BUNDESVERBAND FÜR ANGEWANDTE THERMOGRAFIE E.V.	German guideline	September 2018

VATh-Guideline: Electrical Infrared Inspections ▪ Low Voltage

Planning, execution and documentation of infrared surveys on electrical systems and components ≤ 1kV

VATh- Guideline: Electrical thermal imaging

Planning, execution and documentation of infrared surveys on electrical systems and components.

Directive du VATh: Thermographie électrique

Pour la planification, réalisation et documentation de mesures infrarouges d'installations et d'équipements électrotechniques

Low voltage
up to 1kV AC or 1,5kV DC

Basse tension
(Basse Tension jusqu` à 1 kV ca et 1,5 kV cc)

Annotations:

This guideline is intended as assistance and directive for the planning, execution and documentation of thermographic inspections on low voltage electrical systems and electrical components.

This guideline represents the current state of technology.

Explications concernant la directive:

Cette directive sert de support, d'aperçu et de guide pour la planification, la réalisation et la documentation des mesures infrarouges d'installations et d'équipements électrotechniques dans le domaine basse-Tension (BTA).

Cette directive est la version de l'état actuel de la technique.

This guideline comprises 16 pages

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VATh- Guideline: „Electro-Thermography“

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All statements are based on the current standard of knowledge. The Bundesverband cannot accept any responsibility or liability. Recommendations or objections for upcoming versions should be addressed to the office of the Bundesverband.

In the case of disputes the German version of this guideline is relevant.

Table of contents

1. Educational prerequisites and personal skills

The following prerequisites must be fulfilled and represents the basis for a qualified thermographic training:

a) A completed apprenticeship in the field of electrical engineering with the skill of a journeyman, master craftsman or engineer. Engineers, who graduated from a college or technical college without having completed an apprenticeship as an electrically qualified person, must provide a certificate according to DIN VDE 1000-10 / 4.2.
b) At least two years of professional experience in the field of Electro-Thermography and several years of experience in the field of electronic engineering according to VDE1000-10 / 4.2 is required (Annotation: several years experience in the related field of activity).

It is mandatory to prove at least a successfully completed level 1 course according to DIN EN ISO 9712* and a specific training course reagrding fundamentals of electrical components along with the assessment of typical electrical thermal anomalies (e.g. DIN EN ISO 9712*, Sector: Electrical Applications – Level 2).
According to the guidelines for personnel in the field of non-destructive testing, only the persons are allowed to run an inspection and evaluation without supervision of a level 2 or 3 certified person, if they are certified according to DIN EN ISO 9712*, Sector: Electrical Applications – Level 2 or 3.

Due to the generally increased fire risk, the person performing the inspection must be able to assess temperature rises accurately. Therefore, only persons should conducting the survey, who own a certificate “Electrical Thermographer, level 2” according to DIN EN ISO 9712* or “VdS acknowledged specialist for Electro-Thermography” (VdS = German association of property insurance companies) in order to meet the requirements of the insurance industry.

***: has displaced DIN EN 473 and DIN 54162!**

2. Health

The presentation of a certificate proofing the visual capacity according to DIN EN ISO 9712* is indispensable and must be renewed annually.

Also it should be acknowledged that the work in the field of Electro-Thermography is associated with increased health risks. Especially, people with pacemakers or a disposition for dizziness and epileptic seizures need to be aware of that.

3. Safety distance

By definition conducting an electrical inspection is considered to be included in the category “working in hazardous electrical energized areas”. As a consequence of working close to electrically energized components the following safety distance must be mantained according to VDE 0105, Table 102:

Nominal voltage in volts [V]	Safety distance in meters [m]
$50 < U_{\sim} < 1000$ $U_{=} < 1000$	0,5

4. Safety equipment

According to valid accident prevention regulations and other valid regulations the thermographer has to wear personal safety equipment for his own protection.

5. Regulations

Thermographic personnel inspecting electrical systems should generally be independent (no in-house personnel). This ensures that neither superior nor the company management has influence on the inspection. Safety and fire prevention always comes first.

6. Procedure

The thermographic inspection should be scheduled to fulfill the following conditions:

a) a minimum of 20% load of the inspected electrical components regarding to their maximum nominal load.

b) the condition mentioned in item a) must be maintained long enough to ensure that the components have reached a thermal equilibrium state while running the inspection.

