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Edition 1.0 2017-09

TECHNICAL SPECIFICATION

Measurement procedures for materials used in photovoltaic modules – Part 7-2: Environmental exposures – Accelerated weathering tests of polymeric materials

IEC TS 62788-7-2:2017-09(en)

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colour inside

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

IEC TS 62788-7-2, which is a technical specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
82/1212/DTS	82/1262A/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 document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62788 series, published under the general title *Measurement procedures for materials used in photovoltaic modules*, can be found on the IEC website.

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- withdrawn,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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

MEASUREMENT PROCEDURES FOR MATERIALS USED IN PHOTOVOLTAIC MODULES –

Part 7-2: Environmental exposures – Accelerated weathering tests of polymeric materials

1 Scope

This part of IEC 62788 defines test procedures to characterize the weatherability of polymeric component materials used in photovoltaic (PV) modules or systems. The methods in this document have been focused on polymeric backsheets and encapsulants, but may be applied to other materials; however, these were not verified as part of the preparation.

This document includes a suite of artificial weathering exposures, consisting of a steady-state application of simulated solar irradiance, temperature, and humidity conditions maintained at stable levels through the weathering test. Cyclic stresses, including thermal and wet/dry cycles are left for future specifications.

Exposures in this document are intended for reference by other standards and as a tool to support research and product development for PV components and modules. Different exposures may be used to target specific climate/mounting configurations, with the specifics of how to apply the exposures left to those standards (e.g. component characterization standards, module qualification standards).

An informative annex including parametric descriptions of a range of climate/application configurations used in developing the exposure suites is provided as a reference.

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 60904-3, *Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*

IEC 61730-1, *Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction*

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols*

IEC 62788-1-4, *Measurement procedures for materials used in photovoltaic modules – Part 1-4: Encapsulants – Measurement of optical transmittance and calculation of the solar weighted photon transmittance, yellowness index and UV cut-off wavelength*

IEC TS 62788-2, *Measurement procedures for materials used in photovoltaic modules – Part 2: Polymeric materials – Frontsheets and backsheets*

ASTM G151, *Standard Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources*

ASTM G154, *Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials*

ASTM G155, *Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials*

ASTM D7869, *Standard Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836, IEC 61730-1, as well as the following 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
natural weathering
degradation of materials in response to the naturally occurring climatic stresses at the site where PV modules are installed

3.2
artificial weathering
degradation of materials in response to controlled stresses applied using an artificial weathering chamber designed to simulate the effects of natural weathering

Note 1 to entry: Applied stresses, which should be automatically controlled, include simulated solar irradiance, temperature, and humidity.

3.3
specimen
material test coupon designed to comprise a part or component of a PV module, or a sample designed to replicate a part of a PV module

3.4
polymeric material
natural or synthetic materials that are primarily composed of chained molecules of monomers, that may also contain combinations of monomers, combined polymers, crosslinking agents, inorganic fillers, colorants, stabilizers, and other additive materials

3.5
laminate
product made by bonding together two or more layers of the same or different materials

3.6
ambient temperature
temperature of the air in degrees Celsius surrounding the modules or equipment at a PV installation location as measured and documented by meteorological services for that physical location

3.7
black panel thermometer
BPT
uninsulated black painted panel and attached temperature sensing element constructed according to ASTM G113 typically used to control the convective cooling or chamber air temperature in an artificial weathering chamber

3.8
spectral power distribution
SPD
irradiance distribution in units of W/(m^2·nm) as a function of wavelength for an artificial light source used to simulate solar radiation

3.9
chamber temperature
ChT
air temperature maintained within the artificial weathering chamber representing the minimum temperature of specimens under exposure

3.10
action spectrum
susceptibility of a material to damage as a function of wavelength. Action spectrum can be unique to each characteristic examined, e.g., specimen transmittance or mechanical strength

3.11
filter
material which may consist of optical filter glass, or a representative stack of materials used in the module laminate (e.g. glass/encapsulant/encapsulant, as defined in IEC TS 62788-2)

3.12
transparent release material
TRM
UV stable film used within a laminated weathering coupon so as to allow for easy disassembly of the laminate after weathering for subsequent testing, with transmittance > 90 % over the range 280 nm to 450 nm as in IEC TS 62788-2

4 Artificial weathering exposures

4.1 General

A discussion and overview of general procedures for artificial weathering of non-metallic materials is provided in ASTM G151. The development of the practices included in this document are included in Annexes A and B.

The extent of weathering degradation in application, and in artificial weathering devices, can be sensitive to a number of factors, and the following are recommended as best practices:

- Follow manufacturers' recommendations for replacing the lamp and filters. Perform regular calibrations of irradiance, temperature and humidity according to manufacturer's recommendations. Replace reference black panel specimen according to manufacturer's recommendations.
- Exposure conditions within a device will vary with specimen placement; follow manufacturers' recommendations to move the specimens in a pattern designed to ensure consistent exposures between samples. For example, vary the top/middle/bottom position of samples in rotating devices, and shift sample locations within flatbed devices in a prescribed manner.
- Mount the samples in the chamber in a manner to achieve consistent airflow.

