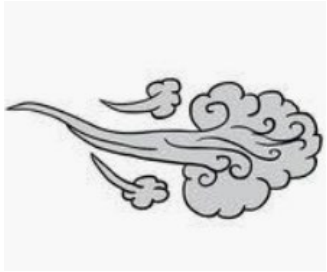
Block 4 – Imaging
Part 1: Infrared Thermography

34553: Applied Photovoltaics

PV Reliability

Sun (High temp. + UV)



Wind/snow load

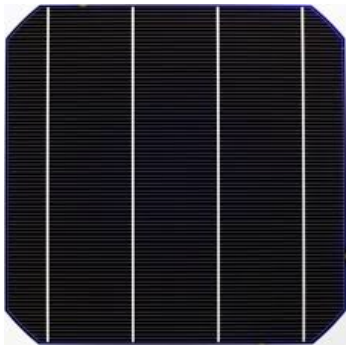
Rain and hail storms

Humidity (H_20)

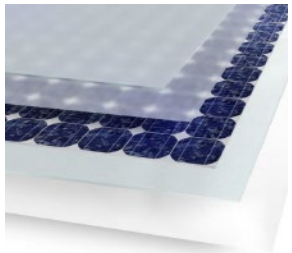
Installation/ handling

How to ensure a cell produces to <u>reliable</u> electricity for 25+ yrs.?

Partial shade

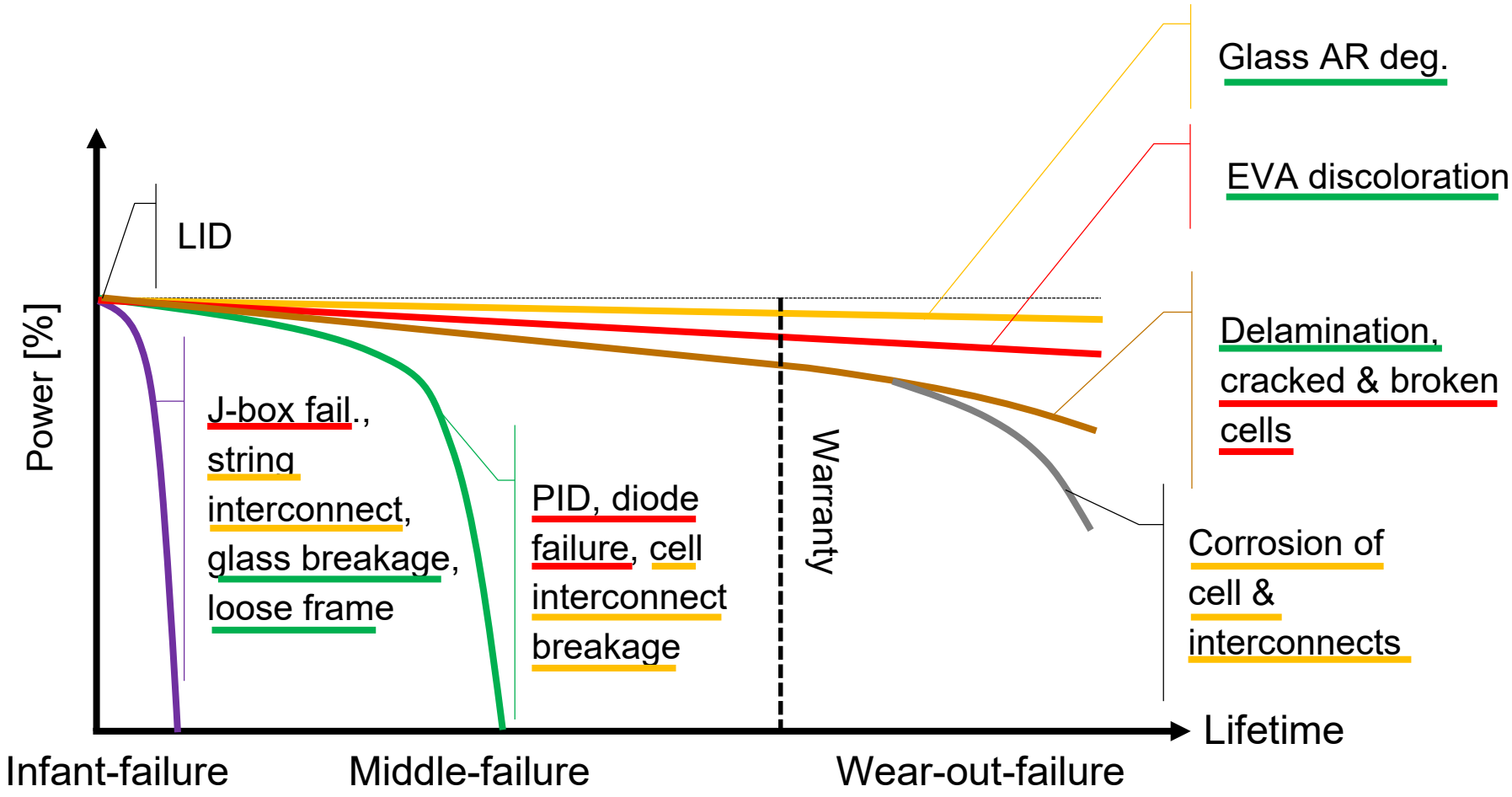


0.2-0.5 mm thick cell

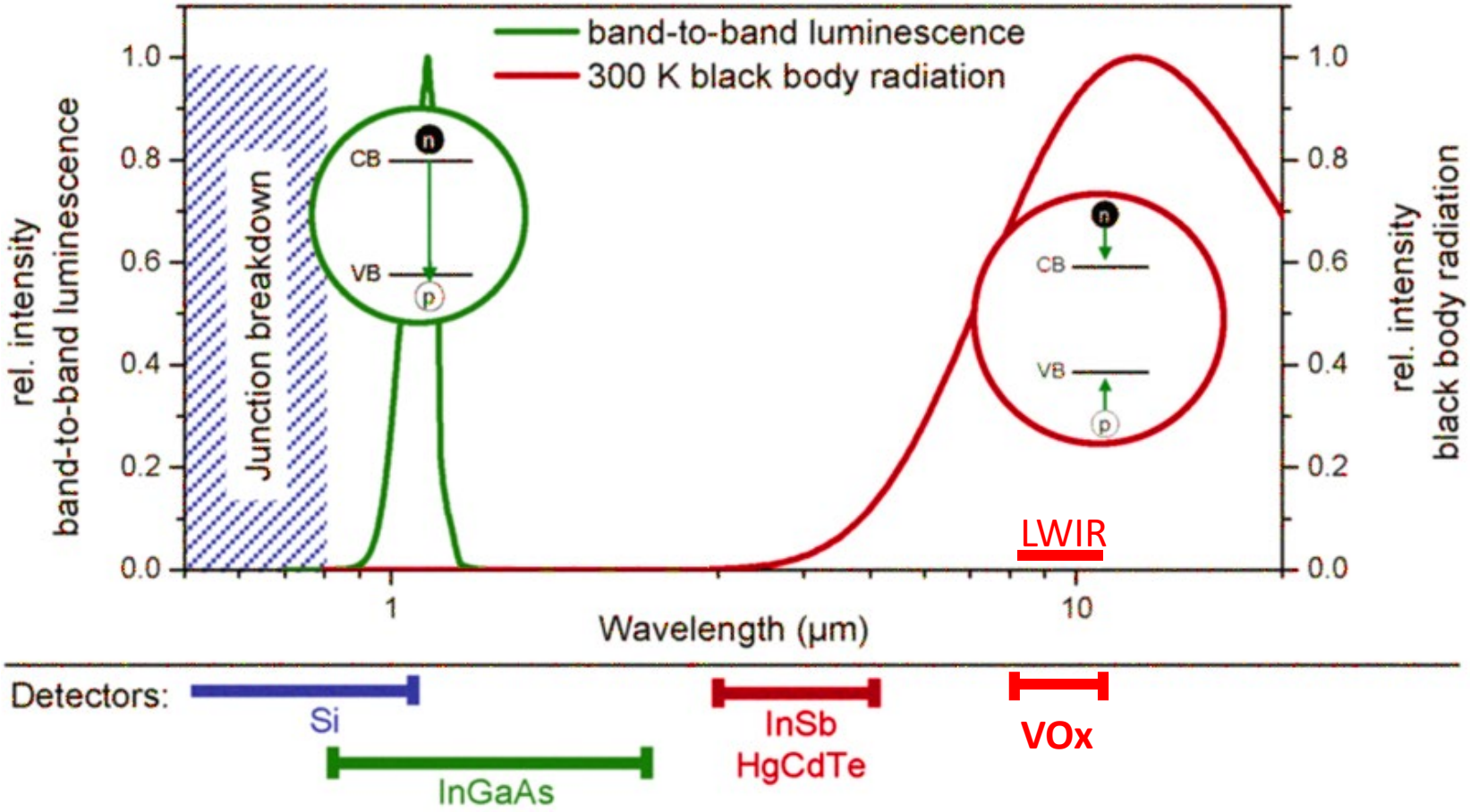


(Protected by some thin polymers and glass)

