WHITE PAPER

PV STRING CABLE TEMPERATURE CORRECTION

HOW DO YOU OBTAIN THE AMBIENT TEMPERATURE?

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July 2021

ECI Publication No Cu0275

Document Issue Control Sheet

Document Title:	White paper – PV string cable temperature correction / How do you obtain the ambient temperature?
Publication No:	Cu0275
Issue:	01
Release:	Public
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Author(s):	Bruno De Wachter
Editorial and language review	Andrew Wilson (English Upgrade)
Content review:	Serge Noels, Fernando Nuño, Angelo Baggini

Document History

Issue	Date	Purpose
1	July 2021	
2		
3		

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PV string cable temperature correction

How do you obtain the ambient temperature?

IEC standards include tables with correction factors for the current-carrying capacity of PV string cables, depending on the cable ambient temperature. But how is this ambient temperature determined?

In Part I, we list all the relevant IEC standards and define the white paper's precise scope.

Part II provides an analysis of what can be found on the subject in existing standards, which is inconclusive. We pose questions which arise from a meticulous reading of these standards.

In Part II we suggest a potential avenue for improving standardisation in this area.

Finally, we wrap up all the questions and summarise our recommendations.

Note that voltage drop, short circuit current, and earth fault current must also be considered when determining the cross-section of PV string cables. These additional factors are not discussed here.

FIGURE 1 – ROOF-MOUNTED PHOTOVOLTAIC SOLAR MODULES AT 2415 PROSPECT STREET IN BERKELEY, CA, USA (PHOTO: ALFRED TWU, LICENSED UNDER CREATIVE COMMONS CCO 1.0)

PART I – RELEVANT STANDARDS AND SCOPE

RELEVANT STANDARDS

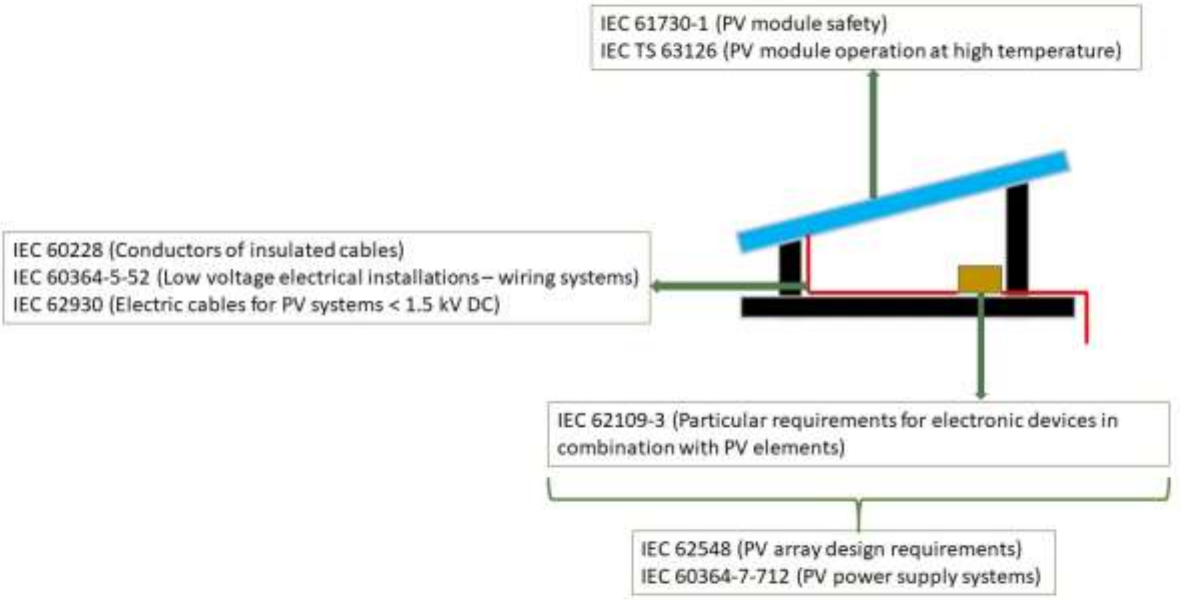


FIGURE 2 – OVERVIEW OF RELEVANT STANDARDS

- **IEC 60228 –** CONDUCTORS OF INSULATED CABLES**:** a general standard indicating the stepwise increase in conductor cross-sections, the associated electrical resistance, and resistance temperature correction factors. It covers both copper and aluminium conductors, whether solid (class 1), stranded (class 2), or flexible (class 5 or 6 depending on the degree of flexibility).

- **IEC 60364-5-52 –** LOW-VOLTAGE ELECTRICAL INSTALLATIONS – PART 5-52: SELECTION AND ERECTION OF ELECTRICAL EQUIPMENT – WIRING SYSTEMS: a general standard on the selection and erection of wiring systems in low voltage installations. It includes tables to determine conductor cross-section based on the required current-carrying capacity, as well as correction factors for cable installation methods and for cable ambient temperatures deviating from 30°C.

- **IEC 60364-7-712 –** LOW VOLTAGE ELECTRICAL INSTALLATIONS – PART 7-712: REQUIREMENTS FOR SPECIAL INSTALLATIONS OR LOCATIONS – SOLAR PHOTOVOLTAIC (PV) POWER SUPPLY SYSTEMS: on the safety of electrical installations for PV arrays. This standard references IEC 62930 for determining PV string cable cross-sections.

- **IEC 61730-1 –** PHOTOVOLTAIC (PV) MODULE SAFETY QUALIFICATION - PART 1: REQUIREMENTS FOR CONSTRUCTION: covering construction requirements to ensure PV module safety.

