YOUR COMPANY

Tax code .....

VAT .....

Address .....

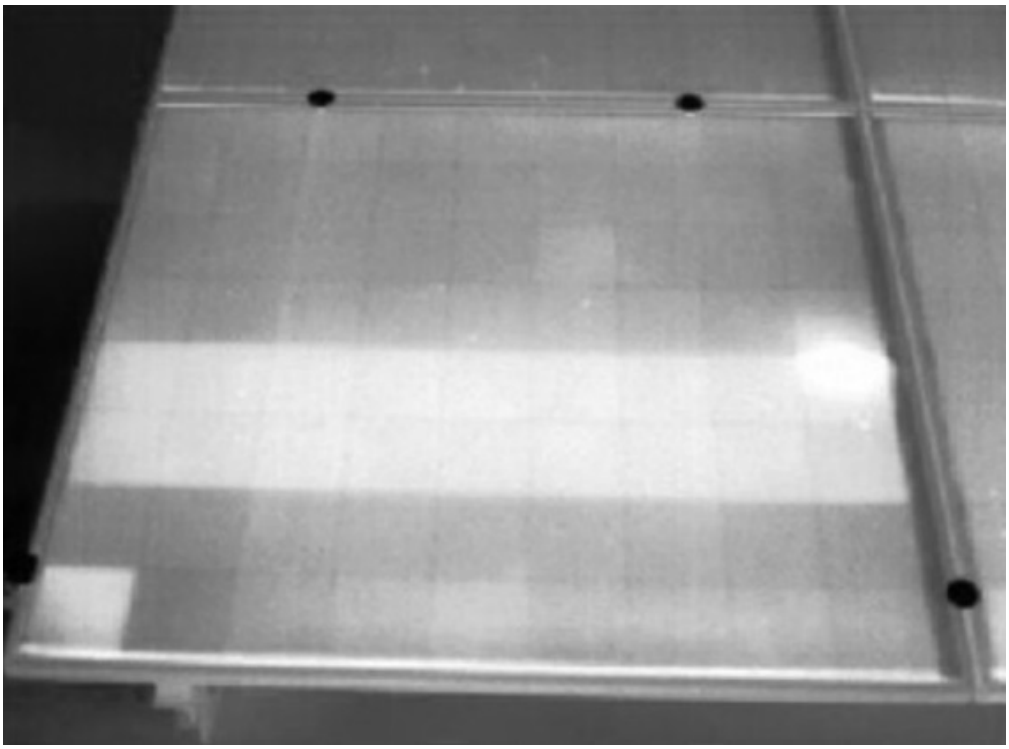
Phone number .....

Fax .....

Email .....@.....

Web site .....

Diagnosis of the module GEO - 251478



IR image file	img_251478.jpg

Customer	
Name/Business name	.....
Tax code	.....
VAT number	.....
Address	.....
Phone number	.....
Email	.....@.....

Contents

Sections

Figures

Schemes

Certified technician

Surname and name	YOUR NOME
Certification	.....
Qualification	.....
More	.....

Getting started

Thermography to diagnose PV systems

The correct operation of the photovoltaic systems is guaranteed if each component operates under prescribed (by the manufacturer) temperature conditions. In the case of cells and photovoltaic modules, the reference temperature is called NOCT (Nominal Operating Cell Temperature): it influences the correct operation of the module, its life duration and the production of electrical energy. Conversely, its alteration reduces the production of electrical energy, causes a premature aging of the module, can propagate damages to nearby cells. Therefore, to monitor the temperature of each single cell of the photovoltaic module is extremely important for both the present and the future production of the electric energy. In the case of photovoltaic systems which receive a government fee, whose ROI depends on the produced energy, the continuous and scheduled monitoring by means of thermography can help to detect anomalies before they become failures, thus preventing out of service and allowing to respect the temporal and financial targets, as foreseen at the time of the investment planning.
For these reasons, the thermography is an essential tool to keep under control the correct operation of the photovoltaic system, also having the characteristic of allowing the measurement under load (i.e. without out of service), then without interrupting the production of electrical energy. These advantages make thermography internationally recognized as a technique for the diagnostics of photovoltaic systems.
The **thermography** allows to measure the thermal radiation emitted from the photovoltaic module, while the **infrared Thermocamera** allows to transform this radiation in the corresponding temperature, using a series of equations that take into account all the effects present during the acquisition (direct radiation, reflected, transmitted, emissivity, humidity, dew point, etc.). To make this conversion, knowledge and skills are required, which are subject to specific training. Only certified personnel is enabled to the execution of the thermographic measurements and the data intepretation (UNI EN 473/ISO 9712).
The Thermocameras today available on the market are designed to detect the wavelengths of two specific ranges: 3÷5 µm (mid-wave) and 8÷14 µm (long-wave).
The result of such thermographic inspection is an image, said **thermogram** (in false color or in grayscale) in which each color corresponds to a temperature.
Thermal images, however, have to be interpreted by experts in order to diagnose the correct operation of the module or the critical issues and their entities. This task requires competence, experience and time.

Technical standards

The following is a non-exhaustive list of technical rules on the thermography; some of them regard the criteria for a correct procedure of the infrared measurement, other ones are related to the qualification and certification of the infrared thermography operator.