Overview of PV failures

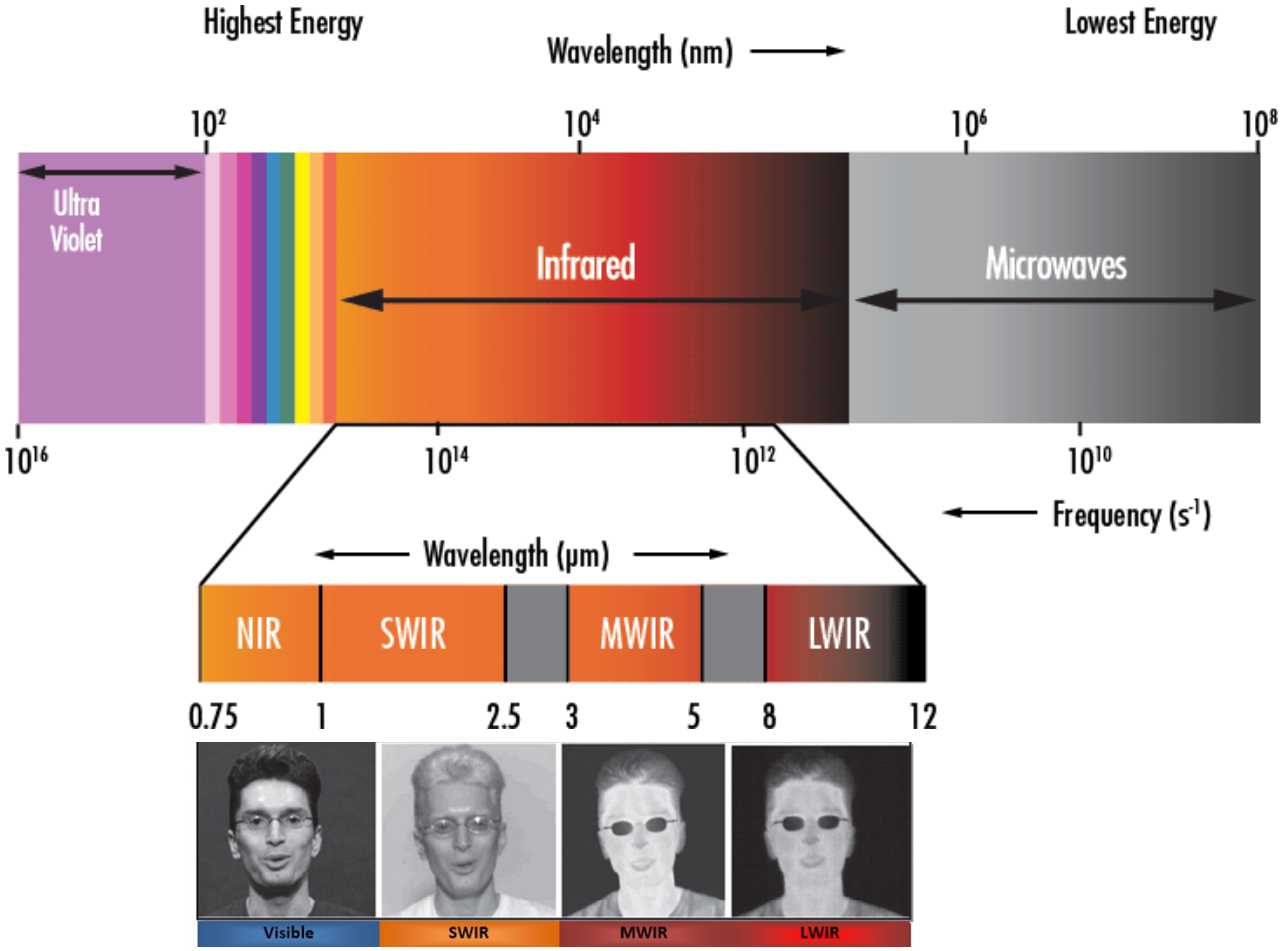


Spectral range of Si photon emission - Detectors



Modified from: Kasemann, M., Kwapil, W., Schubert, M.C., et al. 33rd IEEE Photovolt. Spec. Conf., 2008, 1–7

Wavelength Regions and Imaging



Infrared Thermography - Principles

- **IEC/TS 60904 -12** “Infrared Thermography of Photovoltaic Modules” (under development)
- **IEC/TS 62446-3** “Photovoltaic modules and plants – Outdoor infrared thermography”

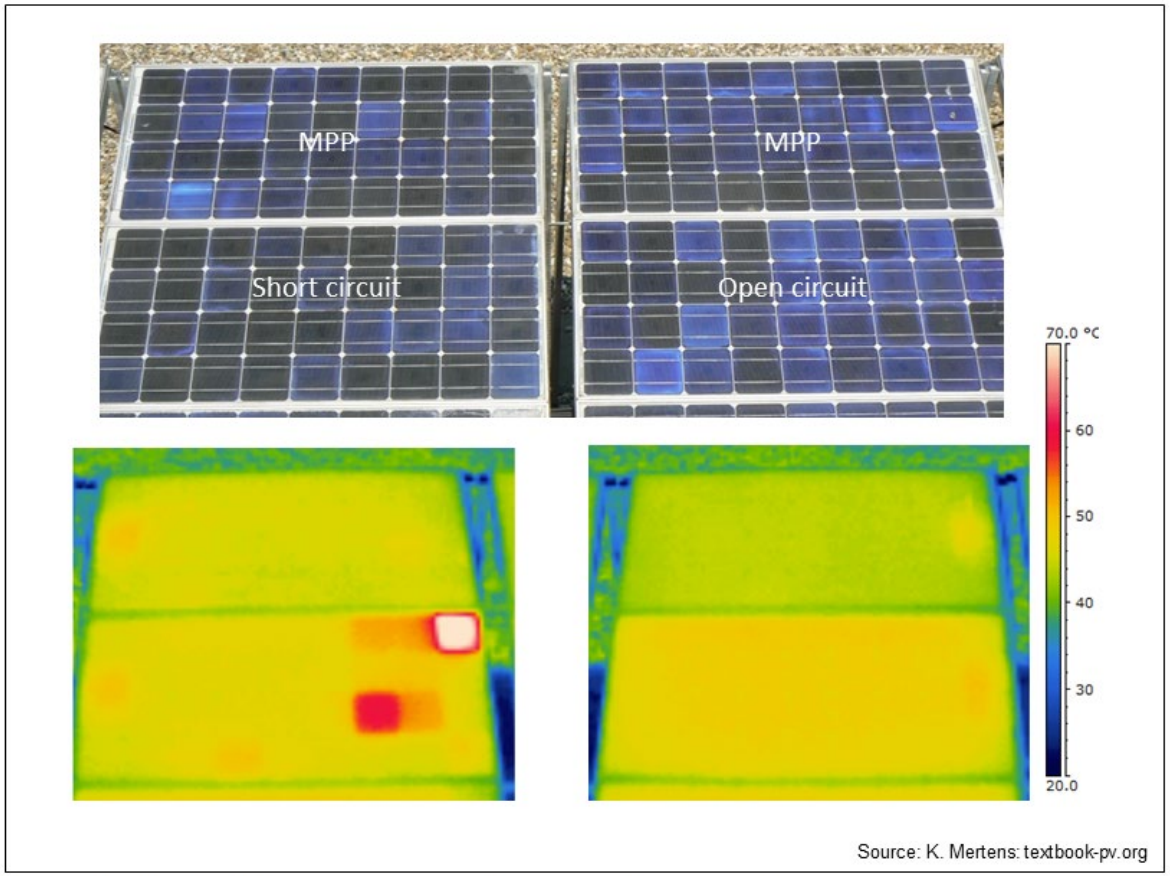
- **Steady state:** Sun illumination or I_{SC}/I_{MPP} in lab conditions.
- **Camera Position:** 90 to 60 degrees from the panel (glass)
- **Sun Irradiance:** 700-600 W/m^2 minimum
- **Emissivity:** 0.85 (glass)