- **IEC 62109-3 –** SAFETY OF POWER CONVERTERS FOR USE IN PHOTOVOLTAIC POWER SYSTEMS - PART 3: PARTICULAR REQUIREMENTS FOR ELECTRONIC DEVICES IN COMBINATION WITH PHOTOVOLTAIC ELEMENTS: covering particular safety requirements for electronic devices such as power converters used in combination with photovoltaic elements.

- **IEC CD 62548 –** PHOTOVOLTAIC (PV) ARRAYS - DESIGN REQUIREMENTS: a standard under development on the design of PV arrays. The text refers to IEC 60364-7-712.

- **IEC 62930 –** ELECTRIC CABLES FOR PHOTOVOLTAIC SYSTEMS WITH A VOLTAGE RATING OF 1.5 kV DC: the other standards refer to this for determining PV string cable cross-sections.

- **IEC TS 63126 –** GUIDELINES FOR QUALIFYING PV MODULES, COMPONENTS AND MATERIALS FOR OPERATION AT HIGH TEMPERATURES, containing guidelines for qualifying PV modules components and materials for operation at high temperatures. For cables, this standard references IEC 62930.

SCOPE

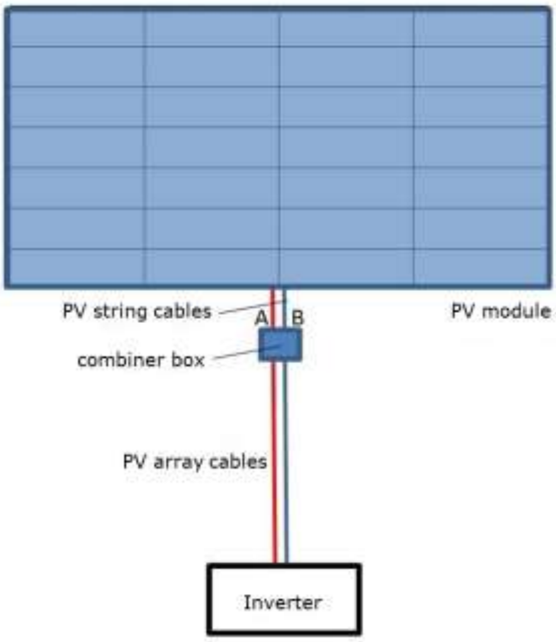


FIGURE 3 – SITUATION OF PV STRING CABLES

The scope includes PV string cables up to 1.5 kV as defined in IEC 60364-7-712 clause 712.3.7: "*the cable interconnecting the modules in a PV string, or connecting the string to a combiner box, PCE or other DC loads*". These cables run outside, above ground or on roofs. PV module mounting systems and cable installation methods can vary, as discussed later in the white paper.

IEC 62930 subclause 1 states that single-core cross-linked insulated power cables with a cross-linked sheath are used on the direct current side of the PV system, but it does not explicitly exclude the use of other types of cables. The most common type of cross-linked insulation is polyethylene (XLPE).

IEC 62930 subclause 5.1.1 states that the conductors shall be copper, in accordance with IEC 60228.

IEC 62930 subclause 5.1.2 specifies that cables directly connected to PV modules should have flexible conductors (class 5 or 6 as defined in IEC 60228).

For a single-core cross-linked insulated power cable with cross-linked sheath, the maximum current-carrying capacity for each cross-sectional area is stipulated in IEC 62930 Table A.3:

Table A.3 – Current carrying capacity of PV cables

Nominal cross sectional area of conductor	Current carrying capacity according to method of installation		
	Single cable free in air	Single cable on a surface	Two loaded cables touching, on a surface
mm^2	A	A	A
1,5	31	30	24
2,5	42	40	33
4	57	54	45
6	72	69	58
10	98	96	80
16	132	130	107
25	183	174	138
35	227	215	171
50	287	273	209
70	361	344	269
95	433	411	328
120	508	483	382
150	590	560	441
185	671	638	506
240	808	767	599
300	913	866	693
400	1 098	1 041	825
Ambient temperature: 30 °C (see Table A.4 for other ambient temperatures).			
Maximum conductor temperature: 90 °C.			

TABLE 1 – IEC 62930, TABLE A.3 – CURRENT-CARRYING CAPACITY OF PV CABLES (USED WITH THE PERMISSION OF CEB-BEC)

Such a maximum current-carrying capacity is required to avoid the *conductor temperature* exceeding the maximum value the insulation can withstand continuously and safely over its lifetime. This is 90°C in the case of cross-linked insulated power cables with a cross-linked sheath, to which the above table applies. The temperature limit is 70°C for PVC insulation, and 105°C for mineral insulation not exposed to touch. The cable has a certain temperature overload capacity that can be used for a limited time without harming the integrity of the insulation. This is discussed later in the white paper.

Tables B.52-1 to B.52-13 and B.52-16 to B.52-21 in IEC 60364-5-52 give correction factors for multi-core cables and for various installation methods.

The *current-carrying capacities* and the *installation correction factors* are valid for an *ambient temperature* of 30°C. For other ambient temperatures, a table with *temperature correction factors* for the current-carrying capacity should be used (B.52.14 for ambient air temperatures, and B.52.15 for ambient ground temperatures).

