation of the functionality and power consumption of built-in appliances, such as a light or radio integrated into the power control unit. Built-in appliances are defined in 4.1.4 and identified in the visual screening in F.4.1.5 c) 10).

The average power consumption of some built-in appliances is measured in the full-battery run time test (Annex M) or appliance full-battery run time test (Clause FF.9). This is the case for products with a single built-in light and for some products with built-in non-lighting appliances. For these built-in appliances, the average power determined from the full-battery run time test (Annex M) or appliance full-battery run time test (Clause FF.9) can be more representative of typical operating conditions than the single-point measurements performed in the assessment of DC ports. In such cases, the measurement of power consumption in EE.4.2.6 f) for the tested setting(s) of the appliances that underwent the full-battery run time test or appliance full-battery run time test may be omitted, and the average power consumption from the full-battery run time test or appliance full-battery run time test may be used instead. This substitution is not possible if the full-battery run time test configuration included multiple appliances (e.g. a built-in light and a removable, external light point).

EE.4.2.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- DC power supply with sufficient output current to achieve the maximum current identified in EE.4.1 d).
- Two DC ammeters or multimeters.
- Two DC voltmeters or multimeters.
- Electronic load or variable and fixed resistors with specifications calculated in EE.4.2.6.
- Resistor(s) selected to draw a current of 0,1 mA ± 10 % at the nominal port voltage for each port. (The electronic load may be used if it has sufficient resolution.)

NOTE For voltages of 5 V, 6 V, and 12 V, this requirement can be met using standard resistor values of 51 kΩ, 62 kΩ, and 120 kΩ, respectively, with 5 % tolerance.

In some cases, it can be necessary to use multiple laboratory power supplies in parallel to achieve the required current. Unless otherwise specified by the power supply manufacturer, a diode should be used at the output of each power supply to prevent backfeeding. If the power supplies do not include current-sharing functionality, set one power supply to constant-voltage mode to control the voltage and set the remaining power supplies to constant-current mode with a voltage limit not exceeding the battery’s overcharge protection voltage threshold, as measured in the charge controller behaviour test (Annex S).

The currents required in this test can exceed the maximum range of many multimeters. In this case, a current transducer or current sense resistor and voltmeter may be used instead of an ammeter or multimeter. The voltage should be measured at the DUT to compensate for the voltage drop across the ammeter or current sense resistor.

If an electronic load is used, and the electronic load contains current and voltage measurement functionality that meets the requirements for DC ammeters and voltmeters in Table CC.2 after accounting for any voltage drop between the port and the load, this functionality may be used instead of an ammeter and/or voltmeter at the port.

The electronic load shall be galvanically isolated from the power supply if this is necessary in order to avoid altering the behaviour of the DUT.

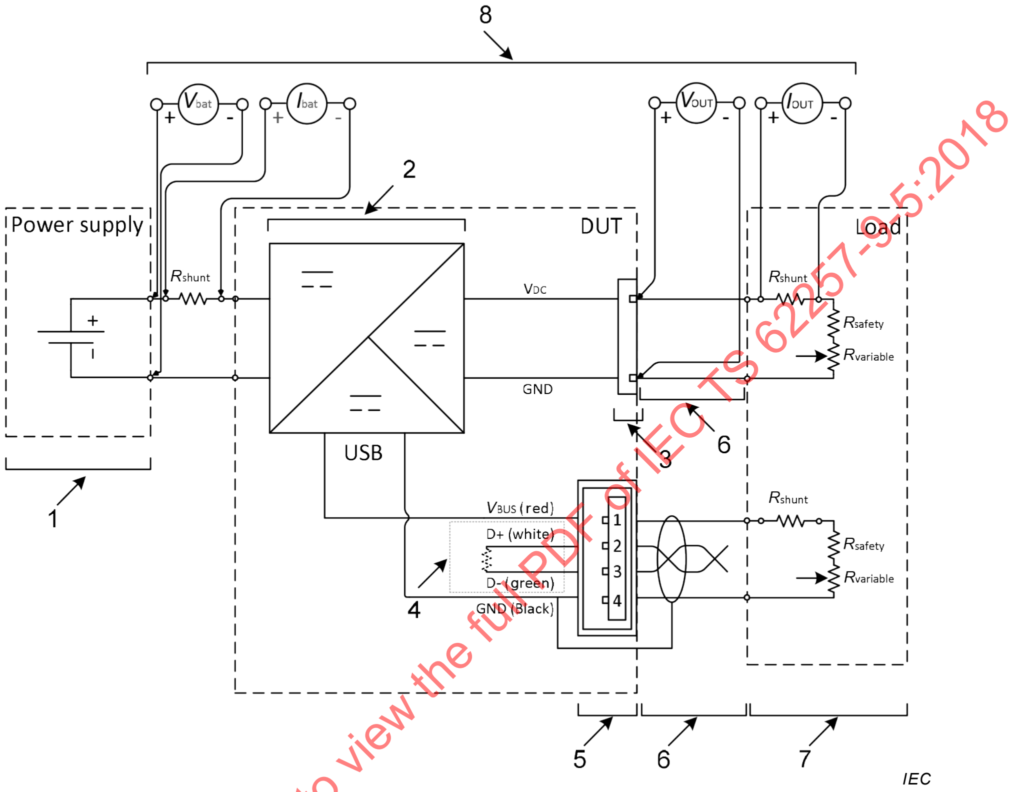
This test involves a calculation of electrical power; see Clause CC.3 for related recommendations. For most products, the current and voltage will be constant during the test, so it is not necessary to use a power-measuring instrument. However, some products incorporate pulse-width modulation (PWM) controllers, e.g. for dimming lights connected to the ports. For such products, if the PWM function is active during the measurement, a power-measuring instrument should be used, as described in Clause CC.3.