Camera – FLIR Duo Pro R

Specifications

Overview	Duo Pro R 640	Duo Pro R 336
Thermal Imager	Uncooled VOx Microbolometer	
Spectral Band	7.5 – 13.5 µm	
Thermal Sensitivity	< 50 mK	
Thermal Sensor Resolution Options	640 x 512	336 x 256
Thermal Lens Options	13 mm: 45° x 37°	9 mm: 35° x 27°
	19 mm: 32° x 26°	13 mm: 25° x 19°
	25 mm: 25° x 20°	19 mm: 17° x 13°
Thermal Frame Rate	30 Hz	
Visible Sensor Resolution	4000 x 3000	
Visible Camera FOV's	56° x 45°	56° x 45°
Radiometry		
Measurement Accuracy	+/- 5 C or 5% of readings in the -25°C to +135°C range +/- 20 C or 20% of readings in the -40°C to +550°C range	
Physical Attributes		
Size	85 × 81.3 × 68.5 mm 85 × 86.5 × 68.5 mm (640/25 mm lens only)	
Weight	325 g 375 g (640-25 mm only)	325 g
Image Processing & Display Controls		
Imaging Modes	IR-only, Vis-only, Picture-in-Picture (IR in Vis)	
MSX Image Enhancement?	Yes	
Multiple Color Palettes?	Yes – Adjustable in App and via PWM	
IMU Sensor		
GPS?	Yes (GPS, GLONASS)	
Other Sensors	Accelerometer, Gyroscope, Magnetometer, Barometer	
Interfaces		
USB 3.0	Power in, USB Mass Storage	
10-Pin Accessory Port	Power in, Analog Video Out, PWM, MAVLink	
Micro-HDMI	Digital Video Out	
Input Voltage	5.5 - 26.0 VDC (10-pin JST Port)	
	5.0 VDC (USB-C Port)	
Power Dissipation (avg)	10 W	10 W
Remote Control?	Yes - PWM (3 channels), MAVLink	
MAVLink interface?	Yes	
Digital Video Output	1080p60, 1080p30, 720p60	
Mounting Features	1/4"-20 TPI Tripod Mounts (qty 2, bottom surface)	
Environmental		
Operating Temperature Range	-20°C to +50°C	
Storage Temperature Range	-20°C to +60°C	
Operational Altitude	+38,000 feet	

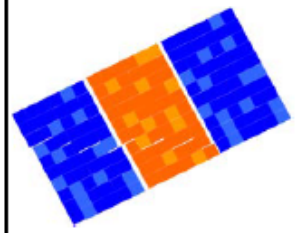
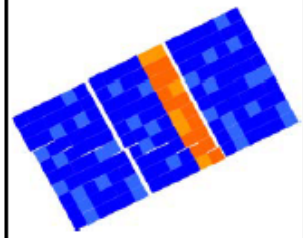
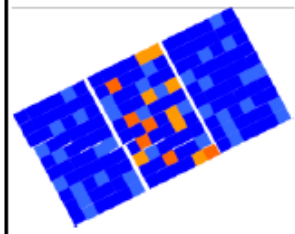
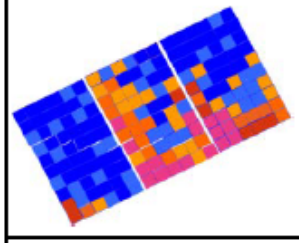
Different states



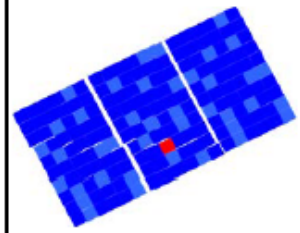
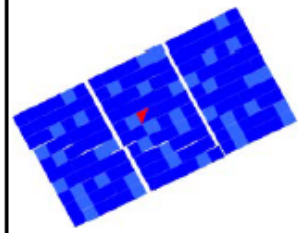
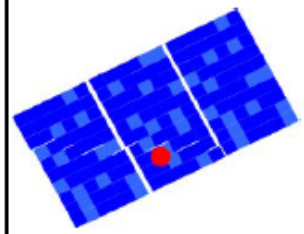
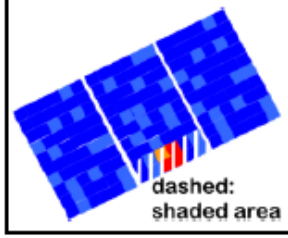
Thermography picture of modules in various operating conditions: The module in open circuit shows a homogenous heating, whereas the short circuit operation leads to different heating of the cells (photo: Münster UAS)

A fault can be established if the hotspot is **>10 °C** than the coolest cell in the module.

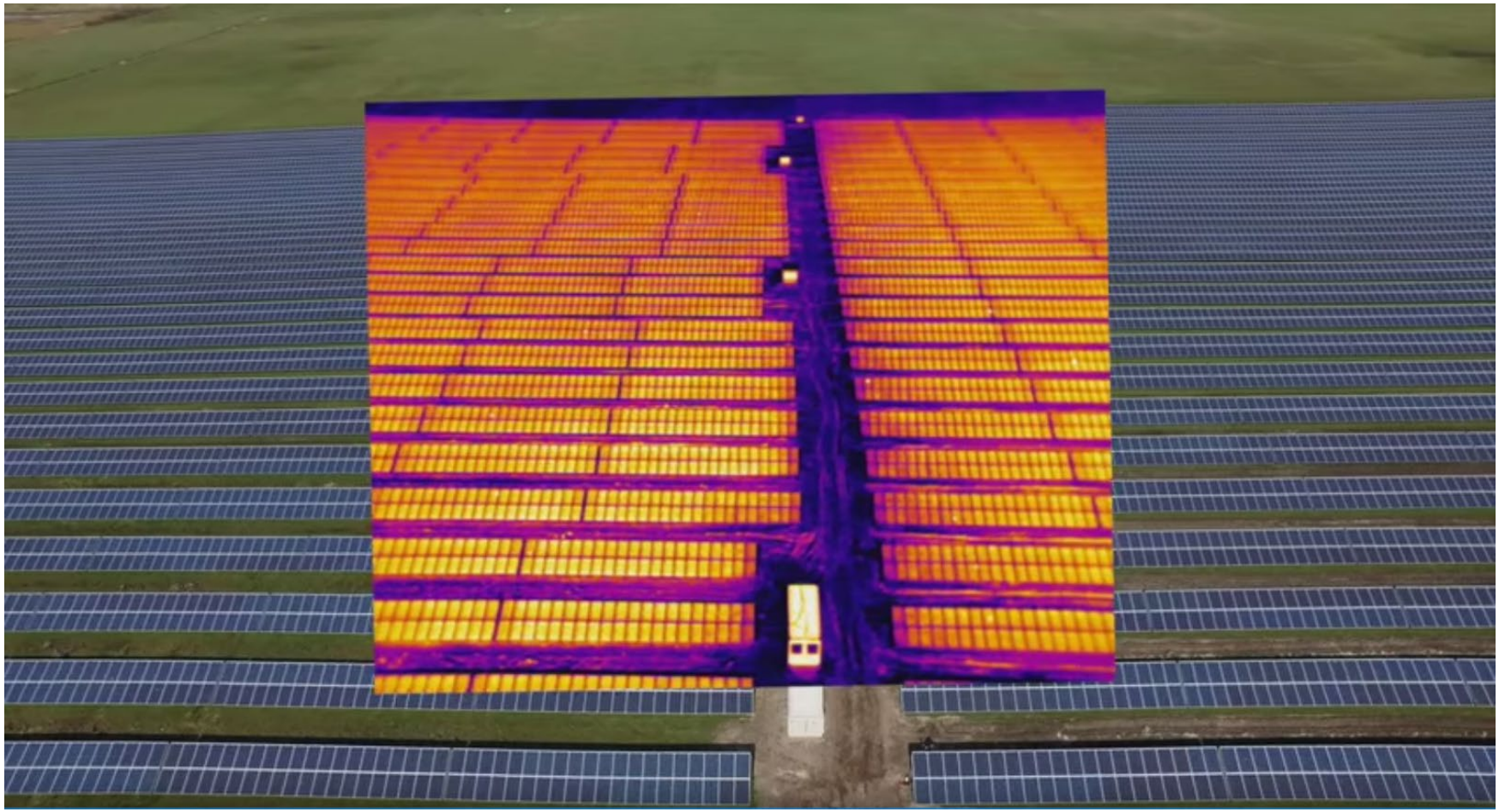
Diagnosis

Pattern	Description	Possible failure reason	Electrical measurements	Remarks, Chapter	Safety	Power
	One module warmer than others	Module is open circuited - not connected to the system	Module normally fully functional	Check wiring	A	System failure
	One row (sub-string) is warmer than other rows in the module	Short circuited (SC) or open sub-string - Bypass diode SC, or - Internal SC	Sub-strings power lost, reduction of V_{oc}	May have burned spot at the module 6.2.7 One diode shunted	B(f)	const. or E
	Single cells are warmer, not any pattern (patchwork pattern) is recognized	Whole module is short circuited - All bypass diodes SC or - Wrong connection	Module power drastically reduced, (almost zero) strong reduction of V_{oc}	Check wiring 6.2.7 all diodes shunted	A *when ext. SC,* B(f) *when Diodes SC*	const. or E
	Single cells are warmer, lower parts and close to frame hotter than upper and middle parts.	Massive shunts caused by potential induced degradation (PID) and/or polarization	Module power and *FF* reduced. Low light performance more affected than at STC	- Change array grounding conditions - recovery by reverse voltage 6.2.5 (PID)	A	C (v,h,t)