PART II – ANALYSIS OF EXISTING STANDARDS AND PUBLISHED RESEARCH

AMBIENT TEMPERATURE CORRECTION FACTORS

Table 52.14 in IEC 60364-5-52 gives ambient temperature correction factors according to the type of cable insulation:

Ambient temperature[a] °C	Insulation			
			Mineral[a]	
	PVC	XLPE and EPR	PVC covered or bare and exposed to touch 70 °C	Bare not exposed to touch 105 °C
10	1,22	1,15	1,26	1,14
15	1,17	1,12	1,20	1,11
20	1,12	1,08	1,14	1,07
25	1,06	1,04	1,07	1,04
30	1,00	1,00	1,00	1,00
35	0,94	0,96	0,93	0,96
40	0,87	0,91	0,85	0,92
45	0,79	0,87	0,78	0,88
50	0,71	0,82	0,67	0,84
55	0,61	0,76	0,57	0,80
60	0,50	0,71	0,45	0,75
65	–	0,65	–	0,70
70	–	0,58	–	0,65
75	–	0,50	–	0,60
80	–	0,41	–	0,54
85	–	–	–	0,47
90	–	–	–	0,40
95	–	–	–	0,32
[a] For higher ambient temperatures, consult the manufacturer.				

TABLE 2 – IEC 60364-5-52, TABLE 52.14 – AMBIENT TEMPERATURE CORRECTION FACTORS (USED WITH THE PERMISSION OF CEB-BEC)

Table A.4 in IEC 62930 also provides temperature correction factors for "single-core cross-linked insulated power cables with a cross-linked sheath":

Table A.4 – Current rating conversion factors for different ambient temperatures

Ambient temperature °C	Conversion factor
0	1,22
10	1,15
20	1,08
30	1,00
40	0,91
50	0,82
60	0,71
70	0,58

TABLE 3 – IEC 62930, TABLE A.4 – AMBIENT TEMPERATURE CORRECTION FACTORS (USED WITH THE PERMISSION OF CEB-BEC)

The figures correspond to the correction factors for XLPE insulated cables in IEC 60364-5. Note that the table in IEC 62930 covers only temperatures up to 70°C, which might not be enough, as we discuss later. The main question here is what is meant by *ambient temperature*, and how it can be determined.

How can the *ambient temperature* for the tables with current-carrying capacity correction factors be determined?

ENVIRONMENTAL TEMPERATURE

PV string cables are installed externally, either on the ground or on the roof of a building. They can be installed bare or in trunking, conduit or in a cable bundle. Sometimes they are installed within roof insulation. Independent of the installation method, it is evident that the outside air temperature to which cables are exposed is different from the room temperature inside a building, and exhibits much more seasonal and daily variation.

A first indication of the outside temperature can be obtained from the meteorological measurement station closest to the PV system. The temperature is measured in a Stevenson screen instrument shelter, one meter above ground, an arrangement which allows outdoor air to pass freely but protects the thermometer from direct sunlight and precipitation. IEC 61730-1 refers to this as *the environmental temperature*.

Where ground-mounted PV modules are installed at sufficient height and with PV string cables running on the ground below, the cables are a long way from the modules, in the shade, and will have adequate ventilation. In such cases, the environmental temperature can be used as the cable ambient temperature. The situation is different for rooftop installations. In some cases, cables will be in direct sunlight, while in other cases, they will be in the shade directly under the PV modules. The modules will heat up with the effects of sunlight and the electrical current flowing within them, and will therefore function as an external heat source for the cables running directly below. There will also often be a lack of ventilation under the PV modules. Standard IEC 60364-7-712 confirms that in such installations, PV modules will heat up more than in other conditions (“*Applications using mounting methods that restrict airflow, typically with roof-parallel or building integrated roof top applications, (and in hot climates) could lead to a 98th-percentile [PV module] operating temperature potentially exceeding 70 °C”).*

THE SUN AND PV MODULES AS EXTERNAL HEAT SOURCES

Standard IEC 60364-5-52 page 12, subclause 522.2 suggests what to do when a cable is placed under the influence of an external heat source. It notes examples of external heat sources, including “*heat radiated, convected or conducted from solar gain of the wiring system or its surrounding medium*”.

This is exactly what happens with PV string cables on a roof. Direct sunlight heats the roof, the PV system and parts of the cable system, which reach a thermal equilibrium by losing energy again though radiation and convection. The result is that the temperature around the cable will be higher than the environmental temperature indicated by the local meteorological measurement station.

The standard prescribes four options to neutralise the heat coming from the external source:

- Heat shielding
- Distancing the cable sufficiently from the heat source
- Selecting wiring system components with due regard for the additional temperature rise
- Local reinforcement of the insulating material

In the case of a rooftop PV installation, the second option is impossible. The first and fourth options are possible, but rarely deployed in practice. The third option, careful selection of wiring components, is by far the most common, and IEC standards refer to this in two distinct standards (IEC 60364-7-712 subclause 712.523.101, and IEC 62548 Table 5 note a).

WHAT DOES "AMBIENT TEMPERATURE" MEAN?

The definitions for environmental temperature, ambient temperature and operating temperature are well-rehearsed:

- **Environmental temperature:** the official temperature obtained from the meteorological measurement station closest to the PV system's location, measured in an instrument shelter located one metre aboveground, allowing free passage of outdoor air, but protected from direct sunlight and precipitation. IEC 61730-1 defines the environmental temperature as the "*Air temperature defined in degrees Celsius for the geographic installation location as measured and documented by meteorological services for this geographic location.*" This corresponds to the definition in IEC TS 63126.

- **Ambient temperature:** the temperature of the air surrounding the object of study, in this case the cable system. This is the value that should be used to determine the ambient temperature correction factors. IEC 61730-1 defines *the ambient temperature* as the "*Average temperature of air or another medium in the vicinity of the equipment*." This corresponds to the definition in IEC TS 63126. We will refer to it as the *cable ambient temperature* to be clear that it concerns the ambient temperature of the cable. The ambient temperature is measured when no current is flowing through the cable. It differs from the environmental temperature because it is influenced by local circumstances, which can include direct sunlight, external heat sources such as the PV modules, and lack of ventilation. In principle, it is a unique value of a given installation at a given location, and cannot be retrieved from existing meteorological maps or listings.