This document describes two artificial weathering methods for testing of PV component materials: xenon arc with daylight filters (Method A) and fluorescent ultraviolet devices with ASTM G154 compliant UVA-340 lamps (Method B). Both exposure methods have been shown to produce materials degradation similar to that observed from long term outdoor exposures. However, due to the combination of differences in the spectral power distribution (SPD) as shown in Figure 1, of the light sources and the differing spectral sensitivity of polymeric materials, degradation modes and rates can differ between the two methods and their equivalence shall not be assumed. Method A shall be the referee method in cases of dispute.

The use of light sources other than xenon arc or UVA-340 lamps for weathering exposures is not sufficiently standardized, and their use shall not be considered as equal alternates.

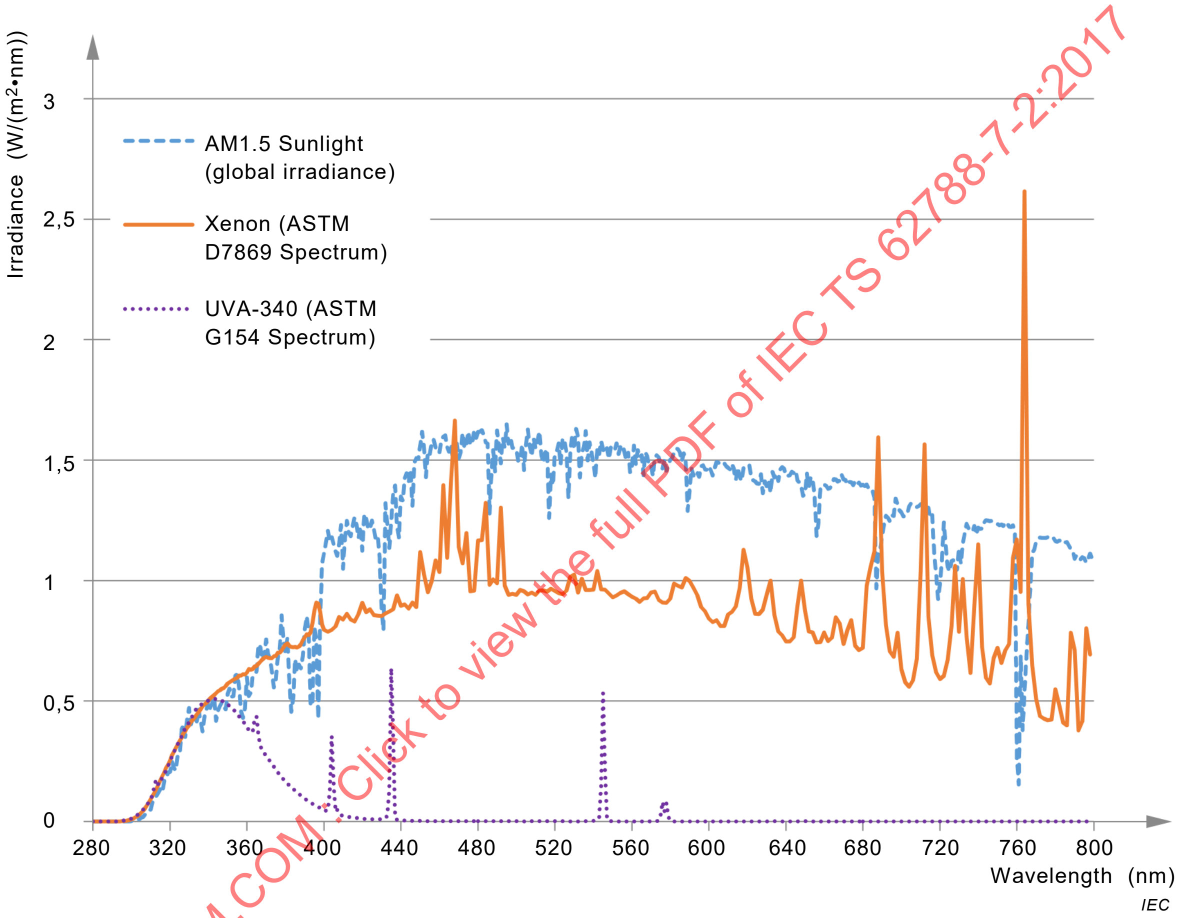


Figure 1 – Spectral irradiance power distributions: solar, xenon arc, fluorescent UV

NOTE The reference terrestrial solar spectrum is shown as in IEC 60904-3. Xenon arc and fluorescent UVA-340 spectra are scaled to match the solar spectrum at 340 nm, whereas the exposures specified in this document are elevated to 0,8 W/(m^2·nm) at 340 nm.

4.2 Method A: filtered xenon arc with daylight filters

4.2.1 General

Xenon arc lamps in combination with the appropriate optical filters produce an irradiance spectrum that is a good simulation of terrestrial sunlight. Compared to other light sources, this light source will produce the most representative response over a wide variety of materials, and is recommended here for qualification of a material and comparisons between different materials.

Operating parameters for xenon arc artificial weathering chambers are specified in ASTM G155.

Exposure set point conditions for Method A are summarized in Table 1.