Since the two conditions listed above are not always fully realizable and since the thermography of electrical systems is to be considered a snap-shot, it is advisable to run an inspection at regular intervals. This will improve the statistical certainty to detect anomalies. A separate risk assessment has to be performed by the employer.

It is recommended, that the end user shall provide a qualified assistant to accompany the infrared thermographer during the inspection. The qualified assistant should be knowledgeable of the operation and history of the equipment to be examined

7. Infrared Camera Equipment

The infrared imaging system beeing used has to meet the following requirements:

Spectral Range:	Cameras working in the MW (Mid-Wave: 3-5 µm) or LW (Long-Wave: 8-12 µm) spectral band can be used.
Measurement Temperature Range	-20° to +500°C (or higher)
OperatingTemperature Range	-10° to +40°C (or higher)
Basic Type:	A split camera/controller concept (monitor and remote control unit separated or alternatively a turnable monitor) is necessary in order to run the inspection also in areas with difficult access
Lenses:	Usually a lens out of the available standard lens set must be used - Wide angle lens - Standard angle lens - Tele lens depending on the particular scope
Thermal resolution:	≤ 100 mK recommended: ≤ 60 mK
Geometrical resolution:	≤ 1,5 mrad (= IFOV of Standard lens)
Detector Pixel resolution:	min. 320 x 240 Pixel
Temporal resolution:	min. 20 frames/sec
Measurement accuracy:	±2K or ±2%
Basic operating functionality:	The camera must offer the capabilities to: - focus the image precisely - freeze an image - switch between color and gray palettes - activate measurement functions: moveable spot and area - adjust all measurement parameters - manual scaling and display the thermogram - saving radiometric data
Power supply:	- A self-contained operation on battery power is indispensable.
Calibration:	- Periodical factory-calibrations (according to the manufacturers requirements) - Frequent automatic comparison/compensation to an internal temperature reference inside the camera

	A validation of the temperature calibration must be done and documented annually. It is recommended to perform a simple calibration check even more frequently.

8. Analysis and reporting software

The expert must own or have access to a suitable software which allows processing, analyzing and reporting the infrared images afterwards. It must be possible to change the measurement parameters used to convert the measured radiation density into temperature and also labeling the results after the inspection.

9. Assessment and Reporting

The inspection report consists of a **basic document** and the actual **evaluation document page(s)**. The particular style of these documents are due to the thermographer. Nevertheless, the data and annotations listed below **must** be included.

In addition the VdS guideline 2860 applies to persons qualified as "VdS acknowledged specialist for Electro-Thermography".

10. Basic document

The following data has to be included on the basic document:

1. Employer
2. Contractor
3. Inspected objects
4. Scope of the inspection
5. Name of the operating thermographer and accompanying persons
6. Date of inspection
7. The used infrared camera system incl. the applied lenses
8. Auxiliary measuring instruments that were used like clamp meter, thermometer, hygrometer, anemometer, pyrometer etc.
9. In case of outdoor inspections the weather conditions (including air temperature [°C], relative humidity [%], wind speed [m/s], Global radiation [W/m^2])

11. Evaluation document

Usually, the evaluation document includes a report, a listing of all inspected system components and the thermograms. Every thermogram should be presented on a separate page measuring at least 80 x 60mm (temperature scale not included). The following information regarding the thermograms must to be presented on this page:

1. A photo with the same image content taken from the same position.
2. The date and exact time the image was taken plus the name of the recorded image file.
3. An accurate object description (building, switchyard, switchboard, control panel, component nr/code etc.)
4. Preferably the load of the component when the image was saved in ampere [A] and/or as percentage [%] of the nominal load.
5. The temperature of the thermal anomaly with the exact location and/or the temperature difference between the fault location and an identical faultless component. The given information must be clear enough that the client can retrace the shown temperature values, resp. temperature difference.
6. Voltage level
7. Fault classification

All inspected components, that have been classified as “thermal abnormality” or “dangerous thermal abnormality” according to DIN 54191 during the evaluation period, **must** be listed in the evaluation report as well as interpreted by the operating thermographer, if necessary provided with annotations and recommendations.
A list including all inspected components along with the noticed anomalys and their classifications has to be added to the report. Non thermal anomalys can be documented by photos as the circumstances require (e.g. heavy dust deposit on electrical systems).

12. Classification of thermal anomalies

According to DIN 54191 anomalies are classified as follows:

- no anomalies (ok);
- thermal abnormality (tA);
- dangerous thermal abnormality (gtA);
- inspection not possible (kB);
- non-thermal anomalies (ntA).