- UNI 10824-1:2000 Prove non distruttive – Termografia all'infrarosso – Termini e definizioni
- UNI EN ISO 9712:2012 – Prove non distruttive - Qualificazione e certificazione del personale addetto alle prove non distruttive
- ASTM E1213: Standard Test Methods for Minimum Resolvable Difference for Thermal Imaging System
- ASTM E1311: Standard Test Methods for Minimum Detectable Temperature Difference for Thermal Imaging System
- ASTM E1316: Terminology for Non Destructive Examinations
- ASTM E1862: Standard Test Methods for Measuring and Compensating for Reflected Temperature Using Infrared Imaging Radiometers
- ASTM E1897: Measuring and Compensating for Transmittance and Using Infrared Imaging Radiometers
- ASTM E1933: Standard Test Method for Measuring and Compensating for Emissivity Using Infrared Imaging Radiometers

- ASTM E1934 Standard Guide for Examining Electrical and Mechanical Equipment with Infrared Thermography
- DIN 54 190-1 Prove non distruttive – Esame termografico – Parte 1: Principi generali
- DIN 54 190-2 Prove non distruttive – Esame termografico – Parte 2 : Attrezzatura
- DIN 54 190-3 Prove non distruttive – Esame termografico – Parte 3: Condizioni

Glossary

- **Aggregate of cells**: set of contiguous cells having homogeneous temperatures.
- **Cells, critical**: cells having average temperature above that one occurring in case of proper operation, with respect to the environmental conditions at the time of acquisition. The level of criticality, from 1 to 3, is higher for cells with greater over-temperature.
- **Cells, homogeneous**: cells having comparable average temperatures.
- **Cells, normal**: cells having average temperature close to the correct operating temperature, respect to the environmental conditions at the time of acquisition.
- **Cells, not classified**: cells with abnormal temperature distribution. This may depend either on external phenomena (shading, reflection of objects, etc.), or on localized phenomena onto the glass (dirt, mud, guano, etc.), or on internal defects of the cell.
- **Cluster of cells**: set of homogeneous cells, consisting of one or more aggregates of cells.
- **Current, short circuit**: maximum current of a photovoltaic module. This data is specified in the data sheet of the photovoltaic module.
- **Grid**: useful tool to delimitate the cells of the photovoltaic module.
- **Histogram of the image**: representation of the tonal distribution of a digital image, in which each tonal value is associated to the number (in relative or absolute terms) of pixels having that value.
- **MPP**: Maximum Power Point of a photovoltaic module. This data is specified in the data sheet of the photovoltaic module.
- **NOCT**: Nominal Operating Cell Temperature. Nominal operating temperature of a well-functioning cell. This data is specified in the data sheet of the photovoltaic module.
- **Peak of the histogram (or mode)**: tonal value of a digital image, corresponding to the maximum number of the associated pixels. In other words, it coincides with the maximum of the histogram.
- **Temperature, apparent**: temperature corresponding to the total energy detected by the sensor (as sum of emitted, reflected and transmitted energy), with no compensation.
- **Thermal image**: image produced by a system of apparatuses sensitive to infrared radiation (sensors), able to represent the distribution of the apparent radiant temperature.
- **Thermocamera**: detector of infrared radiation, capable of generating a thermal image. If the system is sensitive to radiation in the near infra-red (3÷5 µm), it is said mid-wave type; if sensitive to the radiation in the far infra-red (8÷14 µm), it is called long-wave type.
- **Thermogram**: thermal image in false color or grayscale, in which each color or gray level corresponds to a temperature.
- **Thermography**: calculation and representation of the surface temperature by measuring the density of the infrared radiation from a surface.
- **Thermography, qualitative**: analysis of a thermogram, aiming to detect the presence of anomalies.
- **Thermography, quantitative**: analysis of a thermogram, aiming to quantify the level of criticality of any anomalies and to plan the necessary actions.
- **Voltage, open circuit**: maximum voltage of a photovoltaic module. This data is specified in the data sheet of the photovoltaic module.

Module parameters

Module identifier	GEO - 251478
Position	41° Latitude / 17° Longitude
Nominal Power (Pn)	280
Temperature coefficient at Pn [%/°C]	-0.4
Voc (open circuit voltage) [V]	45,35
Vmpp (MPP voltage) [V]	36,85
Impp (MPP current) [A]	7,64
Isc (short circuit cuorrent) [A]	8,20
NOCT [°C]	45
Number of cells for row	9
Number of cells for column	8

Acquisition data

Thermocamera

Model	AA-275
Spectral response	Long-wave Thermocamera (λ = 8÷14 µm)
Detector	uncooled microbolometer
Accuracy	2%
Temperature ranges	From -20°C to +650°C in 3 ranges: from -20°C to +120°C; from 0°C to +350°C; from +200°C to +650°C
FPA	320*240 pixels
FOV	25° x 19°
IFOV	1.36mrad
Emissivity ε of acquisition	0.9
Reflected temperature [°C]	10
Camera-module distance [m]	2
Relative humidity [%]	55
Calibration	Calibration certificate n. 1234 Calibration date 05/05/2016 Certification body AABBCC
More	Image frequnecy 60 Hz Focus: automatic or manual

Other instruments

Model	Solarimeter BBB-YYY
Description	Range: 0 – 1250 W/m2 Spectral band covered: 0,3 µm – 1,1 µm Temperature range: : -30/+80°C voltage: 0 – 10 V current: 0-20 mA, Accuracy: ± 2.5% source: 9 – 30 Vdc protected against reverse polarity, short circuit encapsulating: resistant UV transparent resin (IEC 60904-2)

Model	Anemometer mod. WQ-47A
Description	Wind velocity: 0÷50 m/s (0 ÷ 180 km/h) Internal measured temperature: -30 ÷ +85 °C Calibration according IEC 61400-12-1 Source, protected against short circuit and overvoltage accuraacy: ± 3%, correlation > 0,99995 St.Err 0,022m/s internal temperature accuracy: ± 3°C (-30 ÷ +85 °C) source: 5 ÷ 40 Vdc / 9 ÷ 28 Vac protected against reverse polarity, power < 500mW protection IP65

Parameters and conditions

Date and time of acquisition	11/02/2016 9:10
Solar radiation [W/m^2]	600
Atmospheric temperature [°C]	10
Wind speed [m/s]	3
Conditions of acquisition	The module has been installed in 2011 on the roof of a public building, south oriented with a 45° tilt. No shading affects the module.