EE.4.2.3 Test prerequisites

The output overload protection test (DD.4.2), charge controller behaviour test (Annex S), and solar charge test (Annex R) shall be performed prior to the measurement of steady-state port characteristics. In addition, if the deep discharge protection voltage is measured during the full-battery run time test (Annex M), this test shall be performed prior to the measurement of steady-state port characteristics.

EE.4.2.4 Apparatus

Example apparatus for the measurement of port characteristics during discharge is shown schematically in Figure EE.1.



Key

1 DC power supply in place of DUT's battery

2 DC-DC converter from the battery voltage to output voltage

3 Standardized DC port (e.g. 12 V)

4 Data pins configuration (D+ and D- are shorted with max. resistance 200 Ω for dedicated charging port type). The configuration might be different depending on its capability to charge particular a mobile device

5 Standard USB female port

6 Cable with DC adapter and USB cable with shield and drain wire connected to the ground

7 Load with a fixed resistor to prevent short circuit and variable resistors

8 Voltage and current measurements using DC multimeters and shunt resistors

Figure EE.1 – Schematic of the example DUT with DC port and USB port and variable resistors connected for the measurement of steady-state port characteristics

EE.4.2.5 Special port features

EE.4.2.5.1 General

Some ports have special features that can complicate the testing process. Procedures are defined for two types of special features: security or anti-tampering functions, and pulse width modulation (PWM). For other special features that interfere with testing, the test laboratory should work with the manufacturer to develop a procedure to test the product successfully.

Appliances connected to ports with special features that interfere with testing may be tested as if they were built-in appliances. However, if multiple appliances or combinations of appliances can be connected to such a port, this option should be avoided when possible since each configuration of appliances and settings would then be measured individually as a separate "setting" of the built-in appliance.

EE.4.2.5.2 Ports with security features

Some products include security features so that the ports can only be used to power "authorized" appliances included with the product or sold separately by the manufacturer. In this case, the authorized appliances may be used as the load, instead of an electronic load or variable resistor. The measured current values should be as close as possible to the target values specified in EE.4.2.6. If it is not possible to obtain at least three current values by using the authorized appliances, the laboratory should work with the manufacturer to determine a way to test additional currents.

If the security feature is implemented by varying the current or voltage, a power-measuring instrument should be used as described in Clause CC.3.

EE.4.2.5.3 Ports with pulse width modulation (PWM)

Some ports have PWM functionality incorporated into the power control unit, for example for dimming a light or controlling the speed of a fan. The following quantities should be recorded for the port, for each PWM setting and each port current value tested. (If the PWM duty cycle is continuously adjustable, use the minimum and maximum settings, and an intermediate setting if repeatable):

- On voltage (voltage during the part of the cycle when the port supplies power to the load);
- On current;
- On power;
- Duty cycle (the fraction of the time that the port is "on");
- Frequency;
- Average power;
- Average voltage (optional);
- Average current (optional).