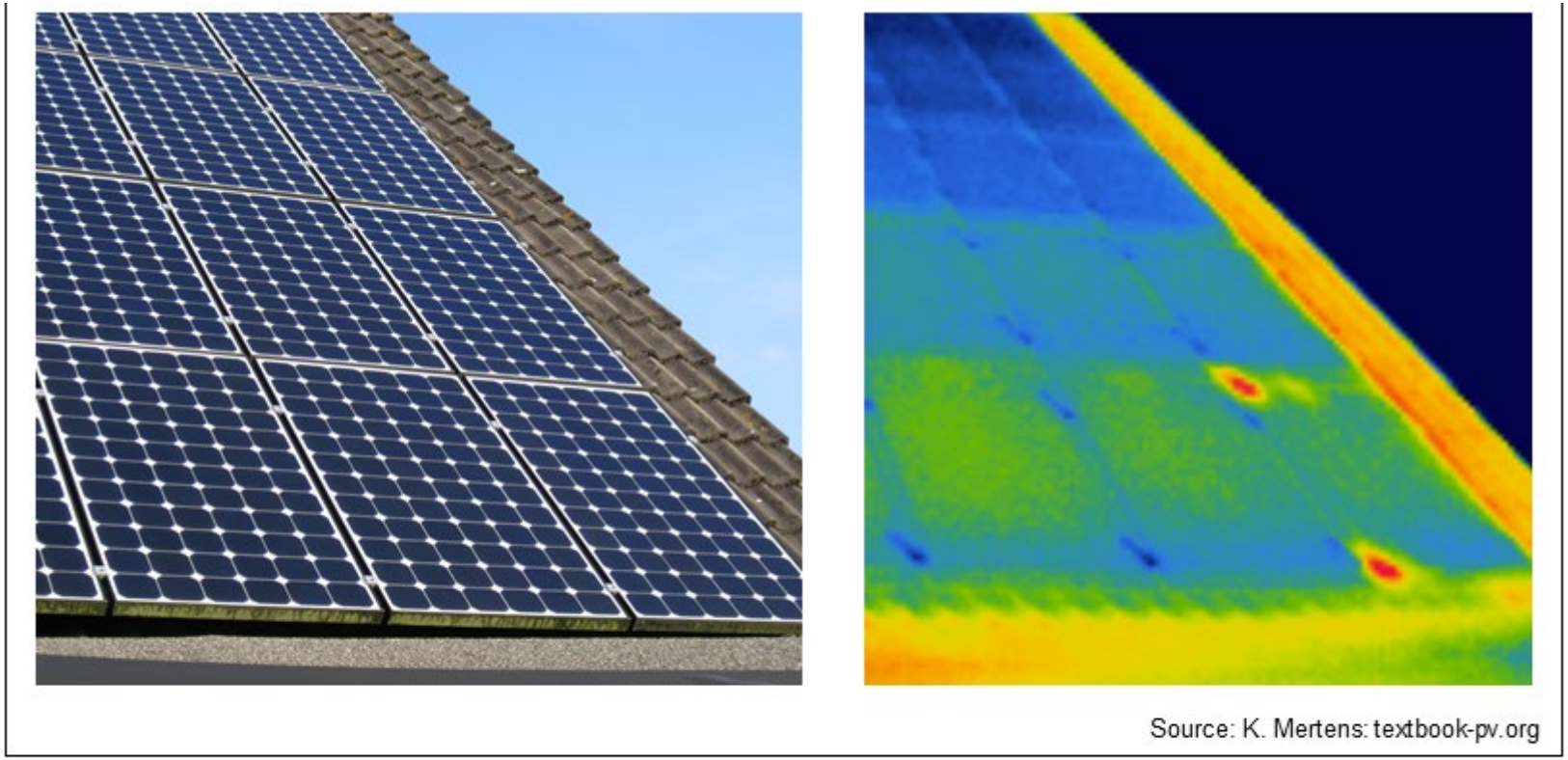
Diagnosis

Pattern	Description	Possible failure reason	Electrical measurements	Remarks, Chapter	Safety	Power
	One cell clearly warmer than the others	- Shadowing effects - Defect cell - Delaminated cell	Power decrease not necessarily permanent, e.g. shadowing leaf or lichen	Visual inspection needed, cleaning (cell mismatch) or shunted cell 6.1.1 (delam.)	A B(f)	A, B, or C(m, tc, h)
	Part of a cell is warmer	- Broken cell - Disconnected string interconnect	Drastic power reduction, *FF* reduction	6.2.2 (cell cracks) 6.2.4 (burn marks) 6.2.6 (interconnects)	B(f)	C(m, tc)
	Pointed heating	- Artifact - Partly shadowed, e.g. bird dropping, lightning protection rod	Power reduction, dependent on form and size of the cracked part	Crack detection after detailed visual inspection of the cell possible 6.2.2 (cell cracks)	B(f)	C(m, tc)
	Sub-string part remarkably hotter than others when equally shaded	Sub-string with missing or open-circuit bypass diode	Massive *Isc* and power reduction when part of this sub-string is shaded	May cause severe fire hazard when hot spot is in this sub-string	A, B(f)	A, C