- **Operational temperature:** the temperature of the object of study. When this object has no internal heat generation, the operational temperature will be similar to the ambient temperature (albeit any fluctuation can lag behind ambient temperature fluctuations due to differences in thermal inertia).

Despite these clear definitions, some international standards on PV systems generate confusion about ambient temperature:

- Standards IEC 60364-5-52 and IEC 62930 make use of the ambient temperature in their cable sizing methodology without specifying how it is determined.

- Standard IEC TS 63126 uses the terms "ambient temperature" and "operational temperature" when referring to PV modules as if the terms are interchangeable. This cannot be true for cables carrying an electric current, since they are subject to internal heat generation. The operational temperature will depend on the conductor cross-section and will in any case be higher than the ambient temperature. It will reach its highest value somewhere inside the conductor and exhibit a declining gradient towards the outside surface of the insulation caused by heat dissipation.

- IEC 62548 Table 5 appears to confuse temperature definitions. We discuss this later in the document.

How (not) to determine the ambient temperature

How can the ambient temperature be determined with a view to selecting the appropriate correction factor? That is the major question. The following options are currently available, but none of them are suitable.

Based on a misunderstanding (1)

Often, we hear that the ambient temperature can be obtained from meteorological data. This ignores the difference between the *environmental temperature* and the *cable ambient temperature* when referring to a roof-mounted PV system, and leads to under-estimating the actual air temperature around the cable system.

Based on on-site measurement

The cable ambient temperature could be determined through an on-site measurement campaign. To accurately measure all the influences, however, all the systems — including the PV modules — should already be in place, except for the PV string cables subject to cross-section calculations. The measurements must also cover periods of high PV yield and high outside temperatures. This is complicated, if not impossible.

In accordance with IEC 62109-3

IEC 62109-3 stipulates how to obtain the ambient temperature to be used in safety restrictions of electronic devices placed under PV modules:

1. If the PV module is more than 1 metre above the ground or any other surface, the environmental temperature and the ambient temperature at ground level or at the surface beneath can be considered equal.

2. If the PV module is between 10 cm and 1 metre above the surface, +10°C should be added to the environmental temperature to obtain the ambient temperature at the surface below the module.

3. If the PV module is placed between 5 cm and 10 cm above the surface, +15°C should be added to the environmental temperature to obtain the ambient temperature at the surface below the module.

4. If the PV module is placed less than 5 cm above the surface, the ambient temperature beneath it should be derived from testing an individual module.

5. The temperature conditions under building-integrated or building-attached photovoltaics still require further study.

The first case is typical of ground-mounted PV modules, the second for installations on a flat roof, while the third and fourth typically apply to PV installations on a sloping roof.

Could a similar procedure be followed for cables? If the answer is yes, the following aspects still need to be tackled:

- A clear distinction should be made between installations on a flat surface and those on an inclined surface;
- What about cables that are not installed under the PV modules, but in direct sunlight?
- The fourth case requires on-site testing, which is not practically feasible (see “Based on a measurement campaign?” above);
- No method has been put forward to assess conditions under building-integrated PV modules.

In accordance with IEC 60364-7-712

The current IEC 60364-7-712 standard , subclause 712.523.101, states that "*The ambient temperature for cables subjected to direct heating from the underside of PV modules shall be considered to be at least 70°C*"[1]. This means that cables running directly *under* the PV modules, with no direct sunlight (in shade), but under the influence of the PV modules as an external heat source, should be sized for an ambient temperature of *at least* 70°C. What is meant by *at least*? Up to what distance will cables be under the influence of direct heating from the PV modules? Is the answer 1 meter, as specified in IEC 62109-3? And what happens in a situation where cables are not running under the PV modules, but in direct sunlight? What if the cables are running inside an insulated roof under building-integrated PV modules?

What is meant by *at least* in IEC 60364-7-712 subclause 712.523.101?

What happens in a situation where cables are not shaded by the PV modules, but in direct sunlight? Or in roof insulation?

In accordance with IEC 62548 Table 5 Note a

Table 5 in IEC 62548 clause 7.3.7.1.2 includes the following note:

"*The operating temperature of PV modules and consequently their associated wiring can be significantly higher than the ambient temperature. A minimum operating temperature equal to the maximum expected ambient temperature +40 °C should be considered for cables installed near or in contact with PV modules*."

This note is confusing and unspecific. The first sentence suggests that the operating temperature of PV modules and that of their associated wiring is the same. There is no reason for this claim, since the operating temperature depends not just on the ambient temperature, but also on the internal heat generation caused by electric current. It is also not clear what is meant by "the ambient temperature" here. The second sentence is curious too, since the operating temperature is not something that "should be considered"; keeping it below its fixed maximum threshold value is the whole purpose of the calculation. The value to be considered is the ambient temperature which can then be used in the tables to determine the appropriate correction factors.

The note would make sense if by "ambient temperature" it meant *environmental temperature*, and by the "operating temperature to be considered" for the cables it meant the *cable ambient temperature* as defined by IEC 61730-1. If this were the case, the note would read as follows:

"*The operating temperature of PV modules and consequently the ambient temperature of the associated wiring can be significantly higher than the environmental temperature. A minimum PV module operating temperature (and thus cable ambient temperature) equal to the maximum expected environmental temperature +40 °C should be considered for cables installed near or in contact with PV modules*."

[1] This standard is currently under revision. The issue of cable ambient temperature is likely to be addressed in a less ambiguous way in the forthcoming version of the standard.