Image pre-processing

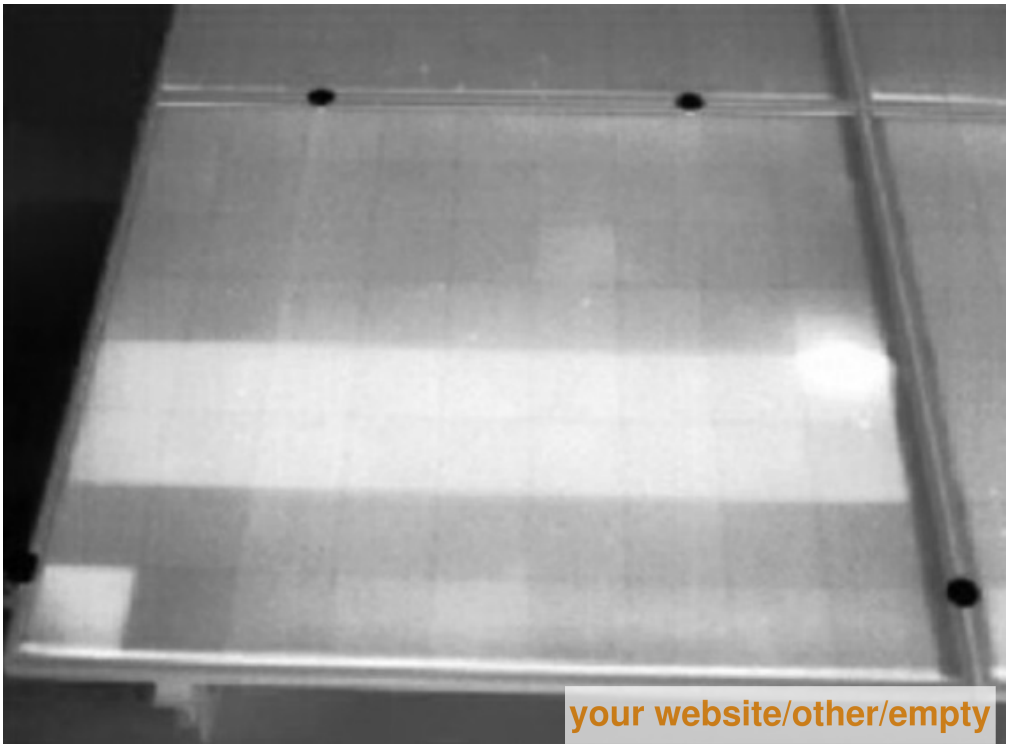


Figure A - Source IR image.