Examples

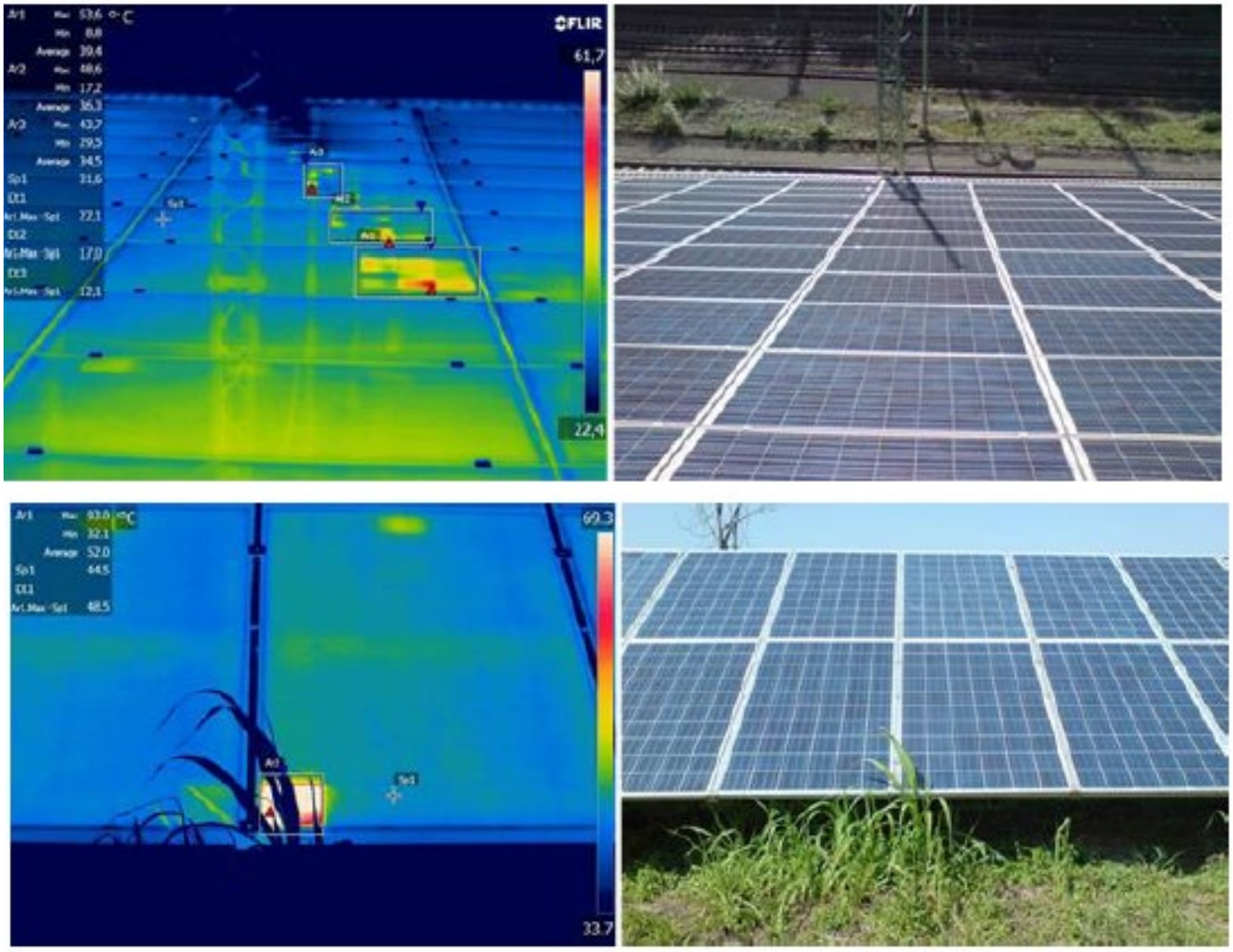


Hot spots



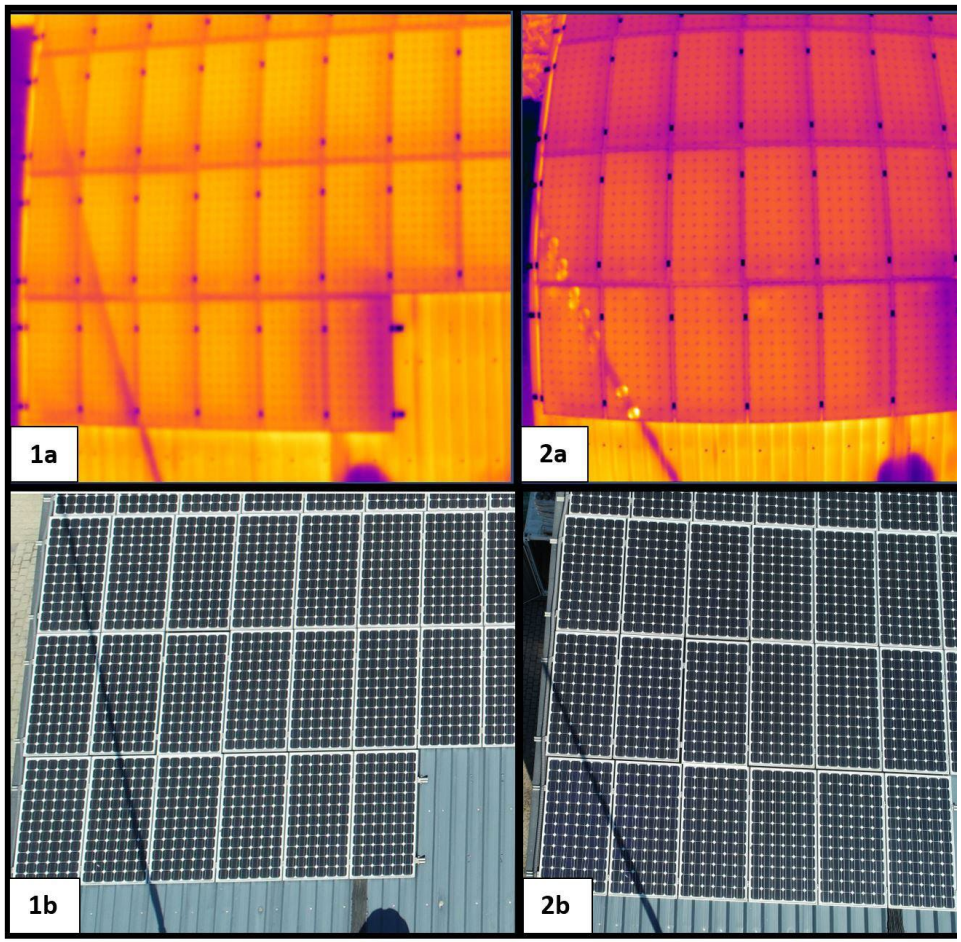
Example of thermographic measurement of an on-roof installation: Two cells of the module at the bottom right clearly show noticeable spots
Image 8 of 25