With this wording, the note would provide guidelines on how to determine the ambient temperature for cables installed near (usually just below) PV modules. That said, the word "near" could still be given greater precision. The question also remains how to bring this standard into alignment with the methods in IEC 60364-7-712 and IEC 62109-3 discussed earlier.

What does *note a* in Table 5 of IEC 62548 mean? How are "operating temperature" and "ambient temperature" defined here?

How can the methods in IEC 62548, IEC 60364-7-72 and IEC 62109-3 for determining ambient temperature be aligned?

BASED ON A MISUNDERSTANDING (2)

Since *Note a* in IEC 62548 Table 5 suggests adding 40°C to what is wrongly called "the ambient temperature", and IEC 62930 Table A.3 stipulates that values are given "for an ambient temperature of 30°C", a superficial reading could lead to the mistaken conclusion that you always have to base your calculations on an ambient temperature of 30°C + 40°C = 70°C. If that were the case, only one row in the table of ambient temperature correction factors would be relevant: that applying to 70°C. This would mean that a similar ambient temperature correction factor would have to be used, no matter the installation method or the geographical location, which cannot be true. It would be absurd to apply the same cable ambient temperature to a cable running inside thermal insulation under a roof in the Australian desert as for a cable in the shade beneath ground-mounted PV modules in Iceland.

PUBLISHED RESEARCH ON CABLE AMBIENT TEMPERATURE

Carrying out a separate temperature measurement campaign for each PV system installation is not a realistic option. What can be done, however, is to consult published research that includes measurement campaigns in similar circumstances. It should be experiments executed during the summer months, measuring the air temperature in the immediate vicinity of the cable sheath or raceway, with an unloaded cable. Two such experiments from reliable sources are presented in Annex 1.

The second experiment, published by IEEE, clearly demonstrates that the difference between the environmental temperature and the ambient temperature is:

- independent of the environmental temperature
- dependent on the way the PV module and PV string cable are installed.

This link with the installation method is also reflected in standard IEC 62109-3, on the safety of electronic devices placed under PV modules, discussed above.

This leads us to the fundamental question: how does the cable ambient temperature change with the installation method?

In what way does the PV string cable ambient temperature depend on how the PV module and PV string cables are installed?

WHICH ENVIRONMENTAL TEMPERATURE SHOULD BE USED?

When the difference between the environmental temperature and the cable ambient temperature is defined, the question remains which environmental temperature from the meteorological data is it most appropriate to use? The highest average daily maximum of the year, or the highest value ever recorded, for example?

Which environmental temperature from meteorological data sources is it most appropriate to use?

To ensure safety, PV string cables have to withstand any type of weather realistically expected to occur. This would mean that we should look at the highest temperature ever recorded in the area. Climate change is real, and these records are climbing at a fast pace. The table below lists highest temperatures for a range of countries (Wikipedia, List of weather records).

Highest temperature ever recorded falls within the range of…	Country
30° - 35°C	Iceland, Ireland
35° - 40°C	Denmark, Estonia, Finland, Lithuania, Latvia, Norway, Sweden, United Kingdom
40° - 45°C	Austria, Belgium, Croatia, Czech Republic, Germany, Hungary, Netherlands, Poland, Romania, Slovakia, Slovenia, Switzerland, Canada, New Zealand, Brazil, Chile, Colombia, Uruguay, Indonesia, Japan, Malaysia, Russia, South Korea, Taiwan, Thailand, Vietnam
45° - 50°C	Bulgaria, France, Greece, Italy, Portugal, Spain, Argentina, Turkey, Nigeria
50° - 55°C	Mexico, Australia, China, India, Israel, Jordan, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, United Arab Emirates, Algeria, Morocco, South Africa, Tunisia
55° - 60°C	United States

TABLE 4 – HIGHEST TEMPERATURES EVER RECORDED FOR VARIOUS COUNTRIES AROUND THE WORLD

If this reasoning were to be correct, complying with IEC 62548 on cross-linked insulated PV string cables would be impossible for some installation methods at many locations around the world, since the derived ambient temperatures would rise above the maximum value of 80°C for these types of cables. In practice, however, there is no cliff edge that makes the cable change from being "safe" to being "unsafe" in a single moment. The cable has a temperature overload capacity whereby it can be used for a limited time at high temperature without harming the integrity of the insulation. How can this limited temperature overload capacity be exploited?

How can a cable's limited temperature overload capacity be exploited?

PART III – A POTENTIAL STANDARDISATION AVENUE

The following is a potential avenue for adapting the international standards relating to PV string cable ambient temperature to make them more definitive and based on credible sources.

CABLE AMBIENT TEMPERATURE CORRECTION FACTORS

The cable ambient temperature correction factors should be consultable in a single table, included in either IEC 62930 or IEC 60364-5-52.

The table should be as technology neutral as possible, leaving open every viable option for the type of cable insulation. Table A.4 of IEC 62930 should be extended with columns for PVC and mineral insulation cables, or alternatively Table 52.14 of IEC 60364-5-52 should extend its “XLPE and EPR insulation” column to include all types of cross-linked insulated power cables with a cross-linked sheath.

The column for cross-linked insulated power cables with a cross-linked sheath should go up to 80°C (as in the current IEC 60364-5-52, Table 52.14) instead of just 70°C (as in the current IEC 62930, Table A.4).

As in the current IEC 62930, a certain overload capacity for a limited time should be taken into account (see later in this document).

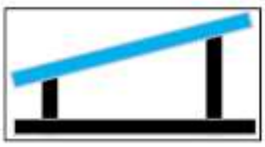
DIFFERENTIATED DEPENDING ON THE INSTALLATION METHOD

Since cables operate under the same conditions as junction boxes and connectors, receiving additional heat from the PV modules as an external heat source, the differences in installation method as described in IEC 62109-3 apply.