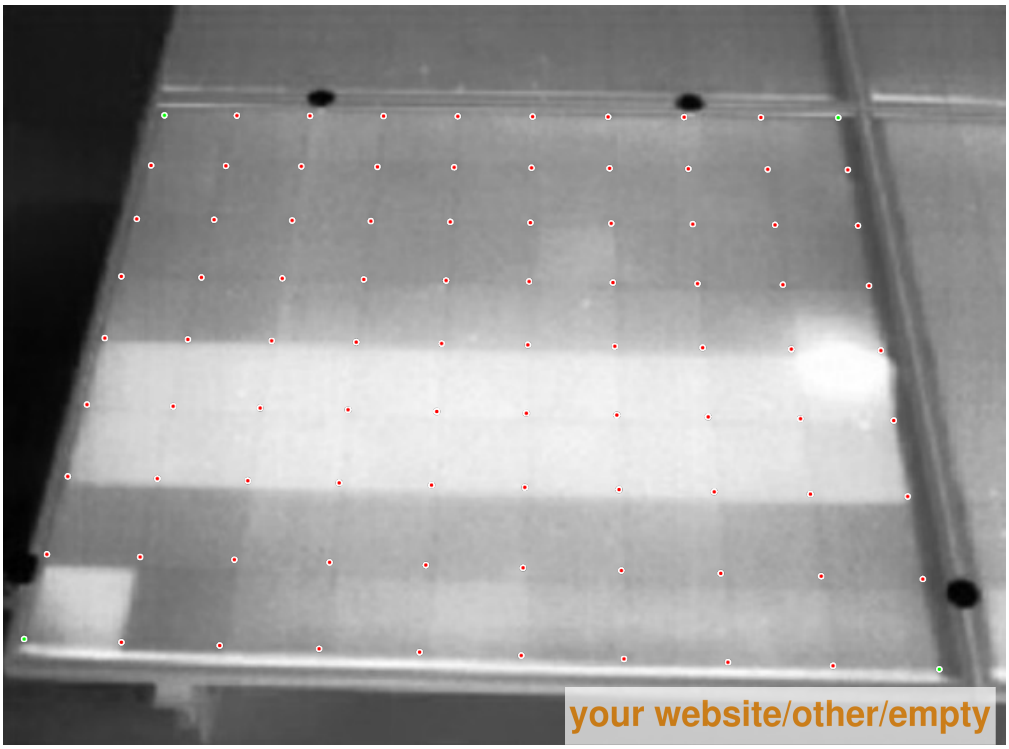
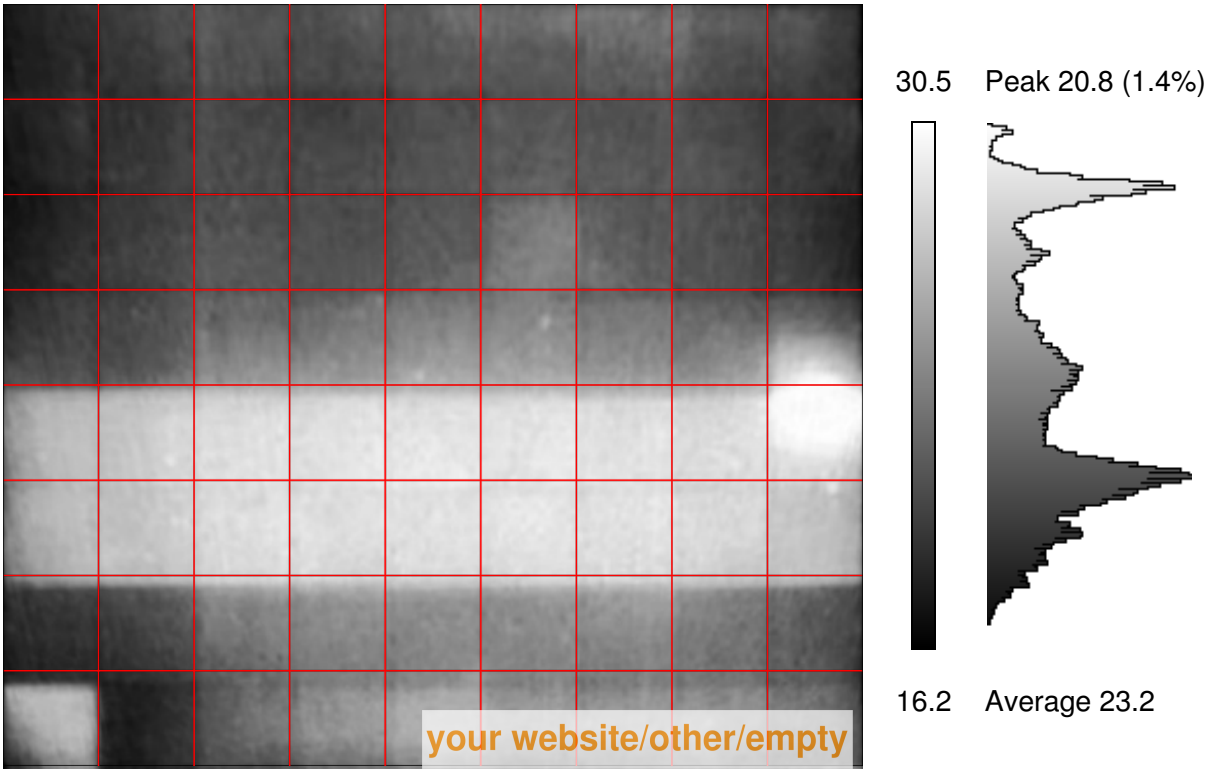
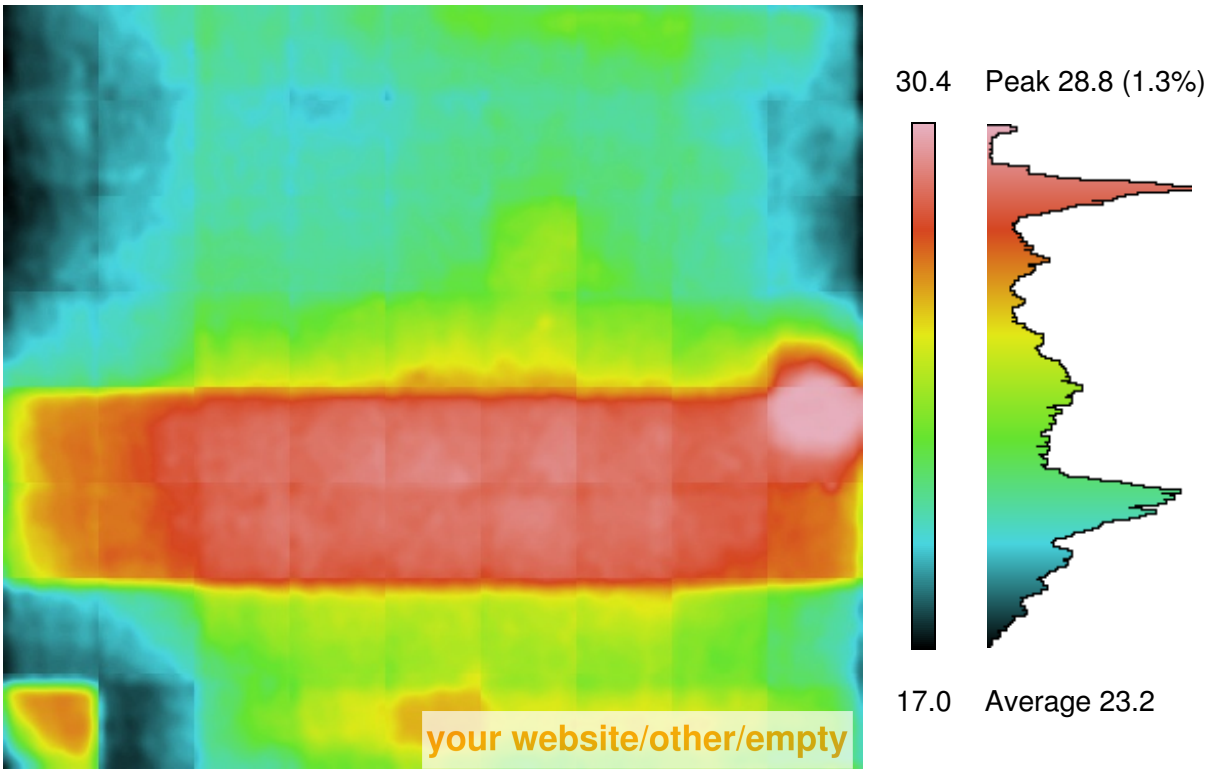


Figure B - Module selection. Module and cell vertexes evidenced in green and in red, respectively



Scheme 1 - Cells grid and histogram (temperatures in °C).