Shading

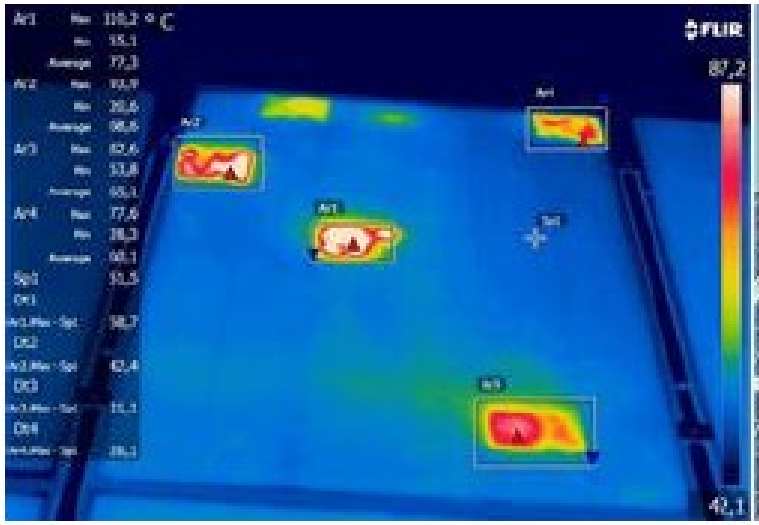


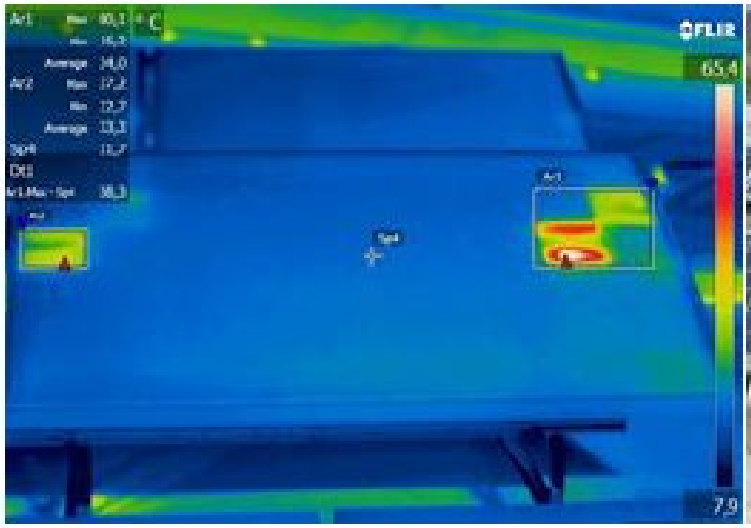
Shading

Voc MPP



Glass breakage





Other Examples

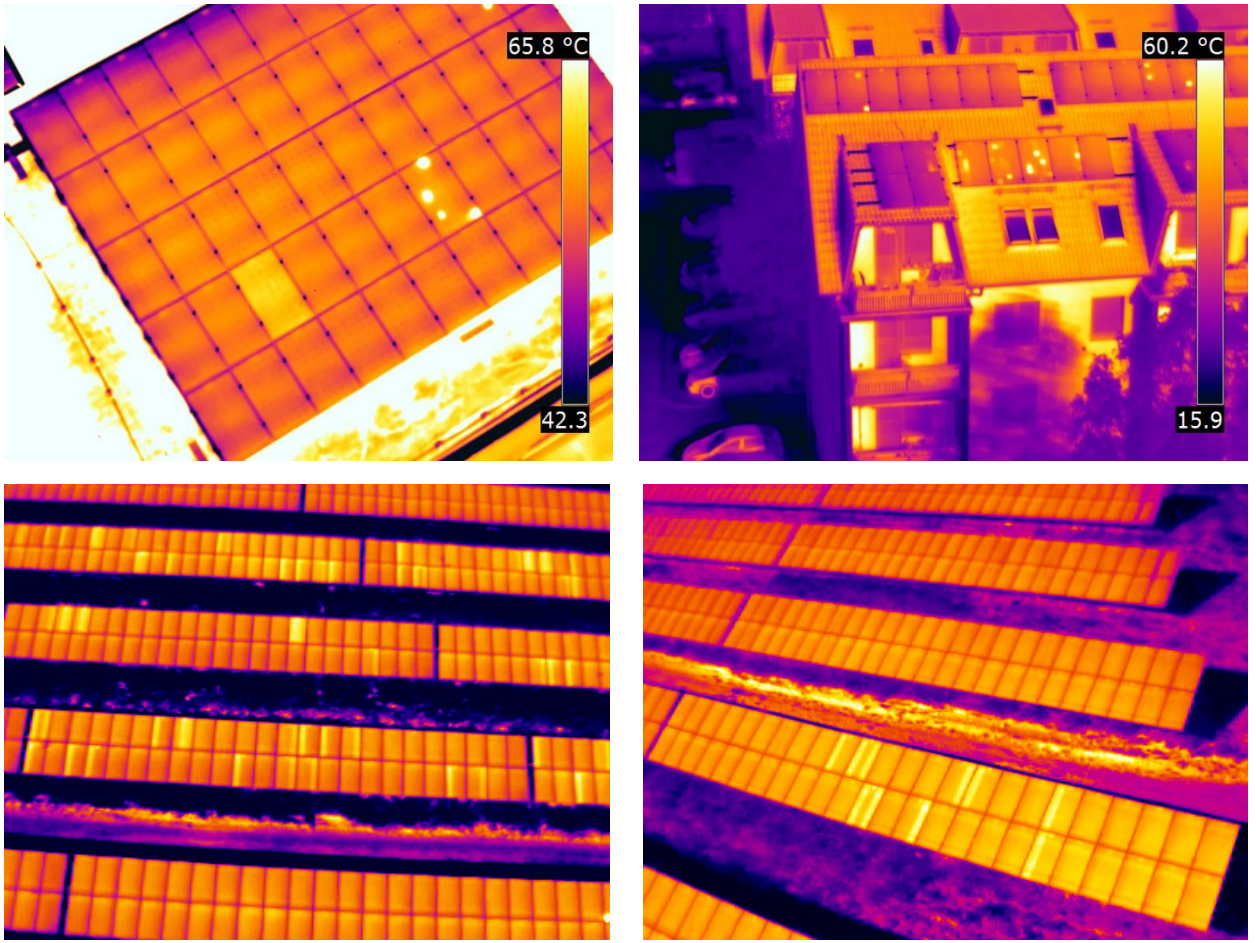


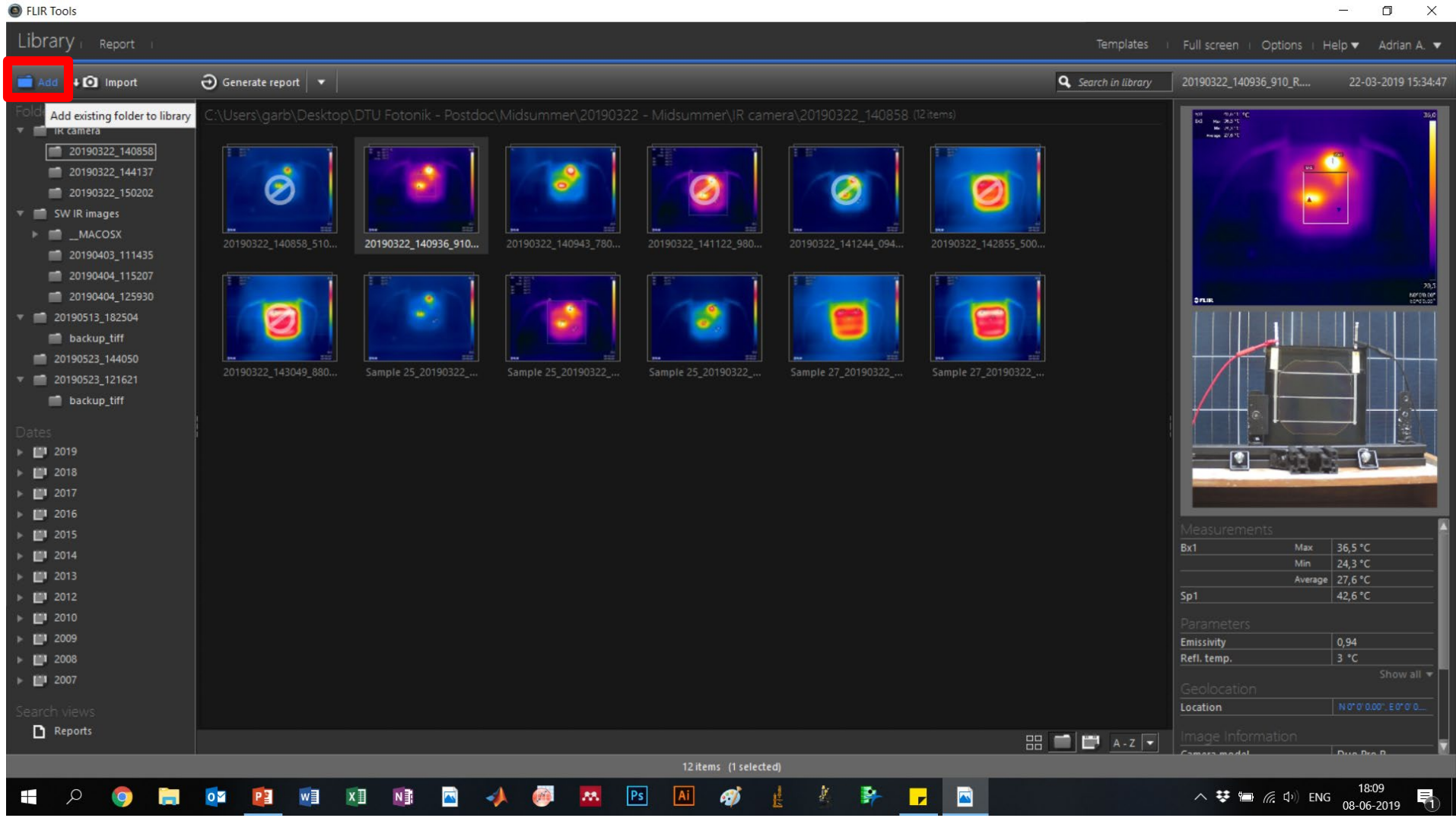
Image processing – FLIR Tools

- Install the software.
  - You need internet connection during installation

User: garb@fotonik.dtu.dk
Password: Apv34553

- Learn how:
  - Read the IRT and Visual images
  - Add palette for better temperature visualization
  - Identify the temperature in specific points
  - Save and store the image to use them in your presentation.