The values at the highest setting should be used for the calculations and plots in Annex EE, and these values should be used in other test procedures that reference these data sets. If the PWM function is active even at the highest setting, the on current and voltage should be used in the calculations and plots; the average values are provided only for information.

These quantities may be measured using an oscilloscope, power meter, or similar instrument, or a combination of instruments. The on current and power may be determined by measuring the instantaneous or average values during the on period or, if the off values are known to be negligible, by dividing the average values (over the full cycle) by the duty cycle. (The latter can be more accurate if the average power and duty cycle measurements have less uncertainty than the instantaneous measurements, as can be the case if the average value is measured with a power meter and the instantaneous measurements are made with an oscilloscope.) The same methods may be used for the on voltage; however, the off voltage is more likely to be nonzero, in which case dividing the average by the duty cycle will give an incorrect result.

EE.4.2.6 Procedure

Perform the following steps.

a) Build the test configuration as in Figure EE.1.

b) Prepare the DUT sample according to Annex G.

c) Use a laboratory power supply to power the DUT power control unit according to Annex H. Set the power supply to the typical battery discharge voltage (Clause M.8).

d) Measure the current and voltage at the battery with no loads applied, using the same instruments that will be used in step e) 14). In the measurement of battery current, the multimeter or ammeter should be set to the same range throughout the test so that any offset will remain constant. Any power switches that do not control individual loads shall be turned on. (For example, if the DUT has a master power switch, turn it on.)

e) For each port under test, perform the following steps.

   1) If there are multiple identical ports of this type, select one to be the "loaded port" and one to be the "unloaded port." This selection may be arbitrary. The loaded port is the port to be characterized, to which the load is connected. The voltage at the unloaded port will be measured to characterize the effect of a connected load on the other ports.

   2) Connect a resistor to the loaded port to draw a current of 0,1 mA ± 10 % at the nominal port voltage (see DD.4.3.2). If an electronic load will be used in place of the safety resistor and variable resistor, the load may be used instead of a resistor if the programming resolution is sufficient to achieve the required current value.

   3) Measure the loaded port voltage using the same instrument that will be used in step 14). Record the port voltage and either the port current or the resistor value.

   4) Remove the resistor (if used).

   5) Connect a resistor of the same value used in step 2) to the unloaded port (if present).

   6) With the resistor connected, measure the unloaded port voltage using the same instrument that will be used in step 14). This is the zero-load voltage.

   7) If using an electronic load, connect the electronic load to the loaded port if this was not done in step 2) or 3). Skip steps 8) through 10) and proceed to step 11).

   8) Calculate the safety resistor value, R_{safety}, corresponding to a current of 100 % of the maximum current at the nominal port voltage (from F.4.1.5):

$$R_{safety} = \frac{V_{nom,port}}{I_{max,port}}$$

   where

   R_{safety} is the safety resistor value, in ohms (Ω);

   $V_{nom,port}$ is the nominal voltage of the port (from F.4.1.5), in volts (V);

   $I_{max,port}$ is the maximum current for the port, in amperes (A).

   The safety resistor should have a power rating sufficient to allow the maximum voltage of the port to be applied:

$$P_{Rsafety} \geq \frac{V^2_{max,port}}{R_{safety}}$$

   where

   $P_{Rsafety}$ is the maximum power rating of the safety resistor, in watts (W);

   $V_{max,port}$ is the maximum expected voltage of the port, in volts (V);

   R_{safety} is the safety resistor value, in ohms (Ω).

   9) Calculate the value of the variable resistor $R_{variable}$. The full-scale resistance of the variable resistor in series with the fixed resistor R_{safety} should result in a current of no more than 10 % of the maximum current for the port (EE.4.1 d)) at the nominal port voltage (F.4.1.5):

$$R_{\text{variable}} \geq \frac{V_{\text{nom,port}}}{0{,}1 \times I_{\text{max,port}}} - R_{\text{safety}}$$

where

R_{variable} is the variable resistor value, in ohms (Ω);

$V_{\text{nom,port}}$ is the nominal voltage of the port (from F.4.1.5), in volts (V);

$I_{\text{max,port}}$ is the maximum current for the port, in amperes (A);

R_{safety} is the safety resistor value, in ohms (Ω).