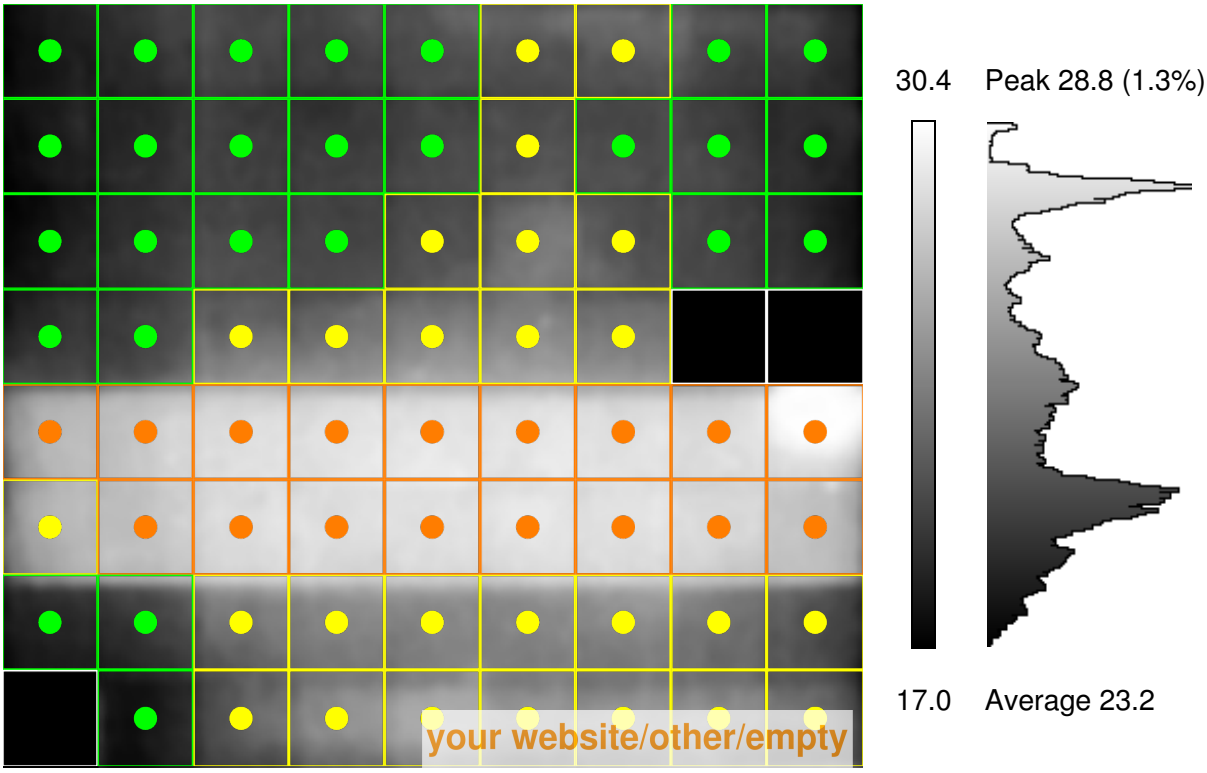


Scheme 2 - Region of interest (after strong filtering) and histogram (temperatures in °C).

Analysis

Cells analysis

This analysis subdivides the cells of the module in three main categories: normal cells, hot cells, unclassified cells. The normal cells are those well-functioning, since they have a temperature close to that one defined by the manufacturer. The hot cells have a higher temperature than that one indicated in the technical specifications, and thus present a criticalness, to which is assigned a level from 1 to 3: the higher it is, the greater the over-temperature of the cell, the more serious itsconsequences may be (less energy production, premature aging, propagation of the negative effects on neighboring cells, exceeding the maximum temperature set by the manufacturer, etc.). The remaining cells present an abnormal distribution of the surface temperature and are not classified, because their anomaly may depend either on external factors (clouds, shading, dirt, etc.) or on internal failures.

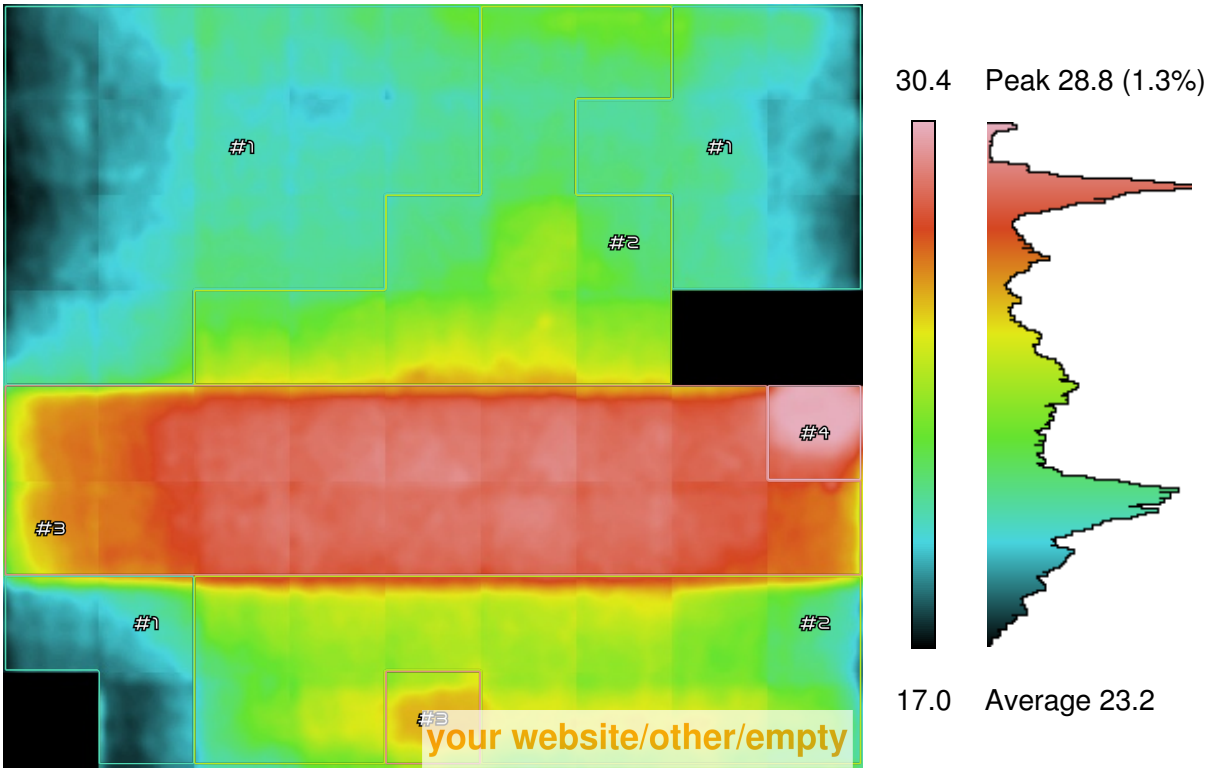


Normal cells	26 (36%)
Hot cells | criticality 1	26 (36%)
Hot cells | criticality 2	17 (24%)
Hot cells | criticality 3	0 (0%)
Not classified cells	3 (4%)