Table 1 – Method A exposure conditions

Condition #	Chamber air temperature °C	Black panel temperature °C	Irradiance $W/(m^2 \cdot nm)$ at 340 nm	Relative humidity %
A1	45	70	0,8	20
A2	55	80	0,8	20
A3	65	90	0,8	20
A4	75	100	0,8	20
A5	85	110	0,8	20 (nominal)

NOTE Table 1 provides operational set-point conditions for the xenon arc artificial weathering chambers. Water spray is not used in this document. Laboratory measurements have shown that these conditions will for example produce a nominal specimen temperature for white backsheet film specimens of 75 °C for A3.

4.2.2 Light source, irradiance levels

This practice uses a xenon arc light source with optical filters conforming to Annex A.1 of ASTM D7869. The irradiance set-point shall be 0,80 $W/(m^2 \cdot nm)$ at 340 nm. In chambers equipped to control the irradiance from 300 nm to 400 nm, the set point shall be 81 W/m^2. A representative xenon arc spectrum is compared to the terrestrial solar spectrum in Figure 1.

Higher irradiance intensity levels do provide a higher dose in a shorter time, but the same results should not be expected for a material exposed to the same dosage at two different irradiance set points, e.g. 0,8 $W/(m^2 \cdot nm)$ for 4 000 h, and 1,6 $W/(m^2 \cdot nm)$ for 2 000 h. Both false positive and false negative results have been observed at highly accelerated exposure levels. A common observation is for the rate of UV degradation to be significantly sub-linear, e.g. in the example above, the specimen exposed at the greater irradiance would exhibit less degradation (false positive). Conversely, another common result of artificial weathering is for materials exposed at high relative irradiance levels to show a type of degradation that does not occur in service (false negative)[9][1], [10], [11]. The elevated irradiance level selected for this specification is intended to provide a degree of acceleration compared to the application environment, and in general, maintain a similar mode of degradation as in application.

4.2.3 Temperature

Annex A provides a treatment of the range of module temperatures occurring during peak UV stress in field applications. In a weathering chamber, the actual specimen temperature during exposure will vary depending upon the absorptance of the specimen (radiant heating), the Chamber Temperature (ChT) and the heat transfer within the chamber (convective cooling). The ChT and Black Panel Thermometer (BPT) control the lower bound and upper bound of the specimen temperature, respectively. Specimen temperatures for white or clear materials (typical frontsheets, backsheets, and encapsulants) will be closer to the ChT than to the BPT in a xenon arc device. Conversely, a black specimen will be close to the BPT. BPTs in this practice were set at a level that may be obtained by contemporary equipment. For a better understanding of the specimen response to the conditions of Table 1, the temperature may be measured for a specimen under test.

NOTE When used in a PV module a black backsheet will see a temperature rise similar to that of a white backsheet because the majority of the energy absorption occurs in the cells, not the backsheet. Outdoors, a module with a black backsheet would be expected to see a temperature as much as 2 °C or 3 °C hotter than a white backsheet, but in a weathering instrument a 20 °C or greater temperature difference can exist between white and black specimens facing a xenon arc lamp.

———————

[1] Numbers in square brackets refer to the Bibliography.

4.2.4 **Moisture** (relative humidity, RH)

The RH shall be set at the levels listed in Table 1.

4.2.5 Length of exposure

Exposure durations of 1 000 h, 2 000 h and/or 4 000 h at a fixed irradiance level are recommended.

Cumulative radiant dosages for several benchmark locations and 1 000 h artificial weathering chambers running Method A and B are included in Annex B, Table B.2 for reference.

While artificial weathering exposures are sometimes reported in terms of total radiant dosage, this is insufficient to describe the exposure. The exposure set point conditions (from Table 1), the specimen temperature and duration of exposure are critical parameters. A dosage calculation may be provided for reference.

UV degradation rates are material specific, and can be synergistic with heat, humidity, thermal cycling, and mechanical cycling, so a generalized service life translation factor applicable to all locations is not possible or appropriate.

4.3 Method B: Fluorescent UVA-340

4.3.1 General

The UVA-340 set-points in this method were selected to match the xenon arc irradiance at 340 nm. As shown in Figure 1, the spectral output of a UVA-340 lamp is similar to the xenon arc spectrum below 350 nm, but above 350 nm this lamp produces significantly less irradiance with essentially no irradiance beyond 380 nm. While the irradiance levels from 300 nm to 360 nm are matched to the solar spectrum (and that of a xenon arc device set to the same irradiance), for a UVA-340 lamp the total UV dose will be lower due to the lower relative output of wavelengths between 360 nm and 400 nm. Materials which are sensitive to UV radiation in the range from 300 nm to 360 nm will respond with representative rate and mode of degradation, while materials sensitive to longer wavelengths of radiation will see less degradation or may demonstrate different damage mode(s).

Similarity of test results in the two devices is material dependent. For this reason, Method A (filtered xenon arc) shall be regarded as the reference method, and method B as an auxiliary method.

Exposure set point conditions for Method B are summarized in Table 2, with more details in the subclauses below.

Table 2 – Method B exposure conditions

Condition #	Black panel temperature °C	Chamber temperature °C	Irradiance W/(m²·nm) at 340 nm	Relative humidity %
B1	55	Not specified	0,80	Typically not controlled
B2	65	Not specified	0,80	Typically not controlled
B3	75	Not specified	0,80	Typically not controlled
B4	85	Not specified	0,80	Typically not controlled
B5	95	Not specified	0,80	Typically not controlled

NOTE The BPT set-point is targeting a nominal specimen temperature of 75 °C for condition B3 for white specimens, and is based on laboratory measurements of typical UVA-340 devices. Condition B3 and condition A3 are therefore intended to achieve UV exposures at comparable temperatures for white specimens [1].