Add Folder


FLIR Tools
Library
Report
Templates
Full screen
Options
Help
Adrian A.
Add
Import
Generate report
Search in library
20190322_140936_910_R....
22-03-2019 15:34:47
Add existing folder to library
C:\Users\garb\Desktop\DTU Fotonik - Postdoc\Midsummer\20190322 - Midsummer\IR camera\20190322_140858 (12 items)
IR camera
20190322_140858
20190322_144137
20190322_150202
SW IR images
__MACOSX
20190403_111435
20190404_115207
20190404_125930
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backup_tiff
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Search views
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Sample 25_20190322_...
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Measurements
Bx1
Max
36,5 °C
Min
24,3 °C
Average
27,6 °C
Sp1
42,6 °C
Parameters
Emissivity
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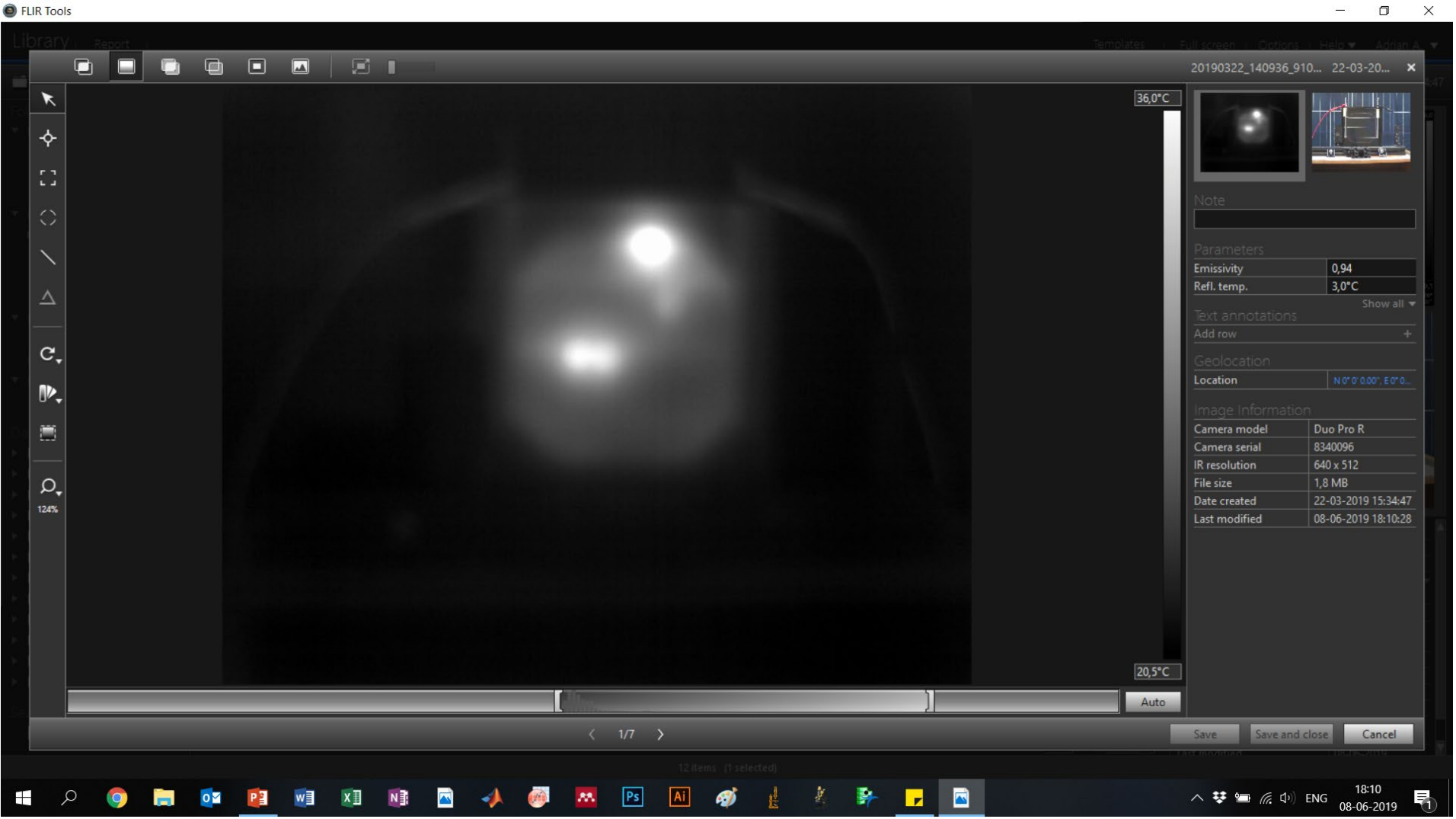
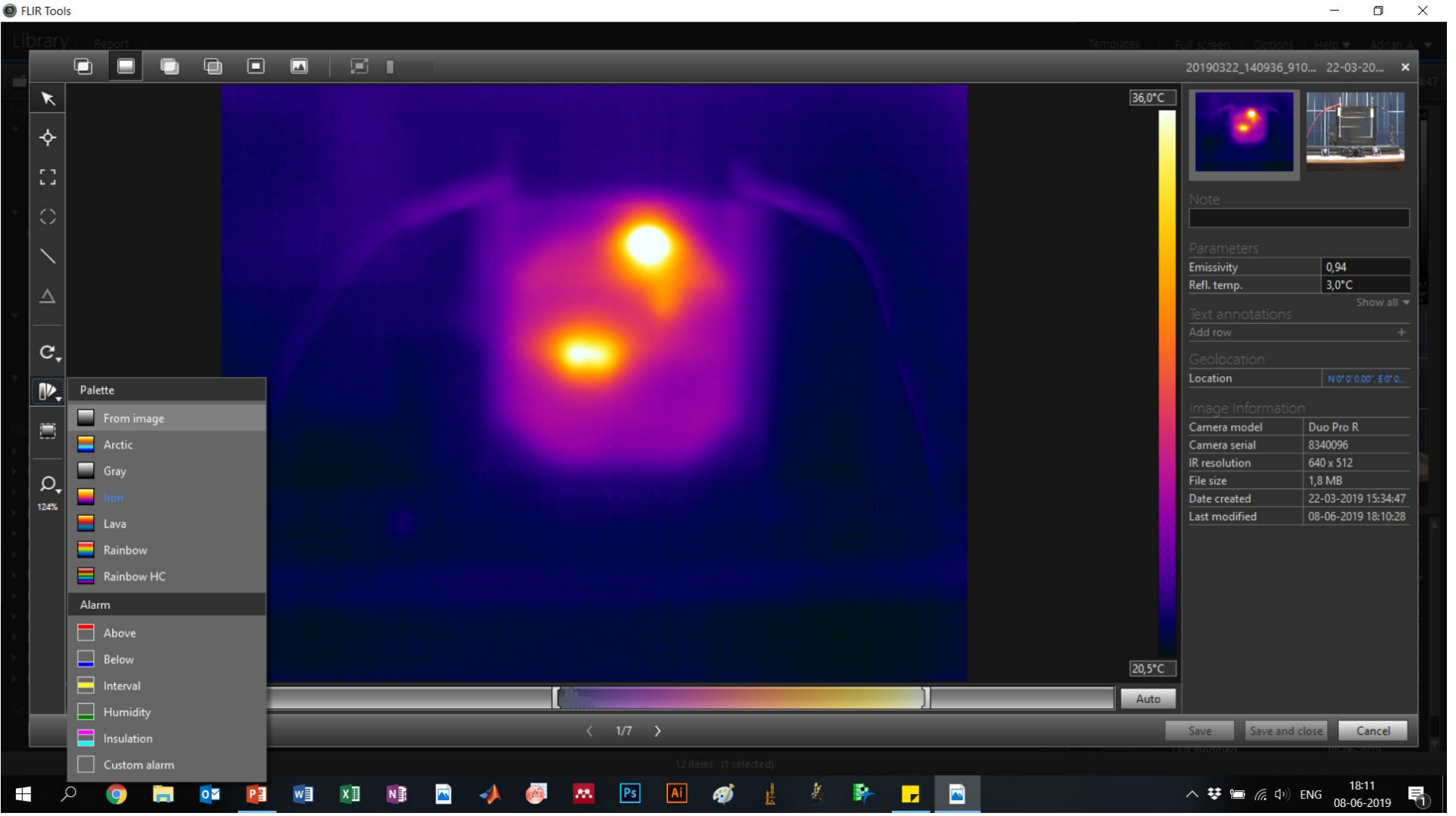
Refl. temp.
3 °C
Show all
Geolocation
Location
Image Information
A - Z
12 items (1 selected)
ENG
18:09
08-06-2019