The variable resistor should have a maximum current rating sufficient to allow the maximum current of the port to be applied and a resolution sufficient to achieve the required current values (10 %, 20 %, 40 %, 60 %, 80 %, and 100 % of the maximum current) to within 5 %.

NOTE 1 Variable resistors are generally rated by their manufacturers according to the maximum power dissipation of the full resistance element. If a maximum current rating is not given by the component manufacturer, the minimum allowable power rating can be calculated based on the full-scale resistance:

$$P_{\text{Rvariable}} \geq I^2_{\text{max,port}} \cdot R_{\text{variable}}$$

where

$P_{\text{Rvariable}}$ is the maximum power rating of the variable resistor, in watts (W);

$I_{\text{max,port}}$ is the maximum current for the port, in amperes (A);

R_{variable} is the variable resistor value, in ohms (Ω).

10) Connect the safety and variable resistors, in series, to the output of the loaded port.

11) Adjust the variable resistor or electronic load so that the current is 10 % of the maximum current for the port (EE.4.1 d)), with a tolerance of ± 5 %. The electronic load should be used in constant-current mode if available.

12) Adjust the power supply voltage so that the voltage at the battery terminals remains constant, at the value set in c), throughout the test as the load is increased. It is very important to minimize any drift or droop in the simulated battery voltage.

13) Allow the voltage to stabilize, adjusting the power supply voltage if necessary.

14) Using a DC ammeter and voltmeter, or two multimeters, record the current and voltage at the loaded port. Simultaneously, measure and record the voltage and current at the battery input terminals and the voltage at the unloaded port (if applicable).

15) Repeat steps 10) to 13) with total resistance values corresponding to 20 %, 40 %, 60 %, 80 %, and 100 % of the maximum current (within 5 %). If the DUT cannot sustain 100 % of the maximum sustained current measured in the output overload protection test, reduce the current to a level that can be sustained with a stable port voltage for the duration of the test. (In this case the 5 % tolerance requirement does not apply.) This situation does not in itself result in a failure for functionality or truth in advertising (see EE.4.5). Reduce the current in increments of no more than 2,5 % of the maximum current.

16) Perform any additional measurements necessary to verify compliance with the product specification, if applicable.

17) Disconnect the resistors or electronic load from the loaded port, and disconnect the resistor from the unloaded port if applicable.

f) Perform the following procedure for each built-in appliance, if any, as defined in 4.1.4 and identified in the visual screening F.4.1.5 c) 10). Note that according to F.4.1.5 c) 10) some light points may be considered "built-in" even if they can be unplugged. This step may be omitted for certain built-in appliances that underwent the full-battery run time test or appliance full-battery run time test, as described in EE.4.2.1.4.

   1) Identify the appliance settings to be measured by referring to the procedure in Clause FF.6 that pertains to the type of appliance under test.

2) Turn on the built-in appliance. Record whether the appliance functions correctly.

3) If testing at the typical battery discharge voltage, perform the following steps to measure the appliance power consumption. These steps are not required at the low-battery voltage, overcharge protection voltage, or average charging voltage.

   i) Allow the appliance to stabilize according to the appropriate stabilization procedure in Clause FF.6. (It is not necessary to determine the appliance operating voltage according to Clause FF.5.)

   ii) Measure and record the power consumption at the battery, following the appropriate procedure (i.e. test conditions and averaging period) in Clause FF.6.

   iii) If multiple settings are to be measured, repeat the measurement for each setting, following the appropriate stabilization procedure in Clause FF.6.

g) Perform the following procedure for each included appliance, without an internal battery, intended to be connected to the port under test, other than built-in appliances, which were tested in step f). This step may be omitted for appliances that will undergo the appliance operating voltage range test (Clause FF.8). Repeat the step for all appliance samples as described in EE.4.2.1.3.

1) Connect the appliance to the port. If the appliance can be turned off, leave the appliance connected to the port but turned off for at least 5 min.

2) Turn on the appliance and allow it to operate for at least 5 min. Record whether the appliance functions correctly. If the appliance has multiple settings or operating modes, operate the appliance for 5 min in a setting or mode with high expected power consumption and 5 min in a setting or mode with low expected power consumption.

EXAMPLE For a fan, use the highest and lowest speeds.

3) Disconnect the appliance.

h) Perform the following procedure for each appliance with an internal battery, intended to be connected to the port under test, other than built-in appliances, which were tested in step f). This step may be omitted for appliances that will undergo the appliance operating voltage range test (Clause FF.8). Repeat the step for all appliance samples as described in EE.4.2.1.3.