4.3.2 Light source, irradiance levels

This practice uses a fluorescent UV lamp artificial weathering chamber with UVA-340 lamps as defined in IEC 60904-3. A representative UVA-340 spectrum and the terrestrial solar spectrum are compared in Figure 1. Irradiance set-point is controlled at 0,80 W/(m^2·nm) at 340 nm.

4.3.3 Temperature

The temperature in a fluorescent UVA-340 lamp artificial weathering chamber is typically controlled by a BPT only. Due to a lack of significant visible or IR radiation in the lamp SPD, the ChT and specimen temperature will be close to the BPT, even for colored materials.

4.3.4 Relative humidity

Most fluorescent UVA-340 lamp artificial weathering chambers do not provide for relative humidity control. Chamber relative humidity is therefore a function of laboratory conditions. For fluorescent UVA-340 lamp artificial weathering chambers with humidity control, the RH for the B-condition in Table 2 shall be 20 %.

4.3.5 Length of exposure

Exposure durations of 1 000 h, 2 000 h or 4 000 h at a fixed irradiance level are included as recommended options. Due to spectral differences between xenon and UVA-340 lamps, the cumulative doses will be different for the two methods.

Cumulative radiant dosages for several benchmark locations and 1 000 h artificial weathering chambers running Method A and B are included in Annex B, Table B.2 for reference.

While artificial weathering exposures are sometimes reported in terms of total radiant dosage, this is insufficient to describe the exposure. The exposure set point conditions (from Table 1), the specimen temperature and duration of exposure are critical parameters. A dosage calculation may be provided for reference.

5 Weathering specimens

5.1 General

A variety of weathering specimen types are described in Table 3.

Both frontside (direct) irradiance to the module and backside (indirect) irradiance can cause degradation to polymeric materials. Specimens may be exposed in either manner.

5.2 Specimen constructions

5.2.1 General

While the details of the weathering specimen composition and geometry should be specified in the referencing standard, the following general specimen types and related considerations apply.

5.2.2 Single film or sheet

Prior to exposure, the specimen shall be treated to simulate the manufacturing process. For example, materials which are part of the module laminate shall be processed in a heat/vacuum laminator as for a manufactured module.

5.2.3 Design specific laminate

The representative specimen should be prepared with, as much as is reasonably possible, the same component packaging materials and processing conditions as used in the corresponding module design.

5.2.4 Single component with representative filter

The specimen shall be prepared with the same component packaging materials and processing conditions as used in the corresponding module, except: a stable transparent release material (TRM) is included in the laminated stack adjacent to the material under test, allowing for separation of materials after weathering exposure. This specimen design allows for material component(s) to be exposed with the benefit of the UV filtering effects achieved in the application.

In a similar manner, a long wave pass optical filter can be used, either in front of the specimen or at the light source to emulate optical filtering effects of other components in a PV module.

Reported results shall include the UV cut-off wavelength of the filter as defined in IEC 62788-1-4 (the point where the transmittance reaches 10 %) or the front-facing module packaging component material(s).

5.2.5 Design specific laminate with separable film

The representative specimen (e.g. specimen G) is prepared to allow for an area to be characterized before and after weathering. To reduce edge effects of moisture and air, the transparent release material can be cut to a smaller size than the component materials, leaving a 1 cm laminated area around the perimeter. All materials used in the stack shall be identified as stated in Table 3.

Table 3 – Weathering specimen types – examples

Specimen types	Description	Component material(s)	Include in report: identification of test material, description of stack, lamination conditions, plus:
A	Backsheet, frontsheet	Film	Product identification
B	Design specific laminate	G/E/E/BS FS/E/E/substrate	Product identification for all stack components
C	Encapsulant (glass/glass)	G/E/G	Type of glass, encapsulant product ID
D	Encapsulant (glass/backsheet)	G/E/BS	Type of glass, encapsulant product ID, backsheet product ID
E	Backsheet with representative filter (laminate)	G/E/E/(TRM)BS	Type of glass, encapsulant product ID. UV transmission curve of transparent release material UV cut-off of encapsulant.
F	Backsheet with representative filter	Filter/backsheet	UV cut-off wavelength of filter, backsheet product ID
G	Design specific laminate with separable film	G/E/E/(TRM)/BS	Product IDs for all stack components. UV transmission curve of transparent release material UV cut-off of encapsulant.

Specimen construction key

G: Glass

E: Encapsulant

BS: Backsheet

FS: Frontsheet

TRM: Transparent release material

The TRM shall have transmittance > 90 % over the range 280 nm to 450 nm as in IEC TS 62788-2. Example of release material is perfluorinated ethylene propylene copolymer (FEP) film, 50 µm to 125 µm in thickness.

UV cut-off wavelength measured as in IEC 62788-1-4.