Scheme 3 - Cell Tipologies: normal (green), critical (yellow, orange, red), not classified (black). Histogram (temperatures in °C) and numerical results.

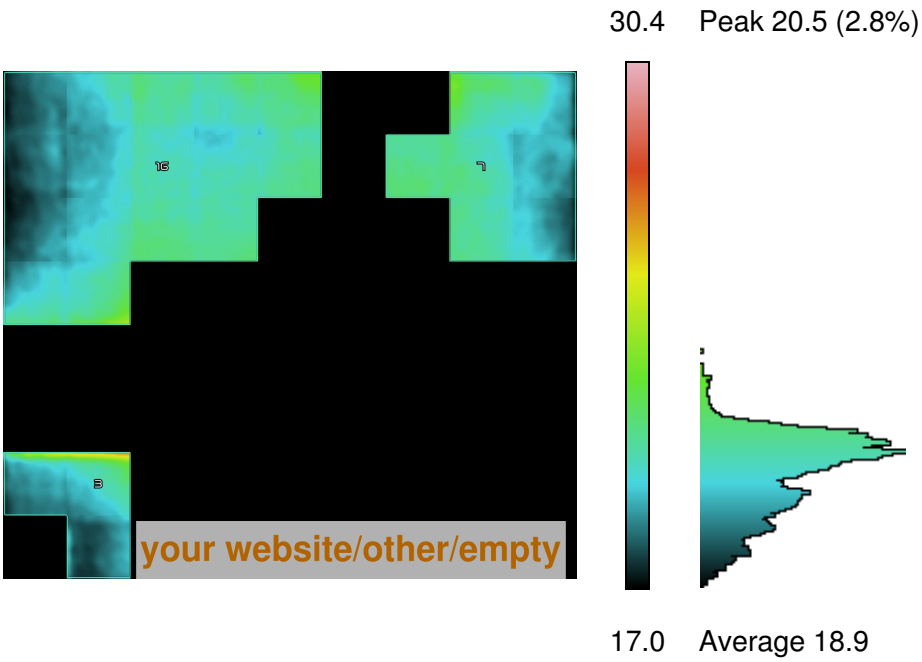
Clusters analysis

The clusters analysis highlights and groups into clusters homogeneous cells, i.e. the cells with similar average temperatures. In a well-functioning module, all the cells have similar temperature, thus constituting a single cluster. In contrast, in the presence of anomalies, the wider dispersion of the temperature values produces several clusters of homogeneous cells: the greater the dispersion of the temperature, the greater the number of homogeneous groups, the lower the number of cells in each cluster. Furthermore, the cells of a single cluster may be connected each other, or they may constitute separate subgroups. Each subgroup of connected cells is an aggregate of homogeneous cells. This analysis, if regularly repeated, allows you to monitor the evolution of the aging of each cell: for example, the migration of a cell from a colder cluster to a warmer one is a symptom of a premature aging of that cell. A proper storage of this report is therefore suggested, for future comparative studies.



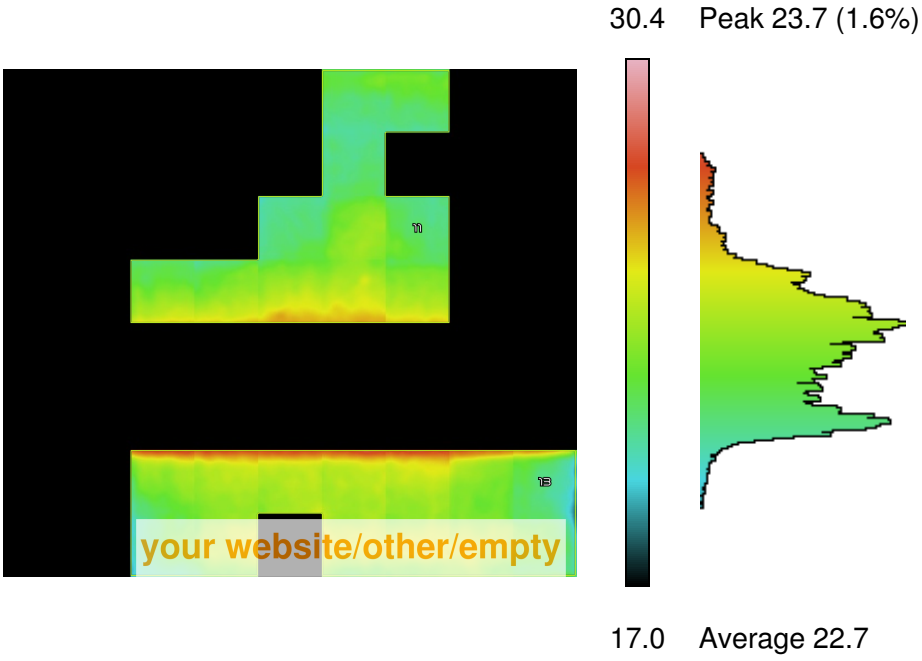
Clusters	Aggregates	Cells
4	8	69/72

Scheme 4 - All the clusters (#N denotes an aggregate belonging to the group #N), histogram (temperatures in °C) and numerical results.