1) Fully discharge the appliance's battery. An appliance battery may be considered fully discharged if the appliance turns off with a low-voltage disconnect or reaches the discharge endpoint determined in the appliance full-battery run time test (Clause FF.9). It is not necessary to measure the appliance performance during the discharge or to stop the discharge precisely at the defined discharge endpoint. Alternatively, the battery may be removed and discharged using a battery analyser, using the discharge parameters from the battery test (Annex K).

2) Connect the appliance to the port and leave it connected for at least 5 min. Determine whether the appliance charges by observing the port current as well as any charging indicators on the appliance. Record whether the appliance charges.

3) Fully charge the appliance's battery. (Alternatively, use a different sample of the appliance with a fully charged battery.)

4) Connect the appliance to the port and leave it connected for at least 5 min. In some cases, an appliance will briefly charge when connected even though the battery was fully charged. In this case, allow the appliance to stop charging (e.g., wait until the current drops to zero or to a low value) before starting the five-minute waiting period.

5) Disconnect the appliance from the port.

6) Check the appliance for functionality. Note any damage or abnormal operation.

i) Change the power supply voltage (simulated battery voltage) to the low-battery voltage, given by the formula below, then repeat steps d) through h). (If the DUT will not turn on or will not stay on at the selected voltage, increase the voltage in 0,05 V increments until the DUT turns on, then decrease the voltage in 0,05 V increments to the lowest value for which the DUT remains on.)

$$V_{low} = 0{,}1 \times \left(V_{OCP} - V_{DDP}\right) + V_{DDP}$$

where

V_{low} is the low-battery voltage, in volts (V);

V_{OCP} is the maximum battery voltage measured during the active overcharge protection test (S.4.2), or, if the active overcharge protection test need not be performed for the DUT, the maximum battery voltage observed during the solar charge test (Annex R), in volts (V);

V_{DDP} is the deep discharge protection voltage measured during the full-battery run time test (Annex M) or charge controller behaviour test (S.4.1), in volts (V);

NOTE 2 This voltage typically corresponds to a remaining run time of approximately 5 % to 10 % of the full-battery run time.

j) Change the power supply voltage (simulated battery voltage) to the maximum battery voltage measured during the active overcharge protection test (S.4.2), or, if the active overcharge protection test need not be performed for the DUT, the maximum battery voltage observed during the solar charge test (Annex R). Repeat steps d) through h) at this voltage. (If the DUT will not turn on or stay on at the selected voltage, decrease the voltage in 0,05 V increments to the lowest value for which the DUT remains on.)

   For products whose ports cannot be used while the product is charging, use the maximum battery voltage during the full-battery run time test (Annex M) instead of the maximum voltage measured during the active overcharge protection test or the solar charge test, and omit step k). Typically, the maximum voltage during the full-battery run time test is the voltage immediately after the DUT is turned on.

k) (optional) Change the power supply voltage (simulated battery voltage) to the average charging voltage measured during the solar charge test (Annex R). Repeat steps d) and e). Steps f) through h) need not be repeated at this voltage.

EE.4.2.7 Calculations

Perform the following calculations for each simulated battery voltage measured in EE.4.2.

a) For each operating point tested, calculate the battery input power and port output power by multiplying the current and voltage values.

b) For each battery voltage setting, calculate the idle power, P_{idle} , by multiplying the current and voltage measured at the battery with no load applied.

c) For each battery voltage setting, port, and load current, calculate the battery-to-port efficiency using the following formula:

$$\eta_{batt\text{-}port} = \min\left(1, \frac{P_{port}}{P_{batt} - P_{idle}}\right) \times 100\ \%$$

where

$\eta_{batt\text{-}port}$ is the battery-to-port efficiency, as a percentage (%);

P_{port} is the port output power, in watts (W);

P_{batt} is the power supplied to the DUT by the simulated battery, in watts (W);

P_{idle} is the idle power, in watts (W).

d) For each battery voltage setting and each setting of each built-in appliance, calculate the power consumption using the following formula:

$$P_{app} = P_{batt,app} - P_{idle}$$

where

P_{app} is the appliance power consumption, in watts (W);

$P_{batt,app}$ is the power supplied to the DUT by the simulated battery when the appliance is in use, in volts (V);

P_{idle} is the idle power, in watts (W).

e) For each port and each battery voltage setting, plot the following (see Figure EE.2).