6 Reporting – artificial weathering exposure

A test report shall be prepared containing the following minimum information:

a) a title;

b) name and address of the test laboratory and location where the tests were carried out;

c) unique identification of the report and of each page;

d) name and address of client;

e) description and identification of the item tested

- identification of the material(s) under test;
- if a laminated stack is used, a description of the materials in the stack;
- lamination/processing conditions;
- additional items for each type of weathering specimen as described in Table 3;

f) characterization and condition of the test item;

g) date of receipt of test item and date(s) of test;

h) identification of the exposure method and condition used;

i) the total hours of exposure;

j) the specimen temperature may be observed and noted;

k) reference to sampling procedure, where relevant;

l) any deviations from, additions to, or exclusions from, the test method and any other information relevant to a specific test, such as environmental conditions; and the procedure(s) and condition(s) used for weathering and any preconditioning conducted prior to measurements;

m) measurements, examinations and derived results supported by tables, graphs, sketches and photographs as appropriate;

n) a signature and title, or equivalent identification of the person(s) accepting responsibility for the content of the report, and the date of issue;

o) where relevant, a statement to the effect that the results relate only to the items tested;

p) a statement that the report shall not be reproduced except in full, without the written approval of the laboratory.

Annex A
(informative)

Characterizing the conditions of polymeric components in fielded modules

A.1 General

A range of in-service conditions were considered to provide context for the artificial weathering exposures described in this document. Parameters of temperature, irradiance, and humidity at the module were derived from climate data for the reference locations in combination with mounting configuration and established temperature models. Focus was given to establishing representative values for the period around solar noon, when irradiance and temperature are at their highest, and the bulk of the photolytic-generated degradation will occur (Figure A.1).

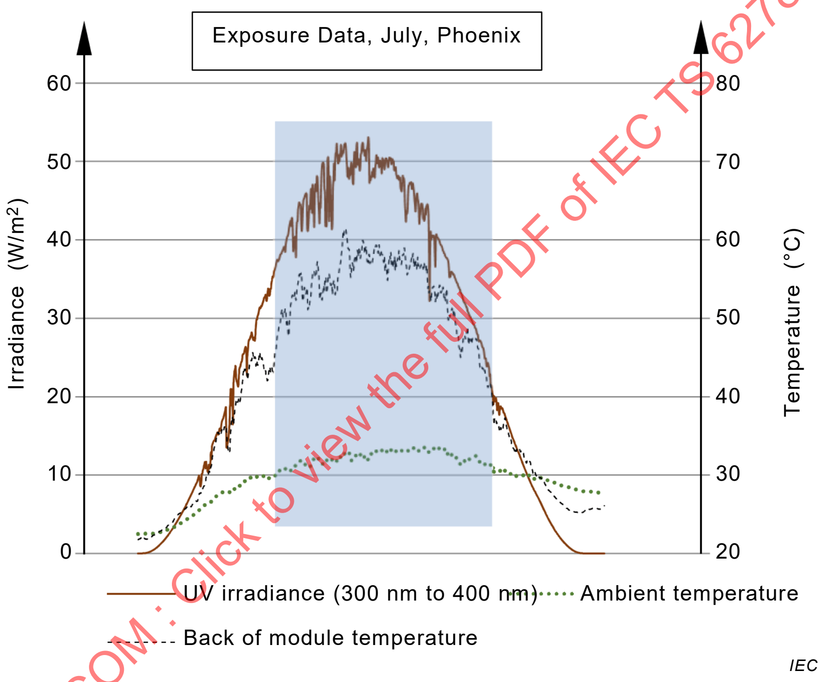


Figure A.1 – Module temperature, UV irradiance, and environmental temperature for a representative July day in Phoenix, AZ

A.2 Climate data and models for module temperature

A.2.1 General

A set of benchmark desert or steppe (arid), tropical, and temperate locations was identified (Phoenix, Arizona; Miami, Florida; Sanary, France; and Golden, Colorado, respectively), and representative conditions for each were summarized based on available climate data (Table B.1).

A.2.2 Irradiance levels

Annual total solar irradiance values are shown in Table A.1. Peak irradiance levels (summer solstice solar noon) are very similar for the selected sites (Table A.3), but cumulative differences over the year arising from site latitude, cloud cover, etc., are significant (Table A.1).

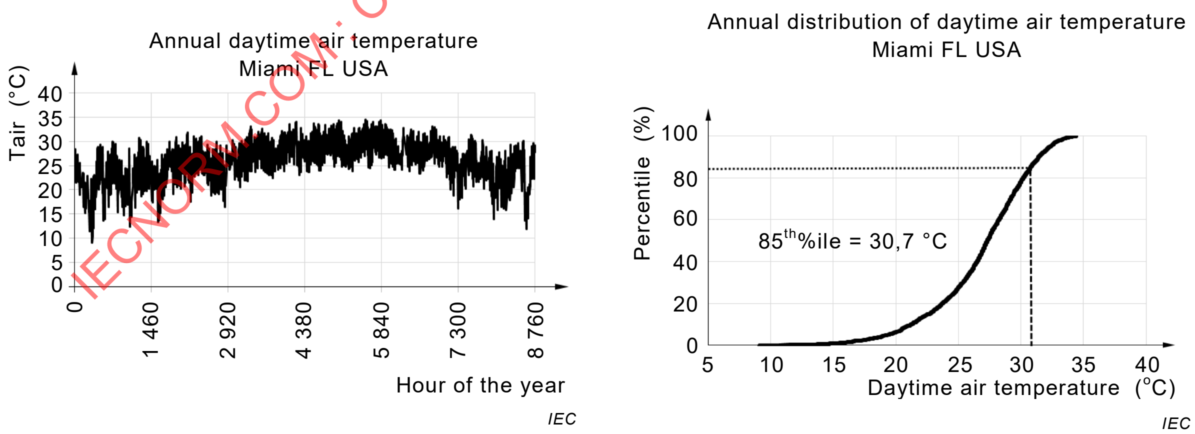
Table A.1 – Average solar radiant dosage levels for benchmark locations, 2000-2015