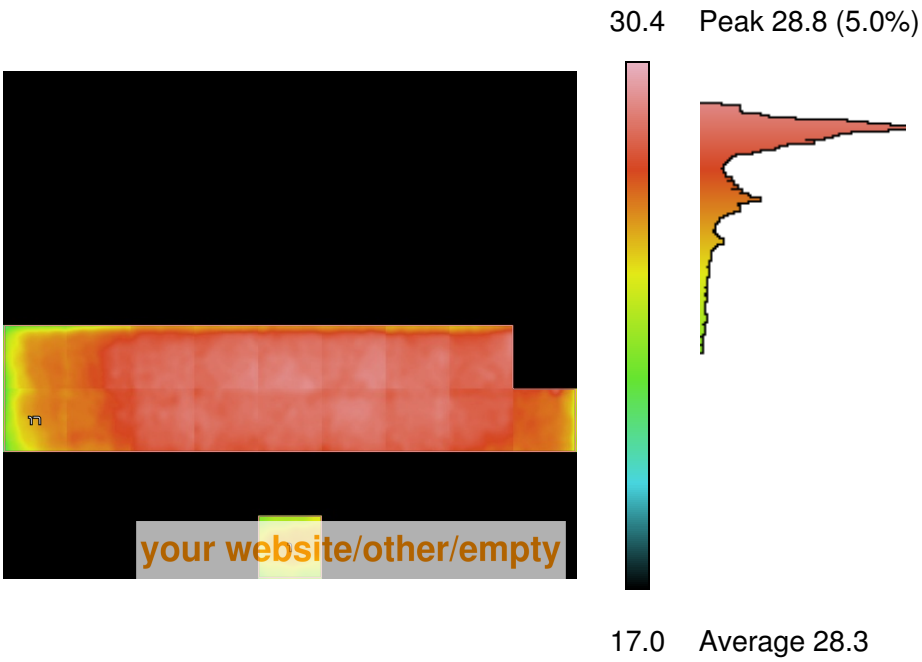
Aggregates	Cells	Cells temperature [°C]		
		Minimum	Mean	Maximum
3	26/72	18.3	19.9	21.2

Scheme 5 - Aggregates in cluster #1 (numbers specify the quantity of cells in the aggregate), histogram (temperatures in °C) and numerical results.



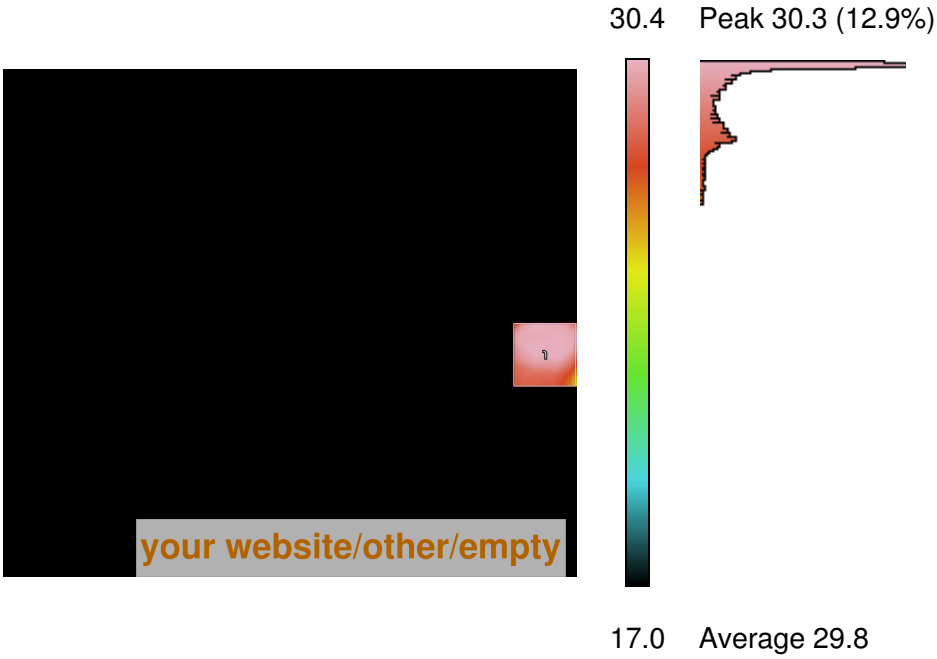
Aggregates	Cells	Cells temperature [°C]		
		Minimum	Mean	Maximum
2	24/72	21.2	23.1	24.4

Scheme 6 - Aggregates in cluster #2 (numbers specify the quantity of cells in the aggregate), histogram (temperatures in °C) and numerical results.



Aggregates	Cells	Cells temperature [°C]		
		Minimum	Mean	Maximum
2	18/72	25.5	28	29

Scheme 7 - Aggregates in cluster #3 (numbers specify the quantity of cells in the aggregate), histogram (temperatures in °C) and numerical results.