Aggregating IEC 62109-3 with the results of the second experiment described in Annex 1 and published by IEEE, we can distinguish six different installation methods:

- **Installation method 1:** The PV module is installed at a height of more than 1 metre above the surface (typically ground-mounted modules), and the cables are running on the surface below.

- **Installation method 2:** The PV module is installed at a height of between 10 cm and 1 metre above the surface (typical for PV modules installed on a flat roof), and the cables are running on the surface below.

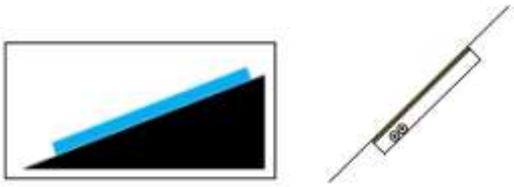


- **Installation method 3:** The PV module is placed on a sloping roof, with 5 cm to 10 cm between the module and the roof, and the cables running on the roof below.

- **Installation method 4:** The PV module is placed on a sloping roof, with less than 5 cm between the module and the roof, and with the cables running on the roof below.

- **Installation method 5:** The cables are running on a roof surface, exposed to direct sunlight.

- **Installation method 6:** Cables are running under a building-integrated PV module, on a sloping insulated roof without ventilation.



The difference between the environmental temperature and the cable ambient temperature is given in IEC 62109-3 for the first three installation methods. The second experiment discussed in Annex 1 gives the difference between the environmental temperature and the cable ambient temperature for the latter three installation methods. This leads us to the following figures:

- Installation method 1: + 0°C
- Installation method 2: + 10°C
- Installation method 3: + 15°C
- Installation method 4: + 18°C
- Installation method 5: + 36°C
- Installation method 6: + 43°C

Allowing higher temperatures for a limited time

The next question is which environmental temperature should be selected?

In IEC 62930 – Clause 1, we see the following concerning single-core cross-linked insulated power cables with a cross-linked sheath:

"*The cables are designed to operate at a normal continuous maximum conductor temperature of 90°C. The permissible period of use at a maximum conductor temperature of 120 °C is limited to 20,000 h. NOTE: The expected period of use under normal usage conditions as specified in this document is at least 25 years*."

A period of 20,000 h over 25 years means an average of 800 h per year, or approximately 9% of the time. This capacity to operate at higher temperature for a limited amount of time could be taken into account by choosing the 91st percentile for the environmental temperatures (i.e. the value which is exceeded for no more than 9% of the time).

IEC TS 63126 includes world maps giving the geographical distribution of the 98th percentile of PV module operating temperatures.

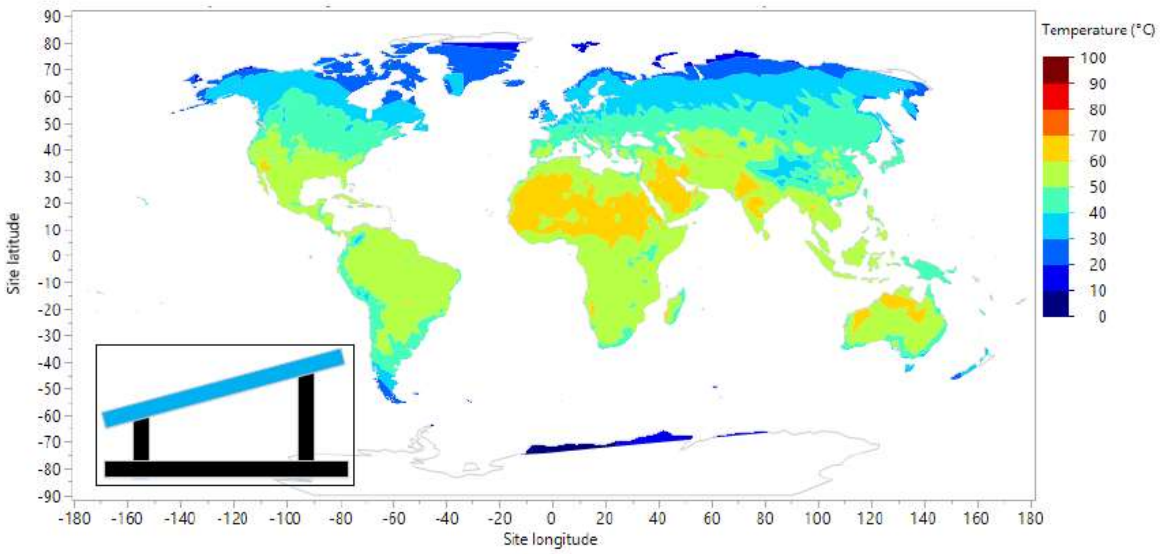


FIGURE 4 – EXAMPLE OF A 98TH PERCENTILE TEMPERATURE WORLD MAP, IN THIS CASE SHOWING THE OPERATING TEMPERATURE FOR AN OPEN-RACK, OR THERMALLY UNRESTRICTED, GLASS SUPERSTRATE, POLYMER BACKSHEET MODULE (FIGURE A.3 FROM IEC TS 63126:2020) (USED WITH THE PERMISSION OF CEB-BEC)

A similar world map could be developed for the 91st percentile environmental temperature, to be used for determining the PV string cable ambient temperature correction factor.

DETERMINING THE CABLE AMBIENT TEMPERATURE

Combining all the above, the PV string cable ambient temperature could be derived from the following table, with the 91st percentile environmental temperature depending on the location on a world map (to be developed). In Spain, for example, the 91st percentile temperature in Santander in the north of the country is 25.1°C, while Seville in the south of the country has a 91st percentile temperature of 37.5°C.