Location	Latitude	Elevation m	60721-2-1 climate classification	Module inclination angle	Annual total solar radiant dosage MJ/m²			Annual UV radiant dosage 295 nm to 385 nm MJ/m²		
					Mean	Min-max range	Coefficient of variation %	Mean	Min-max range	Coefficient of variation %
Phoenix, Arizona	34°	320 and 610	Arid	34°	8 102	7 566-8 636	3,8	358	307-394	6,3
				5°	7 349	6 910-7 738	3,7	355	310-387	5,1
Miami, Florida	26°	2	Tropical	26°	6 546	6 275-6 897	2,4	324	286-358	6,0
				5°	6 400	6 149-6 773	2,5	323	285-351	5,5
Sanary, France	43°	110	Temperate	45°	6 874	6 535-7 089	2,4	261	221-288	9,5
				0°	5 753	5 632-5 996	2,0	230	201-258	9,3
Golden, Colorado	40°	1 730	Arid	40°	7 294	6 850-7 569	3,0	303	258-335	5,9
				0°	6 109	5 830-6 336	2,7	332	319-352	2,8

NOTE Phoenix and Miami data are averages of two separate locations. Sanary data taken 2007-2015.

A.2.3 Temperature

A characteristic temperature was defined for each of the benchmark locations by reviewing the daytime temperatures over one year, and selecting the temperature at which 85 % of daylight hours gave a lower temperature (see example in Figure A.2).



(A) (B)

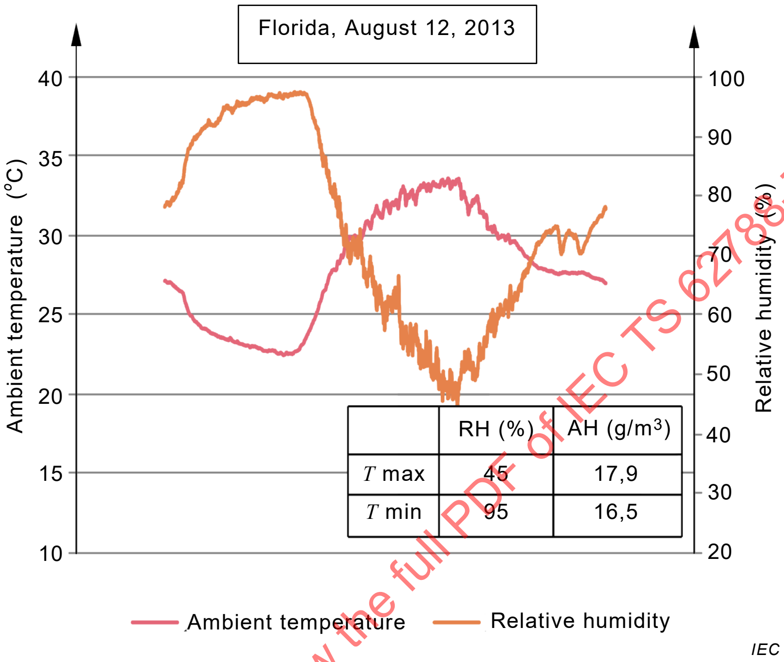
Figure A.2 – (A) Hourly daytime temperatures for Miami over one year and (B) Annual hourly daytime temperatures for Miami, plotted as a cumulative distribution

Module temperatures for rack and insulated-roof mounted modules were derived from published models for the two types of mounting configurations [2], [3], and are shown in Table A.2.

A.2.4 Humidity

The relevant parameter is RH near the module (at the module operating temperature) during the target window around solar noon at a typical high humidity day.

RH varies significantly throughout a daily cycle, with a daily high in early morning and daily low value around solar noon (Figure A.3). Absolute Humidity (AH) is more constant, and so the AH at the T_{max} was used as a reference. This value was then translated to an RH at the 85th percentile temperature for each site.



	RH (%)	AH (g/m³)
T max	45	17,9
T min	95	16,5

Figure A.3 – RH for a representative day in Miami, Florida

Figure A.4 shows the relationship between absolute and relative humidity at different temperatures for RH values of 20 % and 85 %, with the range of absolute humidity observed in terrestrial locations provided as context. Humidity set points in the exposure suites approximate the higher stress levels at the reference sites.