In order to categorize into severity assessment classes, the detected temperature of the suspicoius component must be compared either with a given temperature limit (▸ maximum allowable temperature criteria) or with the temperatures of a similar component under similar operating and environmental conditions (▸ temperature difference or ΔT criteria) as showed in attachment A, chart 1.

Additionally, the measured temperature distribution and temperature gradient have to be reviewed according to the terminology “thermal anomaly”. With respect to DIN 54191, a thermal anomaly describes a state which is not consistent with the normal operation or can’t be explained by the internal construction of the component. For a final classification of the detected anomaly the following circumstances must be considered:

a) -is the current load known and given constantly ?
b) -deviating surrounding conditions ?
c) -high density packing in the cabinet ?
d) -how high is the packing density in the control cabinet, are neighboring resources also affected (simultaneity factor)?
e) -is a redundancy of the inspected component given ?
f) -is an unrestricted visual connection to the actual heat source given?

Severity class	[**1**] OK	[**2**] tA*	[3] tA*	[**4**] gtA
Recommendation	no further action required	check possible cause; repair at next sheduled shutdown, at most within 6 months	check possible cause; repair at next sheduled shutdown, at most within 2 months	short-term deactivation; check possible cause and repair as soon as possible; alternatively reduce load

***:** Thermal indications e.g. on electronic printed circuit boards can cause time-consuming troubleshooting and may lead to long and costly downtimes. Therefore the “tA”-rating was splitted into 2 classes (deviating from DIN EN 54191) which differs only with respect to the recommended time frame for inspection and maintenance.

13. Thermography on photovoltaic-generators

With the increasing use of photovoltaic systems in the commercial as well as the private sector there is rising demand for an appropriate inspection technology to guarantee a safe and profitable operation of these systems. Infrared thermography is highly qualified to be such an inspection method and ist not just limited to commissioning inspections (first inspection in accordance with DIN EN 62446).

Basically, a thermographic inspection on photovoltaic-generators (photovoltaic-module units) must be assigned to the field of electro-technical thermography, which requires a basic knowledge of the functional principles of photovoltaic-generators as well as a founded understanding of thermography as an optical inspection method in order to be done accurately.

In addition to the previous chapters 1. to 12. this section contains annotations highlighting the specific requirements for the infared inspection of photovoltaic-generators.

13.1. Training

In order to run a commissioning inspection, i.e. the first inspection after installation, the executing thermographer must understand the fundamental functionality of photovoltaic-generators. Furthermore he needs to have sufficient knowledge of non-contact temperature measurement technology by using radiometric infrared cameras. These requirements must be proved by having participated an at least two day training focused on photovoltaic installations and photovoltaic thermography. Nevertheless it is strongly recommended to hold a level 1 certificate according to DIN EN ISO 9712. Table 2 in attachment B of this document shows a compilation of the most common thermal patterns on photovoltaic-generators, meant to help categorize suspicious patterns or anomalies found.

If thermal signatures are detected that differs from the examples in the compilation, a certified thermographer needs to be consulted, holding at least a level 2 certificate according to DIN EN ISO 9712 - Sector: Electrical Applications.

For periodic inspections, systematic error diagnosis or system optimization it is considered helpful to consult an expert in the field of photovoltaic installation engineering as well.

13.2. Safety equipment

If working in components that are likely to crash, the appropriate fall protection (e.g. safety harness) needs to be used.

13.3. Other regulations

When inspecting roof integrated systems or systems without a fire resistant separation between the generator and the flammable roof structure (also foil roofs), the focus should be put on fire protection issues. Therefore, the thermography personnel should be independent from the operator and the constructor.

13.4. Operation procedure

First of all it needs to be ensured, that the photovoltaic system is in operation. For this purpose the following approaches can be helpful:

a. control the Information-display(s) on the DC-converter(s)
b. measure the string currents with a current clamp
c. cause a partial shading of a module and check the reaction with the infrared camera.

The thermographic inspection has to be executed under stable radiation and weather conditions, i.e. an irradiation of at least 600 W/m² (at the pv-generator), a cloud coverage not exceeding 2/8 Cumulus and a wind speed of max. 4 Beaufort. After short-term radiation- and load changes (> 10% per minute) a settling time of at least 10 minutes should be kept before proceeding the inspection. The radiation conditions must be measured and documented during the inspection (irradiation power, measured parallel to the pv-generator surface). This allows a recalculation to nominal load conditions afterwards.