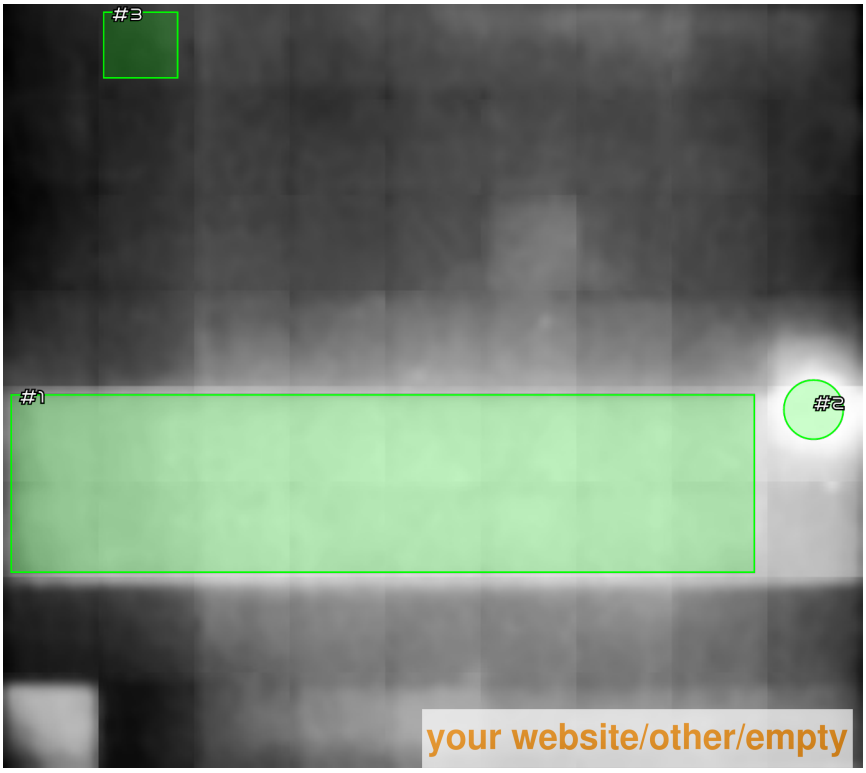


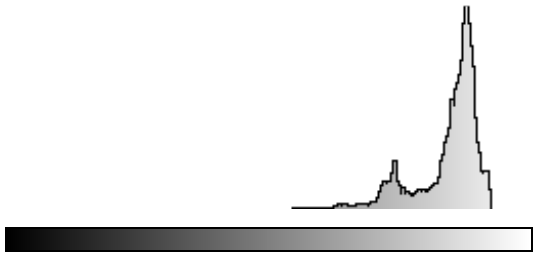
Aggregates	Cells	Cells temperature [°C]		
		Minimum	Mean	Maximum
1	1/72	29.8	29.8	29.8

Scheme 8 - Aggregates in cluster #4 (numbers specify the quantity of cells in the aggregate), histogram (temperatures in °C) and numerical results.

Analysis of details

In this section, analyses performed on specific regions of the image are presented.



Detail #1	Max temperature [°C]: 29.6 Min temperature [°C]: 23.0 Peak [°C]: 28.8 (6.1%) Average [°C]: 28.2	
Detail #2	Max temperature [°C]: 30.4 Min temperature [°C]: 30.0 Peak [°C]: 30.3 (36.3%) Average [°C]: 30.3	
Detail #3	Max temperature [°C]: 20.6 Min temperature [°C]: 19.0 Peak [°C]: 19.2 (7.8%) Average [°C]: 19.6	

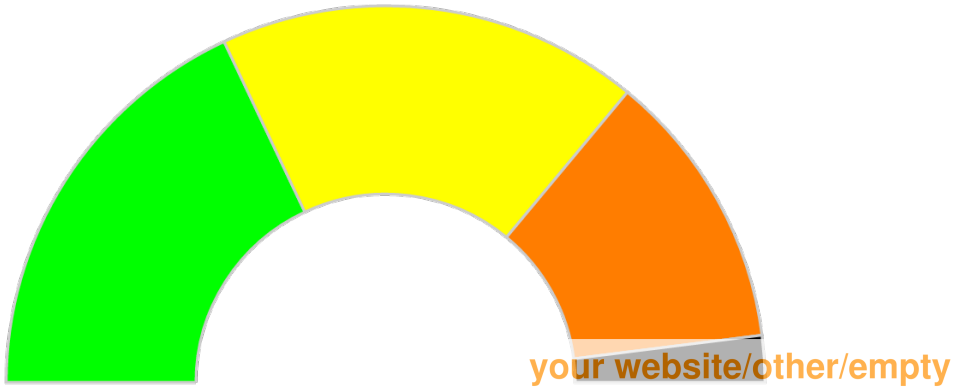
Scheme 9 - Analysed details.

The Detail #1 is constituted by two strings of hot cells, having temperature approximately of 28.2°C, 8.6°C warmer than the temperature of the normal cell in Detail #3.
Detail #2 is an hot spot at about 30.3°C, in correspondence with the junction box.

Diagnosis

The diagnosis summarizes the module state of health, highlights any critical issues, proposing appropriate actions to maintain efficient the photovoltaic system.

Results at a glance



Percentage	Results	Criticalities	Proposed action
36%	Normal cells	0	**Annual Monitoring.** Ordinary maintenance: visual inspection, module cleaning, connection checks, etc.
36%	Hot cells	1	**Half-yearly monitoring.** Abnormal temperature, light reduction of the produced energy, risk of premature ageing
24%	Hot cells	2	**Quarterly monitoring.** High temperature, reduction of the produced energy, risk of adverse effects on the neighboring cells, premature aging.
0%	Hot cells	3	**Substitution of the module in presence of numerous cells with criticality level equal to 3.** Very high temperature, decisive reduction of the produced energy, high likelihood of adverse effects on the neighboring cells.
4%	Not classified cells	N.C.	**Anomaly.** Defected cell, shading, glare, dust/mud/dirt, etc ..

Clusters	Aggregates	Proposed action
4	8	**Planned monitoring.** Monitor the PV module the more frequently as the more numerous are the groups. Check both that the number of the aggregates is not much higher than the number of groups, and that it is not increased since the last inspection. Consider that migration of cells to warmer groups evidences operating anomalies (reduction of produced energy and / or aging of the module).

Scheme 10 - Resumed results and proposed actions.

Technician's prescriptions

The module presents 60% of hot cells, and 36% of normal cells.
4 clusters and 8 aggregates: the aggregates' number is twice the clusters' number.
Since the 36% of the cells presents a level 1 criticality, and the 24% has a level 2 criticality, I recommend the next infrared inspection within 6 months.

List of the attachments

- PV module data sheet
- technician's certificate
- calibration certificate of the thermocamera
- thermocamera data sheet
- solarimeter data sheet
- anemometer data sheet

Phoenix, 2016/07/17

YOUR NOME

.....
(Signature)