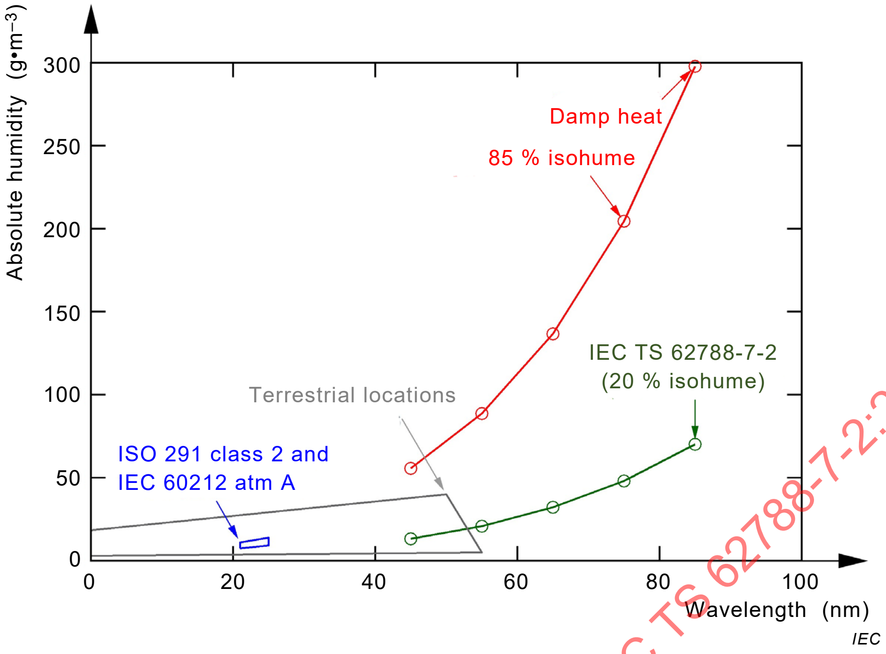


Figure A.4 – Relative humidity values

A.2.5 Backside irradiance

The amount of irradiance on the backside of the module will depend on site-specific variables, including ground cover, position in the array and position on the module. The percentage of incident light that can reach the backside of a PV module can range from near 0 % for close-mounted roof top modules, to near 90 % for modules rack mounted above snow. Typical albedo levels are in the range of 5 % to 15 % [4], [5], [6], [7].

A specific example showing a comparison of frontside and backside irradiance values (Total UV irradiance, 295 nm to 385 nm) on the front and back side of a rack mounted PV module over the course of a day is shown in Figure A.5 (gravel groundcover); measurements indicate the total UV irradiance on the backside (ground facing) face of a module at solar noon at this location as a percentage of the front face irradiance is on the order of 5 %, with the daily total ~7 %.

A representative backside irradiance value was taken as 10 % of the frontside UV dose.

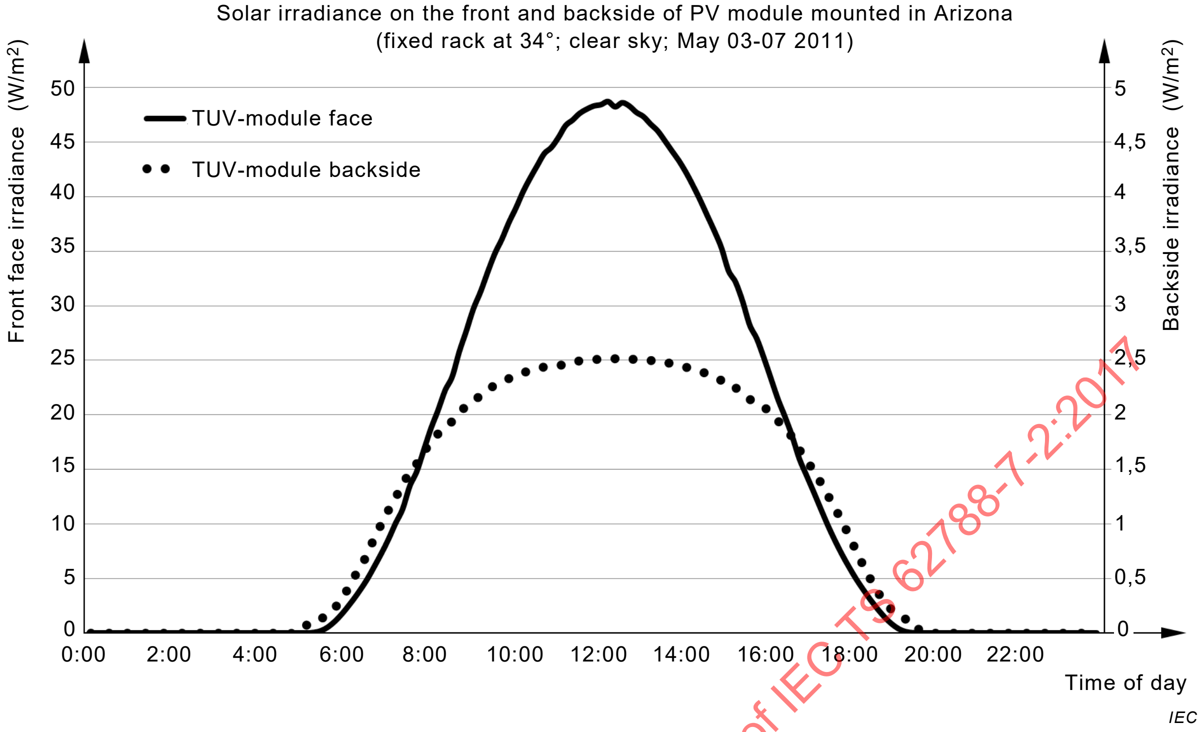


Figure A.5 – Measured solar irradiance on front and back of PV module

A.2.6 Summary

A summary of the representative conditions for rack mounted and insulated roof mount modules at the reference locations is shown in Table A.2. These were utilized in combination with the practical limitations of contemporary weathering devices to design the suite of exposures in Table 1 and Table 2.