13.5. Infrared Camera Equipment

The infrared camera system beeing used should meet the following requirements:

Spectral Range:	A camera working in the LW (Long-Wave: 8-12 µm) spectral band would be preferable due to less solar reflections.
Basic Type:	A split camera/controller concept (monitor and remote control unit separated or alternatively a turnable monitor) is necessary to be able to see the camera monitor and the inspected component simultaneously (especially at close distances) Particular situations could require using the built-in viewfinder or shielding the camera monitor from direct sunlight.
Measurement Temperature Range	-20° to +120°C (or higher)
OperatingTemperature Range	-10° to +40°C (or higher)

Lenses:	Due to the typically strongly varying distances the camera should be equipped with interchangeable lenses, e.g. a standard or wide angle lens (for short distances and overview shots) and a tele lens (for single cells at longer distances). Alternatively flying recording platforms (so-called *drones*) can be used, which allows flexible camera positions
Geometrical resolution:	It is essential to make sure that there are at least 5x5 Pixel (native Detector pixel, no interpolation) on a single cell for an accurate temperature measurement

PHOTO

Although most of the infrared cameras nowadays are equipped with an additional visible camera, the performance of these built-in digital cameras is not sufficient regarding FOV (field of view) and resolution. Therefore, a separate camera has to be used, which allows to adjust the identical FOV like the infared camera and offers a sufficient spatial resolution to resolve even small conductor strips.

Furthermore, the identification of single suspicious photovoltaic modules must be possible even in large photovoltaic installations. Therefore the resolution capability of the visible camera should be at least 30 times the resolution of the infrared camera covering the same FOV.

13.6. Evaluation software

In addition to the features mentioned in chapter 8. *Analysis and reporting software* the software should allow to create polygon areas and providing the minimum-, maximum- and average temperatures along with automatic position markers of the maximum and minimum temperature.

13.7. Documentation

Any typ of thermal anomaly must be documented by at least one thermogram. The radiometric data of these thermograms must to be saved and should be available to the customer to its full extent (if needed). The framework conditions such as irridation power, cloude coverage, wind speed etc. must be documented in order to guarantee the reproducibility of the collected results.

Photovoltaic Installations with more than 100 modules

In case of large pv-installations with more than 100 modules, resp. an extensive number of anomalies it is usually sufficient to provide a list of the anomalies found, comprising the

names of the radiometric image files and a description of the anomaly. But nevertheless, the complete data-set must be available for the customer in the case of further queries.
In case of high volume findings with often very similar thermal patterns it is not necessary to supply a photo to every thermogram for reasons of clarity and to keep a clear overview.

The exact position of every anomaly within the complete installation must be stated clearly by applying two of the following options:

- a thermogram where the position is apparent from the context
- stating the position by refering to a “position”-list, e.g. a list, incorporating the x,y-coordinates of all modules
- mark the relevant item (pv-module or cell) in the wiring diagram of the pv-installation
- specifify the derial number of the module
- marking of the affected module with a waterproof pen on its frame or on the back of the module in the field

Stating the position information twice facilitates finding the suspicious module and reduces the risk of confusion during repair activities.

Annex A, Chart 1

Component or material:	Temperature limit [°C]:	Overtemperature limit ΔT [K]:
-junctions / clamps		
copper, bare	100	60[a]
copper-zinc-alloy, bare	105	65[a]
copper or copper-zinc-alloy, tinned	105	65[a]
Copper or cooper-zinc-alloy, silver-coated or nickel-plated	110	70[a]
-accessible parts		
manually operated / metal	55	15[a]
manually operated / non-metal	65	25[a]
touchable / metal	70	30[a]
touchable / non-metal	80	40[a]
metal housing, close to cable bushings	80	40[a]
non-metal housing, close to cable bushings	90	50[a]
housing surfaces with internal power resistors	240	200[a]
-cables and electrical lines		
PVC insulated	70	40[b]
heat-resistant PVC insulated lines (labeled: V2)	90	60[b]
heat-resistant rubber-wiring cable (e.g.: H07G-U/R/K)	110	80[b]
ETFE wiring cable	135	105[b]

Annex A, Chart 1 (continued)