   1) Output voltage vs. output current.

   2) Output voltage vs. output power (P_{port}).

   3) Battery-to-port efficiency ($\eta_{batt\text{-}port}$) vs. output current.

   4) Battery-to-port efficiency ($\eta_{batt\text{-}port}$) vs. output power (P_{port}).

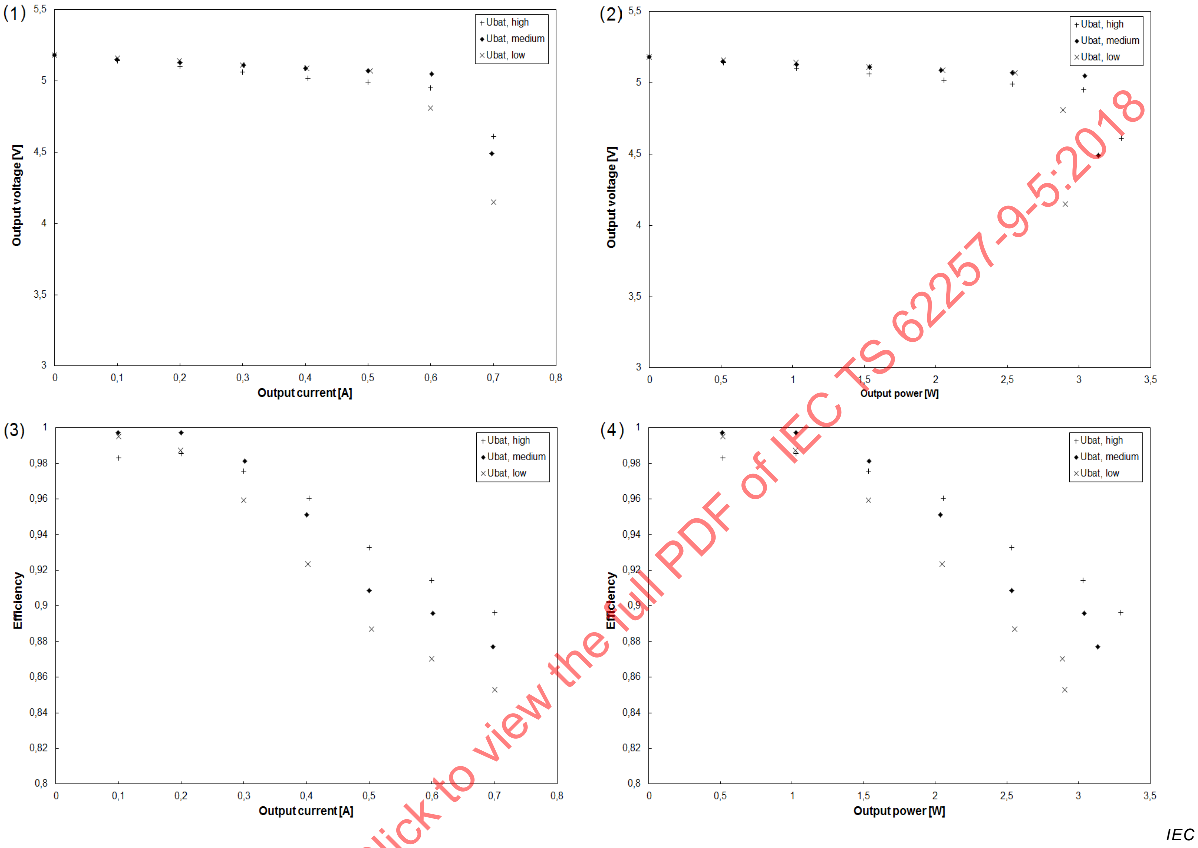


Figure EE.2 – Example of the plots of port characteristics

Perform the following calculations for each set of multiple identical ports at the typical battery discharge voltage only:

f) For each measurement condition, subtract the voltage measured at the unloaded port from the zero-load voltage measured in EE.4.2.6 e) 5). This is the shared voltage drop (ΔV_{shared}).

g) For each measurement condition, subtract the voltage measured at the loaded port from the voltage measured at the unloaded port. This is the individual voltage drop (ΔV_{indiv}).

h) Plot the shared voltage drop (ΔV_{shared}) and individual voltage drop (ΔV_{indiv}) as a function of the current at the loaded port, excluding the measurement at zero current and the highest measured current. Also exclude any additional points that appear to correspond to an unstable or atypical operating condition; typically these points occur at higher currents.

i) Fit a line to each set of plotted points. The slope of ΔV_{shared} in volts vs. port current in amperes is the shared resistance (R_{shared}), in ohms, and the slope of ΔV_{indiv} in volts vs. port current in amperes is the individual resistance (R_{indiv}), in ohms.