Note that the insulated roof mount configuration is unusual relative to a typical roof mounted PV installation, and included so as to represent an upper limit for the operating temperature of most PV installations.

Table A.2 – Summary of estimated module conditions from climate data

Climate	Mount configuration	$T_{85\ \%}$, 85th percentile temperature °C		Calc RH at module %	Maximum total solar irradiance W/m²		Annual UV radiant dosage (nominal) 295 nm to 385 nm MJ/m²			
							Front		Back	
		Ambient	Module		Front	Back	MJ/m²	kW·h/m²	MJ/m²	kW·h/m²
Arid (Phoenix)	Rack	42	55	5,5	1 070	*107*	350	97	*35*	*10*
	Roof		95	2,2		*0*	350	97	*0*	*0*
Tropical (Miami)	Rack	31	49	20	1 000	*100*	330	93	*33*	*9*
	Roof		69	8		*0*	330	93	*0*	*0*
Temperate (Sanary)	Rack	27	44	14	1 030	*103*	220	63	*23*	*6*
	Roof		67	5		*0*	220	63	*0*	*0*

NOTE 1 Irradiance levels for rack (front) are a latitude tilt and roof, at 5 ° tilt from Atlas climate data. Backside values are estimated at 10 % for rack (0 % for roof) and shown in italics in the above table.

NOTE 2 RH of air at the module derived from the environmental AH.

NOTE 3 Module T derived from models in [2],[3].

A.3 Data from module arrays

Fielded module temperature data for rooftop rack systems is shown in Table A.3 for several locations, with the percentile values based on annual daytime hours. These values are comparable to the rack mounted values in Table A.3.

Table A.3 – Measured annual temperature data for fielded modules

Site	Angle	Locator	System	Mounting type	Module type	Module T °C		
						Max	90th %-ile	75th %-ile
AZ1	15	AZ 85050	460 kW	Rooftop rack	c-Si	62,4	53,2	45,7
AZ2	10	AZ 85027	1,1 MW	Rooftop rack	c-Si	73,1	60,6	51,7
CA1	10	CA 94538	160 kW	Rooftop rack	c-Si	62,1	48,9	41,8
CA2	20	CA 93907	360 kW	Rooftop rack	c-Si	67,7	45,5	39
FL	10	FL 33815	283 kW	Rooftop rack	c-Si	66,6	51,4	43,5

Annex B
(informative)

Development of the test methods in this document and recommendations for use

B.1 General

The artificial weathering test methods in this document are comprised of steady state temperature, irradiance, and relative humidity. The approach used here was to consider conditions for the period around solar noon, when irradiance and temperature typically approach their highest levels.

Cycling (e.g. thermal, moisture, and or humidity/freeze/thaw) to achieve stresses representative of daily thermal and/or moisture fluctuations may be considered in future editions of this document.

B.2 UV exposure for components compared to PV module standards

PV module standards IEC 61215-2 (2016) and IEC 61730-2 call for UV exposure testing of modules, at a module temperature of 60 °C, with irradiance levels of up to 250 W/m^2 (280 nm to 400 nm). Total UV dose of the exposure is 15 kWh/m^2 on the front side of the module in IEC 61215, and in IEC 61730, a total dose on the front side of 60 kWh/m^2, and a separate dose of 60 kWh/m^2 on the back side. These exposures will screen out early onset degradation. Note that this range of allowed light sources and irradiance set points can result in inconsistent test results between laboratories or weathering devices, and can result in different degradation modes from that observed in the application.

The component tests in this document are intended to complement the stress exposure testing carried out on modules. Polymeric materials are known to degrade with sunlight exposure, and a test protocol to screen out non-durable materials is essential to assess whether a module construction can perform reliably and safely through its lifetime. This can be achieved by examining the components and materials used in the packaging system. Evaluation at the component level allows for materials to be exposed in smaller specimen sizes for longer duration with higher fidelity light sources.

B.3 Light source selection

This document contains specific spectral requirements for light sources and has standardized the use of two widely available types. Both provide high fidelity replication of natural sunlight, from the solar cut-off wavelength up to 360 nm. The xenon arc spectrum continues to match sunlight closely from 360 nm to 400 nm and is a good match throughout the visible and near-infrared portions of the spectrum. The spectral match from the solar cut-off to 360 nm is particularly important because photons at shorter wavelengths are typically more damaging to polymeric materials than those at longer wavelengths.

B.4 Irradiance levels

B.4.1 Method for specification

The method of specifying the irradiance set point is an important complement to the spectral requirements. A narrow band set point at 340 nm is common practice in the artificial weathering industry. It is used here because the same set point achieves very similar spectral irradiance between xenon arc and UVA-340 light sources in the region from the shortest wavelength of the terrestrial solar spectrum to approximately 360 nm. In the absence of more