Component or material:	Temperature limit [°C]:	Overtemperature limit ΔT [K]:
Heat-resistant silicone-cablet (e.g.: N2GFA, H05S-U/K, H05SS-F)	180	150[b]
rubber twin-, hose-, flat cables (e.g.: H03VH-Y, H03VV-F)	60	30[b]
-Insulating materials (with letter codes)		
Y (e.g.: cotton, paper, polyethylene)	90	
A (e.g.: paper, silk, impregnated with fluid insulating material)	105	
E (e.g.: phenol-, melamine-, epoxy resin, triacetate film)	120	
B (e.g.: micanites, fiberglass, ceramic, porcelain)	130	
F (e.g.: micaceous, fiberglass)	155	
H (e.g.: aromatic polyamides, polyimide, silicone)	180	
N (e.g.: glass*, polytetrafluoroethyle, epoxy EW90)	200	
Oil transformer		
winding, thermic category A, cooling method OF or ON	105	65[a]
winding for cooling method OD	110	70[a]
oil in the upper part of the transformer	100	60[a]
Dry type transformer	According to insulation class	

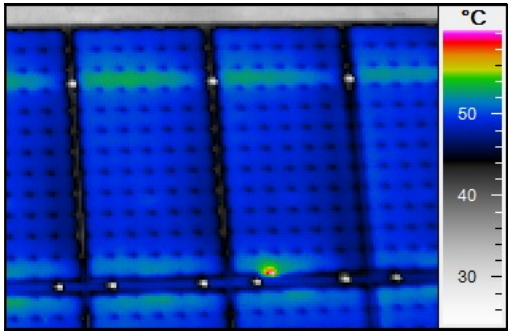
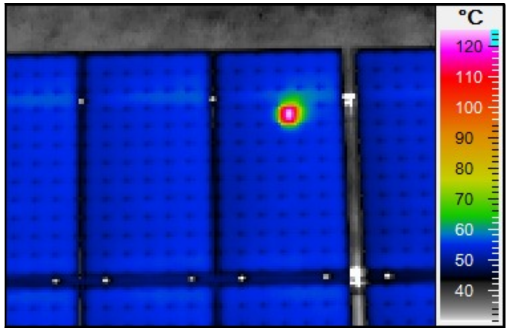
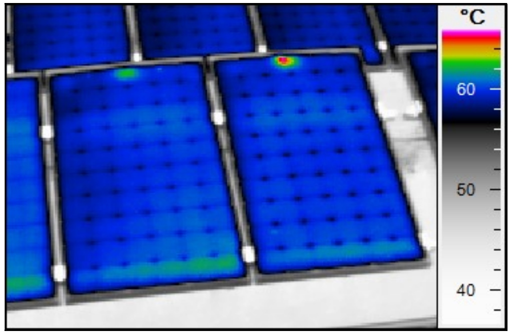
a: ambient temperature: 40°C, average over 24h maximum at 35°C

b: ambient temperature: 30°C

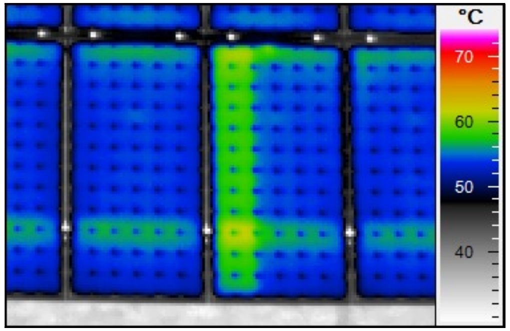
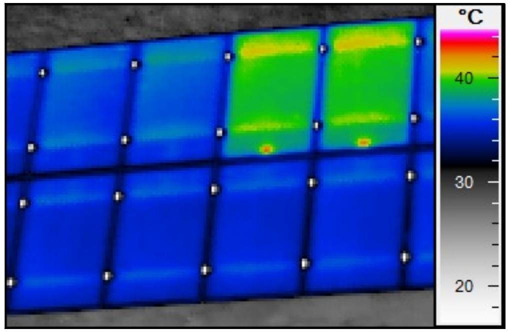
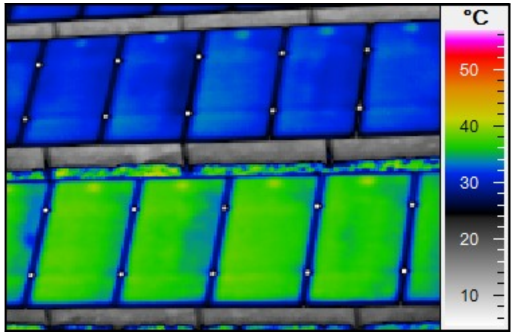
* only a good insulator until 300°C; at around 600°C glass is becoming a conductor!