PV string cable ambient temperature	
Installation method	**Difference between 91st percentile environmental temperature and cable ambient temperature**
1. Ground-mounted: PV module installed at > 1 m above the surface, cables running on surface below	**+ 0°C**
2. On a flat roof: PV module installed between 10 cm and 1 m above the surface, cables running on surface below	**+ 10°C**
3. PV module on an **inclined roof, with 5 cm to 10 cm** between module and roof, cables running on the roof below	**+ 15°C**
4. PV module on an **sloping roof, with less than 5 cm** between module and roof, cables running on the roof below	**+ 18°C**
5. Cables running on roof surface, exposed to **direct sunlight**	**+ 36°C**
6. Cables running **under a building-integrated PV module**, on a sloping, insulated roof without ventilation	**+ 43°C**

TABLE 5 – DIFFERENCE BETWEEN THE 91ST PERCENTILE ENVIRONMENTAL TEMPERATURE AND THE CABLE AMBIENT TEMPERATURE DEPENDING ON THE INSTALLATION METHOD

REMOVING AMBIGUITY

The following ambiguous and inadequately specified references to the PV string cable ambient temperature should be removed and replaced by a reference to the method described above:

- IEC 60364-7-712, subclause 712.523.101 (*The ambient temperature for cables subjected to direct heating from the underside of PV modules shall be considered to be at least 70°C*).

- IEC 62548, subclause 7.3.7.1.2, Table 5, note a (*The operating temperature of PV modules and consequently their associated wiring can be significantly higher than the ambient temperature. A minimum operating temperature equal to the maximum expected ambient temperature +40 °C should be considered for cables installed near or in contact with PV modules*).

PART IV – KEY QUESTIONS AND SUMMARY

KEY QUESTIONS

1. The maximum current-carrying capacity of PV string cables with various cross sections is given in IEC 62930 Table A.3. It is valid for an *ambient temperature* of 30°C. For other ambient temperatures, tables with correction factors are given by IEC 60364-5-52 and IEC 62930. **How can the ambient temperature to be used in these tables be determined?**

2. A first indication can be given by the meteorological outside air temperature obtained from a nearby official measurement station. This is called the *environmental temperature* in IEC 61730-1. This temperature does not always reflect the conditions in the immediate vicinity of the PV string cables. Often, these cables run on rooftops and receive direct sunlight, or they are placed directly beneath PV modules which heat up through sunlight and electric current, and function as an external heat source (IEC 60364-5-52, subclause 522.2). **How can the *cable ambient temperature* be derived from the *environmental temperature*?**

3. IEC 60364-7-712, subclause 712.523.101 states that "*The ambient temperature for cables subjected to direct heating from the underside of PV modules shall be considered to be at least 70°C*" [2]. **How can the cable ambient temperature be obtained with greater precision?**

4. **What if cables are not installed in the shade of the PV modules, but receive direct sunlight instead? What if the cables run inside an insulated roof?**

5. IEC 62548 Table 5 includes the following note: "*The operating temperature of PV modules and consequently their associated wiring can be significantly higher than the ambient temperature. A minimum operating temperature equal to the maximum expected ambient temperature +40 °C should be considered for cables installed near or in contact with PV modules.*" **What exactly is meant by "the operating temperature of the associated wiring" and "the ambient temperature" here?** Could this be better phrased as follows: "*The operating temperature of PV modules and consequently the ambient temperature of the associated wiring can be significantly higher than the environmental temperature. A minimum PV module operating temperature (and thus cable ambient temperature) equal to the maximum expected environmental temperature +40 °C should be considered for cables installed near or in contact with PV modules*"?

6. IEC 62109-3 stipulates how to obtain the ambient temperature that should be considered for the safety of *electronic devices* placed under PV modules. This ambient temperature differs depending on the installation method. An experimental measurement campaign, published by IEEE, also demonstrates that the installation method matters. **How do you relate the PV string cable ambient temperature to the installation method of the PV module and PV string cable itself?**

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[2] This standard is currently under revision. The issue of the cable ambient temperature is likely to be addressed in a less ambiguous way in the forthcoming version of the standard.

7. **How can the statements in IEC 60364-7-712, IEC 62548 and IED 62109-3 on the cable ambient temperature be aligned?**

8. **Which value should we take for the environmental temperature?**

9. Cables have a certain overload capacity for a limited time. According to IEC 62930, the cable conductor temperature can rise to a maximum of 120°C for a limited time of 20,000 h during the 25-year lifetime of the installation, or approximately 9% of the time. As a consequence, **should the 91st percentile be chosen as the environmental temperature?**

SUMMARY OF A POTENTIAL STANDARDISATION AVENUE

The cable ambient temperature correction factors are given by IEC 60364-5-52, Table 52.14. IEC 62930 could refer to this or extend Table A.4 to higher temperature and other types of insulation.

The installation method should be taken into account, classified as follows:

- Installation method 1: The PV module is installed at a height of more than 1 metre above the surface (typically ground-mounted modules), with the cables running on the surface below.
- Installation method 2: The PV module is installed at a height of between 10 cm and 1 metre above the surface (typical for PV modules installed on a flat roof), with the cables running on the surface below.
- Installation method 3: The PV module is placed on a sloping roof, with 5 cm to 10 cm between the module and the roof, and with the cables running on the roof underneath.
- Installation method 4: The PV module is placed on a sloping roof, with less than 5 cm between the module and the roof, and the cables running on the roof underneath.
- Installation method 5: The cables are running on the surface of a roof, exposed to direct sunlight.
- Installation method 6: The cables are running under a building-integrated PV module, on a sloping, insulated roof without ventilation.