NOTE The shared and individual resistance values do not necessarily correspond to physical resistances. In particular, either or both values can be negative.

EE.4.3 Dynamic measurement

EE.4.3.1 General

In this test, the dynamic performance of the DC port is evaluated. The DC port is loaded with a variable pulsed load that represents the typical dynamic load (i.e. mobile charging, LED driver). The voltage and current transients are analysed by recording the data acquisition device (e.g. oscilloscope). Two different input voltages (high and low battery operational voltage) are performed to evaluate the capability of the port to cope with the dynamic load at different levels of states of charge.

This test is based on the DCP overshoot and undershoot voltage test from the *USB Battery Charging 1.2 Compliance Plan*, revision 1.0, published by the USB Implementers Forum.

This test may be omitted for all ports that are not USB ports as defined in EE.4.1.

EE.4.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Table CC.2.

- Electronic load capable of generating a stepped current waveform as defined in Table EE.2, with a minimum step duration of 20 ms and three or four distinct current levels (including zero), depending on whether optional tests are performed. Many commercially available electronic loads meet this requirement; alternatively, the load may be constructed using fixed and/or variable power resistors (see EE.4.2.6 for calculations) and/or power MOSFETs or similar switching devices.
- DC power supply.
- Digital storage oscilloscope or data-logging device capable of recording voltage and current at a rate of at least 1 000 samples per second. This functionality may be incorporated into the electronic load.
- Current transducer or current sense resistor, if needed, to allow current to be recorded by the oscilloscope or data-logging device. This functionality may be incorporated into the electronic load. (For example, some electronic loads provide an analogue current monitor output.)

The oscilloscope or data-logging device shall be galvanically isolated from the power supply and load if this is necessary in order to avoid altering the behaviour of the DUT. Any isolation device shall have sufficient bandwidth to accurately measure the voltage transients.

The voltage drop between the power supply and the DUT's battery input terminals shall be minimized; components such as ammeters and diodes (which are required or permitted in EE.4.2) shall not be included between the power supply and the DUT for the dynamic port measurement.

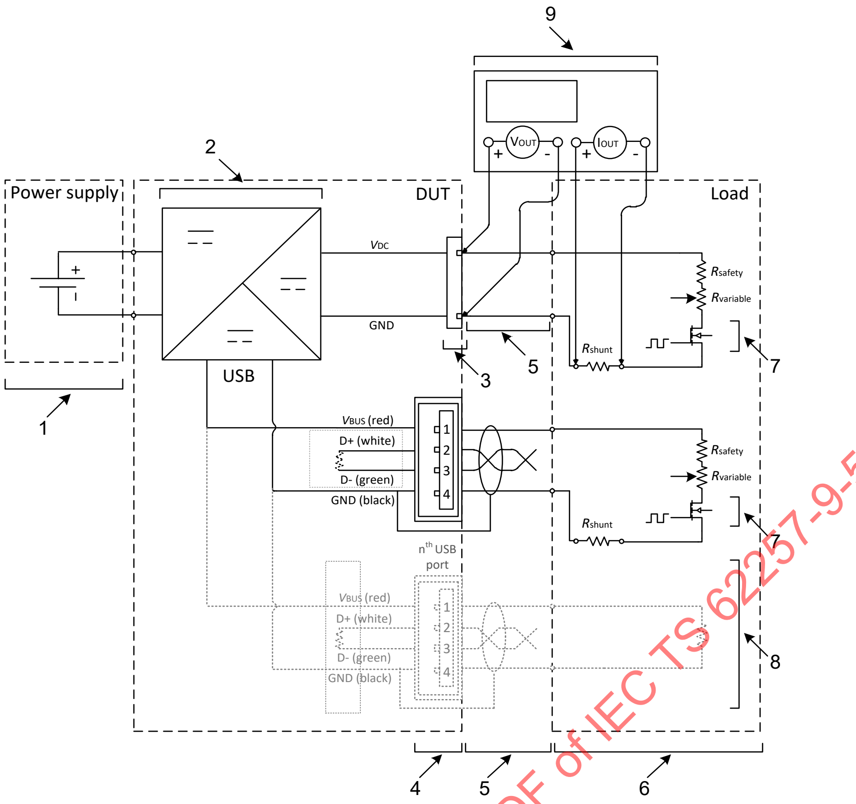
NOTE Since this test is only performed on USB ports, in most cases, a lower power supply current will be used than in the steady-state measurement of high-current ports (EE.4.2), and the test can be performed without using multiple power supplies in parallel.