This chart does not raise a claim to be complete. Extensions and limitations regarding the permitted limit temperatures have to be possibly looked up in the relevant norms.

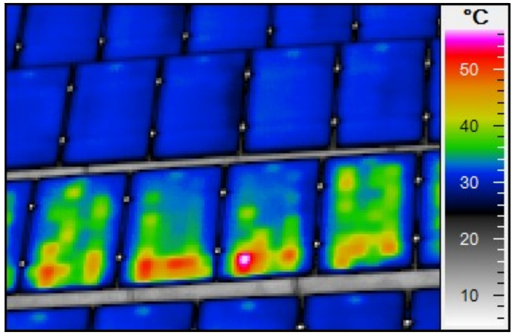
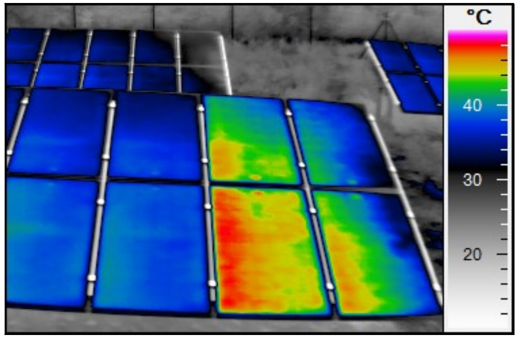
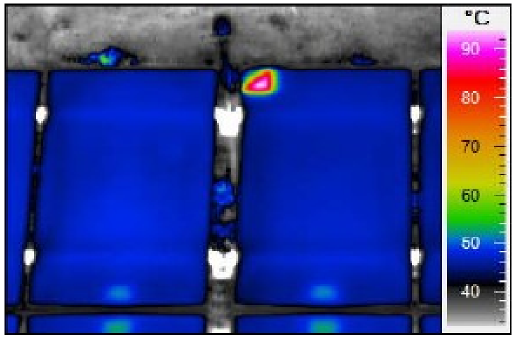
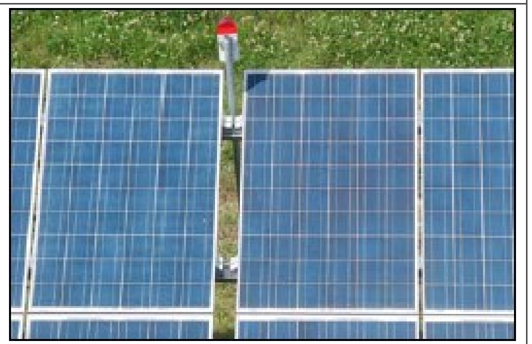
Annex B, Chart 2 Typical thermal patterns incl. severity assessment criteria and repair recommendations

Thermogram	Description	defect class	ΔT [K]:	Recommendation
	Suspicious con-ductor strip	tA	> 3 K	In-depth visible check; **evaluation** by a level 2 certi-fied thermographer based on detailed high-resolution back-side thermogram/photo
	Overheated cell (make shure, that it is no shading effect)	tA	> 20 K	replace module
	Heated junction box	tA	> 3 K	In-depth visible check; **evaluation** by a level 2 certi-fied thermographer based on detailed thermogram of the open junction box from the backside

Annex B, Chart 2 Typical thermal patterns incl. severity assessment criteria and repair recommendations (continued)

Thermogram	Description	defect class	ΔT [K]:	Recommendation
	Module with by-passed sub-string (idle mode)	tA	2- 7 K	replace module; in case of increased risk of fire (flammable material close to the modele) this module must be taken out **immediately**
	Several sub-strings by-passed	tA	2- 7 K	replace module
	Several mod-ules in idle mode	tA	2- 7 K	Check module connectors; Check connection of the com-plete string at the AC-converter resp. the state of the AC-converter

<u>Annex B</u>, Chart 2 Typical thermal patterns incl. severity assessment criteria and repair recommendations (continued)

Thermogram	Description	defect class	ΔT [K]:	Recommendation
	Modules in short-circuit mode	tA	2- 7 K	Check module connectors; Check connection of the complete string at the AC-converter resp. the state of the AC-converter Consult a thermograph level 2 or a photovoltaic expert
	Polarity of connectors reversed	tA	3- 12 K	Check polarity of module connectors; Check polarity of complete string connectors
	Single cell is partly shaded	Not a defect: Recommend to remove the object causing the shadow	20- 70 K	

-all thermograms with the friendly assistance of the "Solarschmiede", Munich-