For the environmental temperature, the 91st percentile should be chosen. This is a way to take into account the temporary temperature overload cable insulation can withstand. A world map with the 91st percentile environmental temperature should be developed. The cable ambient temperature can be derived from the 91st percentile environmental temperature as follows:

- Installation method 1: + 0°C
- Installation method 2: + 10°C
- Installation method 3: + 15°C
- Installation method 4: + 18°C
- Installation method 5: + 36°C
- Installation method 6: + 43°C

The ambiguous and inadequately specified references to the ambient temperature found in IEC 60364-7-712 (subclause 712.523.101) and IEC 62548 (subclause 7.3.7.1.2, Table 5, note a) should be removed and replaced by a reference to the method described above.

ANNEX 1 – PUBLISHED RESEARCH ON THE CABLE AMBIENT TEMPERATURE

UL FILE IN 16969

- UL file IN 16969, Project 11CA25532, October 10, 2011 (1A)
- UL file IN 16969, Project 12CA25371, September 25, 2012 (1B)
- *Fact-Finding Report on Ambient Temperature Adjustment for Raceway and Cable Systems Exposed to Sunlight on Rooftops*

This experiment used a black cable placed in a raceway at 0.5 inch above the surface of a rooftop. It was exposed to direct sunlight, in the absence of wind. The experiment measured the difference between the environmental temperature and the cable ambient temperature as + 35.6 °C.

IEEE ARTICLE

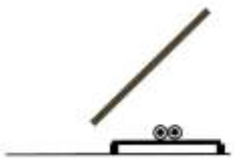
- IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 44, NO. 6, NOV - DEC 2008
  David Brender, Travis C. Lindsey
  Effect of Rooftop Exposure in Direct Sunlight on Conduit Ambient Temperatures

This experiment carried out cable ambient temperature measurement for various environmental temperatures. There is a high degree of consistency in the results, meaning that the temperature rise between the environmental temperature and the cable ambient temperature is independent from the environmental temperature. The experiment was repeated for different installation methods, with the following results for the difference between the two temperatures:

- Cables on a cable tray or rail, in shade, closely under the PV module (< 10 cm): + 18°C
- Cables in a round conduit in direct sunlight: + 35°C
- Cables on a cable tray or rail, in direct sunlight: + 36°C
- Cables bundled on a rail within a sloping, insulated roof without ventilation (building-integrated PV system): + 43°C.

These four situations can be reduced to three:

1. **Installation method 1**: Cables on open cable tray or rail, in shade of the PV modules: **+18°C**



2. **Installation method 2:** Cables on open cable tray or rail, or in a cylindrical conduit, in direct sunlight: **+ 36°C**

3. **Installation method 3**: Cables bundled on a rail within a sloping, insulated roof with no ventilation (under a building-integrated PV module): **+ 43°C.**

These figures are more or less in line with IEC 62548 Table 5 note a, but provide a more varied picture depending on the installation method. Adding +40°C in all cases will result in a cable cross section that is on the safe side for the first two installation methods, and only just enough for the third installation method.

The numbers are also reasonably well aligned with IEC 62109-3. Installation method 1 (environmental temperature + 18°C) can be compared with the situation of a device under a PV module placed between 5 and 10 cm above the ground (environmental temperature + 15°C).

ANNEX 2 – THE MAIN CONCLUSIONS FROM IEC TS 63126

IEC TS 63126 gives *Guidelines for qualifying PV modules, components and materials for operation at high temperatures*. It does not develop any guidance on cables other than referring to IEC 62930, but it can serve as inspiration for developing a similar method of determining the cable ambient temperature.

These are the main conclusions from IEC TS 63126:

- When applying PV module standards (IEC 61215 series, IEC 61730 series, IEC 62790 and IEC 62852), modules should be able to withstand an operational temperature of 70°C for 2% of the time (the 98th percentile temperature). However, for certain installation methods in certain climatic regions of the world, the 98th percentile PV module temperature will be higher than 70°C. Therefore, IEC TS 63126 indicates that manufacturers should provide modules that are tested and approved for Level 1 (98th percentile temperature of 80°C) and for Level 2 (98th percentile temperature of 90°C).

- In an Annex of IEC TS 63126, global temperature maps are provided, indicating the 98th percentile PV module operational temperature. There is a map for each of three different installation methods: modules on an open rack about 1 meter above the ground, modules mounted parallel to a pitched roof, and modules that have their underside integrated into an insulated roof. Figure 4 earlier in this white paper gives an example of such a map.

- The temperature maps show that for the open-rack type, the 98th percentile module temperature never exceeds 70°C. For the roof mounted type, level 1 (80°C) is reached in many warmer regions of the world, and level 2 (90°C) in a few exceptionally hot places. For the roof-integrated types, level 1 is reached in most of the world, and level 2 in many regions with a hot climate.

- IEC TS 63126 also discusses the ambient temperature values that junction boxes and connectors should withstand. These temperatures are systematically +15°C above the values for the PV modules, meaning a maximum +85°C in normal conditions, +95°C in level 1 conditions, and +105°C in level 2 conditions.

For cables, IEC TS 63126 merely refers to IEC 62930, stating that this standard "applies without any modification". *But how do you apply it?* The situation for cables is more complicated than for PV modules, because of the substantial heat loss generated inside, which depends on the cable cross section, and needs to be dissipated to the environment. Therefore, IEC 62930 provides tables with minimum cable sizes depending on the required current-carrying capacity, and with correction factors depending on the cable ambient temperature. Which brings us back to the same question: how do you obtain this ambient temperature?