EE.4.3.3 Test prerequisites

The test prerequisites are identical to those for the measurement of steady-state port characteristics (EE.4.2).

EE.4.3.4 Apparatus

Example apparatus for the dynamic port measurement is shown schematically in Figure EE.3.



Key

1 DC power supply in place of DUT's battery

2 DC-DC converter from the battery voltage to output voltage

3 Standardized DC port (e.g. 12 V)

4 Standard USB female port

5 Cable with DC adapter and USB cable with shield and drain wire connected to the ground

6 Pulse load with a fixed resistor to prevent short circuit and variable resistors

7 Electronic switch controlled by pulse generator

8 Additional USB port

9 Oscilloscope

Figure EE.3 – Schematic of the DUT with DC port and USB port and variable resistors connected for the dynamic measurement

EE.4.3.5 Procedure

The following steps shall be followed to evaluate the transient response of the port.

a) Build the test configuration illustrated in Figure EE.3 with pulsed load specified in EE.4.3.2.

b) Use a laboratory power supply to power the DUT power control unit according to Annex H. Set the power supply to the typical battery discharge voltage (Clause M.8).

c) Connect the voltage and current data acquisition device at the output of the DC port. Set the logging interval or sampling rate to at least 1 ms or 1 000 samples per second.

d) Perform either of the following procedures to conduct the test. Procedure 1 can be performed using low-cost equipment, while procedure 2 can be simpler to perform if a suitable electronic load is used. The currents shall be accurate to within 5 %.

   1) Procedure 1:

i) Configure the pulsed load to alternate between the two current levels shown in the first row of Table EE.2 with a frequency of no more than 5 Hz and duty cycle of 50 %.

ii) Record the voltage and current for at least 100 ms after the current transitions indicated in Table EE.2.

Table EE.2 – Current pairs for dynamic test

Row number	Current 1 A	Current 2 A	Current transitions to record
1	0,0	0,1	Rising edge
2	0,1	0,5	Rising edge
3	0,0	0,5	Rising and falling edges
4 (optional)	0,0	Maximum current from EE.4.1 d)	Rising and falling edges
NOTE This step waveform is based on the DCP overshoot and undershoot voltage test from the *USB Battery Charging 1.2 Compliance Plan*, revision 1.0, published by the USB Implementers Forum.			

iii) Repeat steps 1) and 2) for the remaining current pairs in Table EE.2. Omit row 4 if not required by the product specification or if the maximum current from EE.4.1 d) is less than or equal to 0,5 A.

2) Procedure 2:

i) Configure the pulsed load with a stepped current waveform similar to that illustrated in Figure EE.4 in order to capture all current transitions required in Table EE.2. Omit row 4 if not required by the product specification or if the maximum current from EE.4.1 d) is less than or equal to 0,5 A. The duration of each step shall be no less than 100 ms.

ii) Record the voltage and current for at least 100 ms after the current transitions indicated in Table EE.2.

e) Change the power supply voltage to the low-battery voltage calculated in EE.4.2.6 i), then repeat step d). (If the DUT will not turn on or will not stay on at the selected voltage, increase the voltage in 0,05 V increments until the DUT turns on, then decrease the voltage in 0,05 V increments to the lowest value for which the DUT remains on.) Omit this step if the voltage would be greater than or equal to the typical battery discharge voltage.

f) Change the power supply voltage to the maximum voltage measured during the active overcharge protection test (S.4.2), or the solar charge test (Annex R) if the active overcharge protection test need not be performed for the DUT, then repeat step d). (If the DUT will not turn on or stay on at the selected voltage, decrease the voltage in 0,05 V increments to the lowest value for which the DUT remains on.) Omit this step if the voltage would be less than or equal to the typical battery discharge voltage.