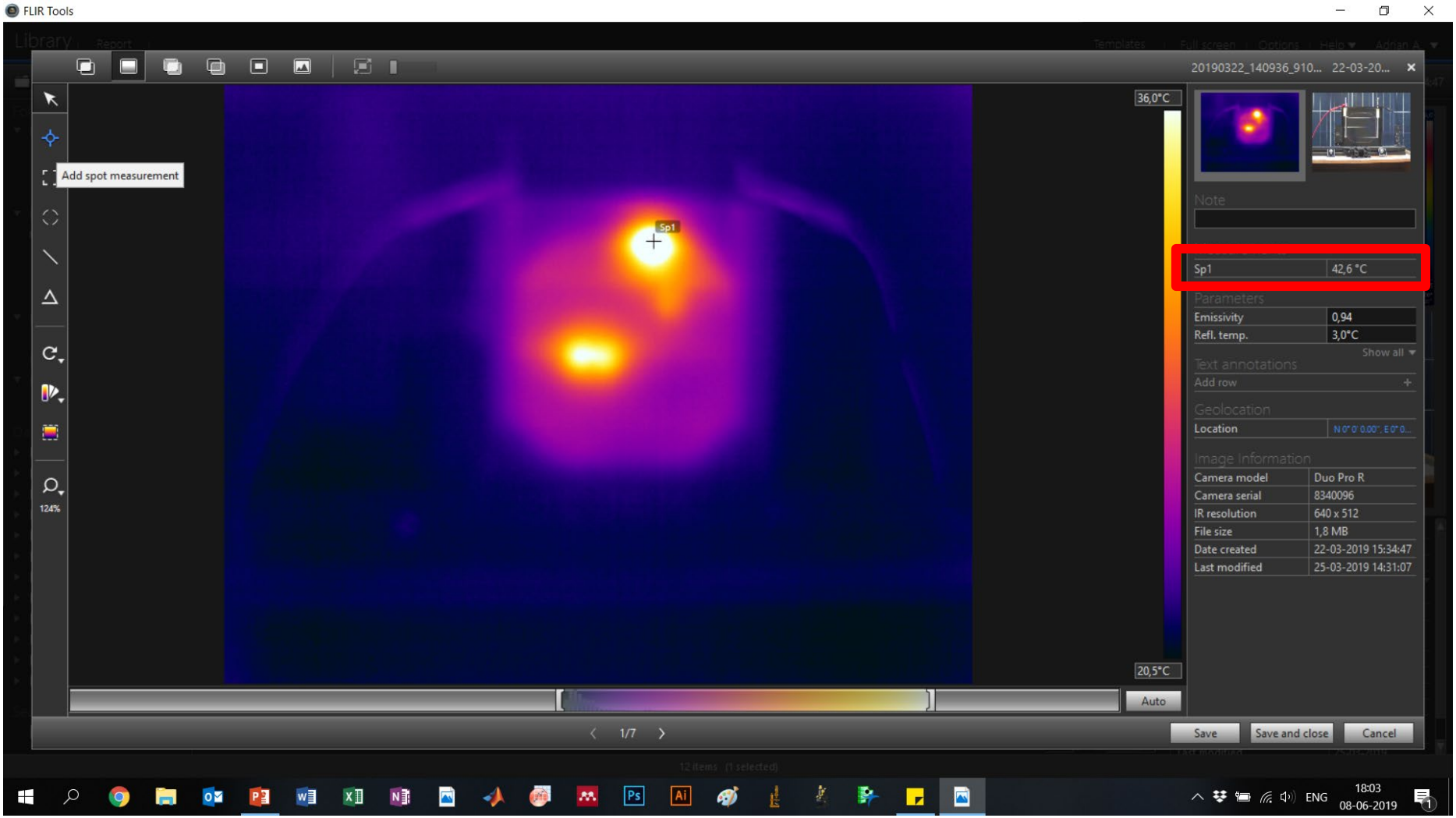
Double click to edit image



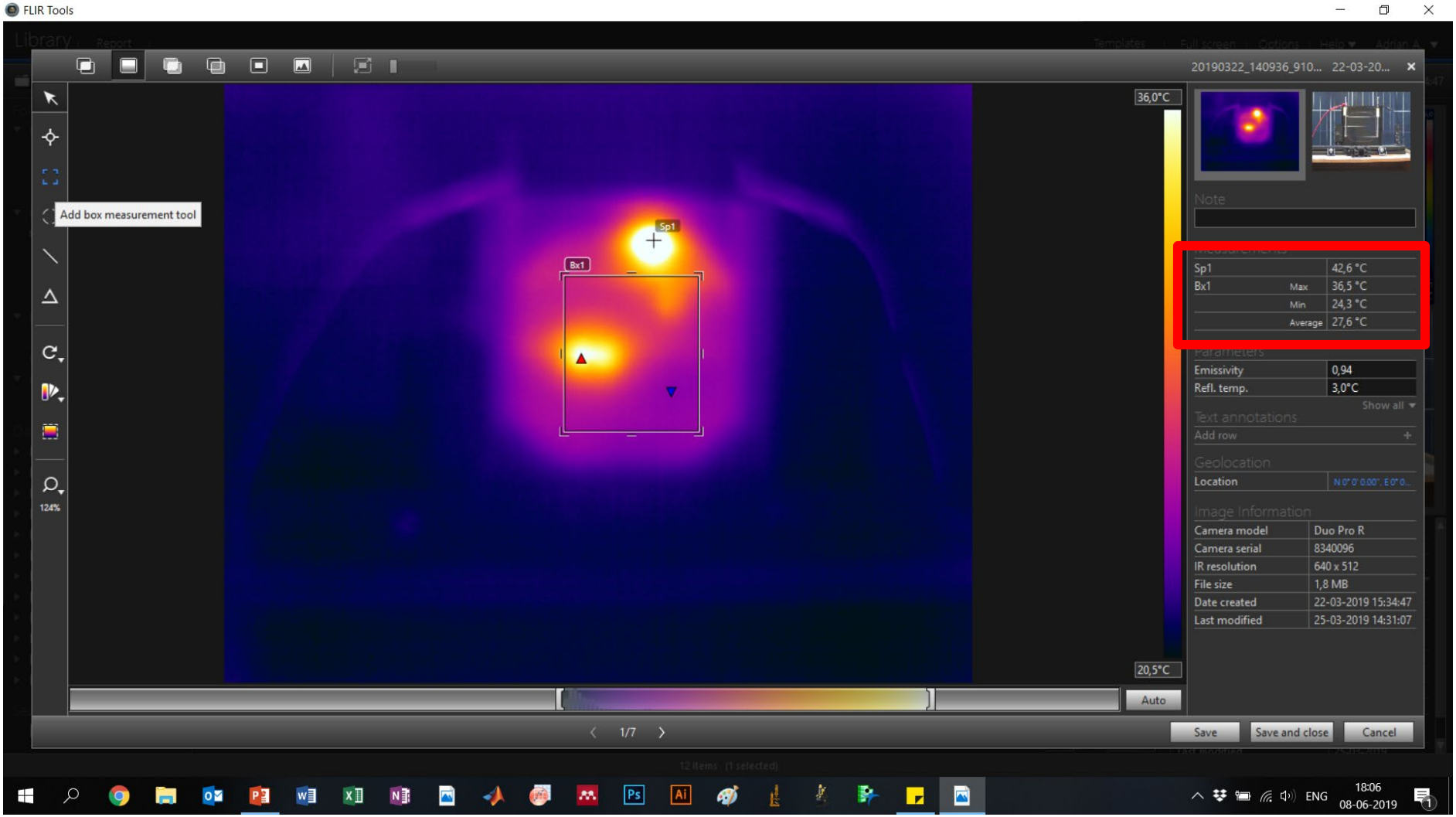
Choose Palette



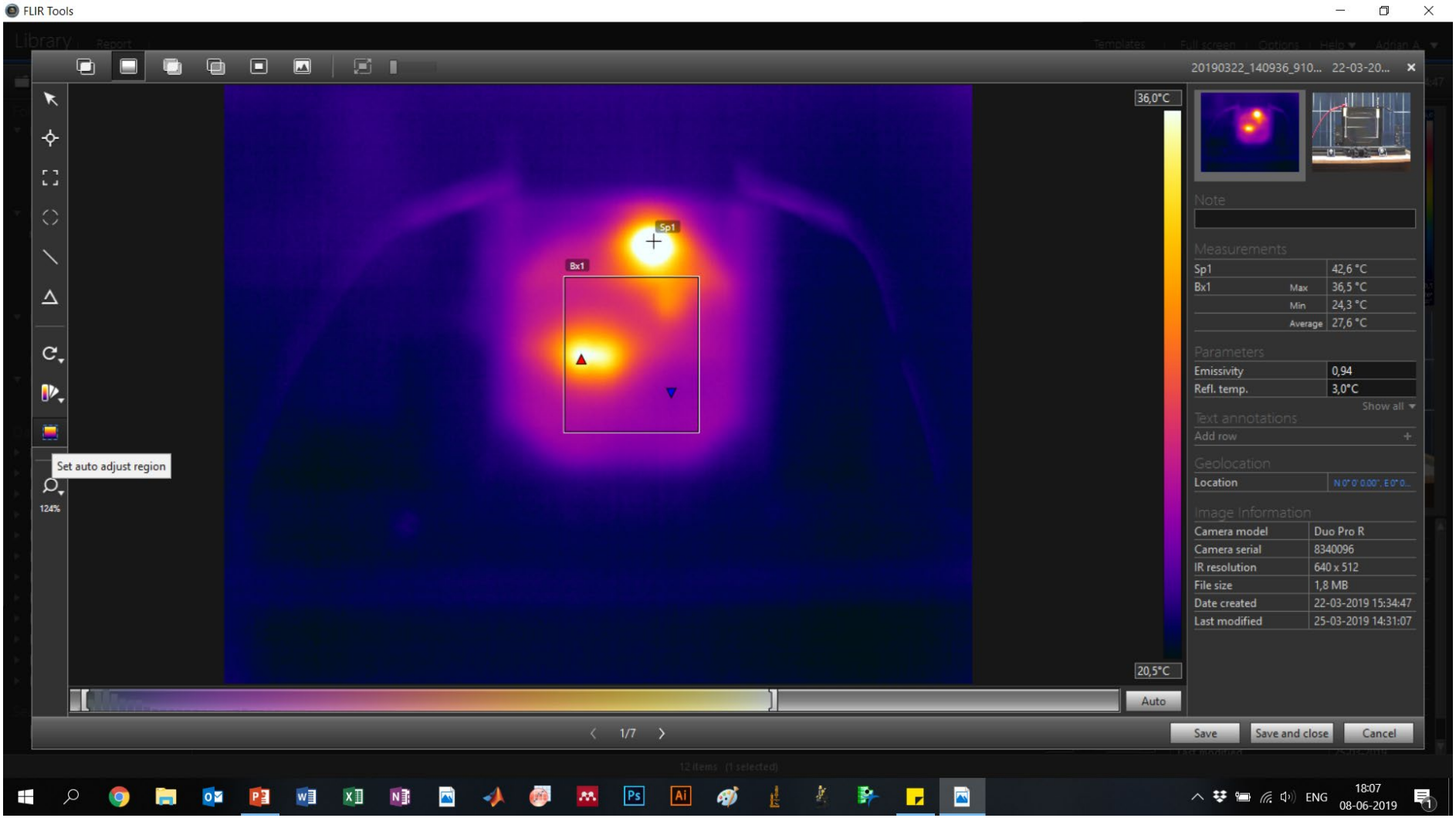
Add a Spot Measurement



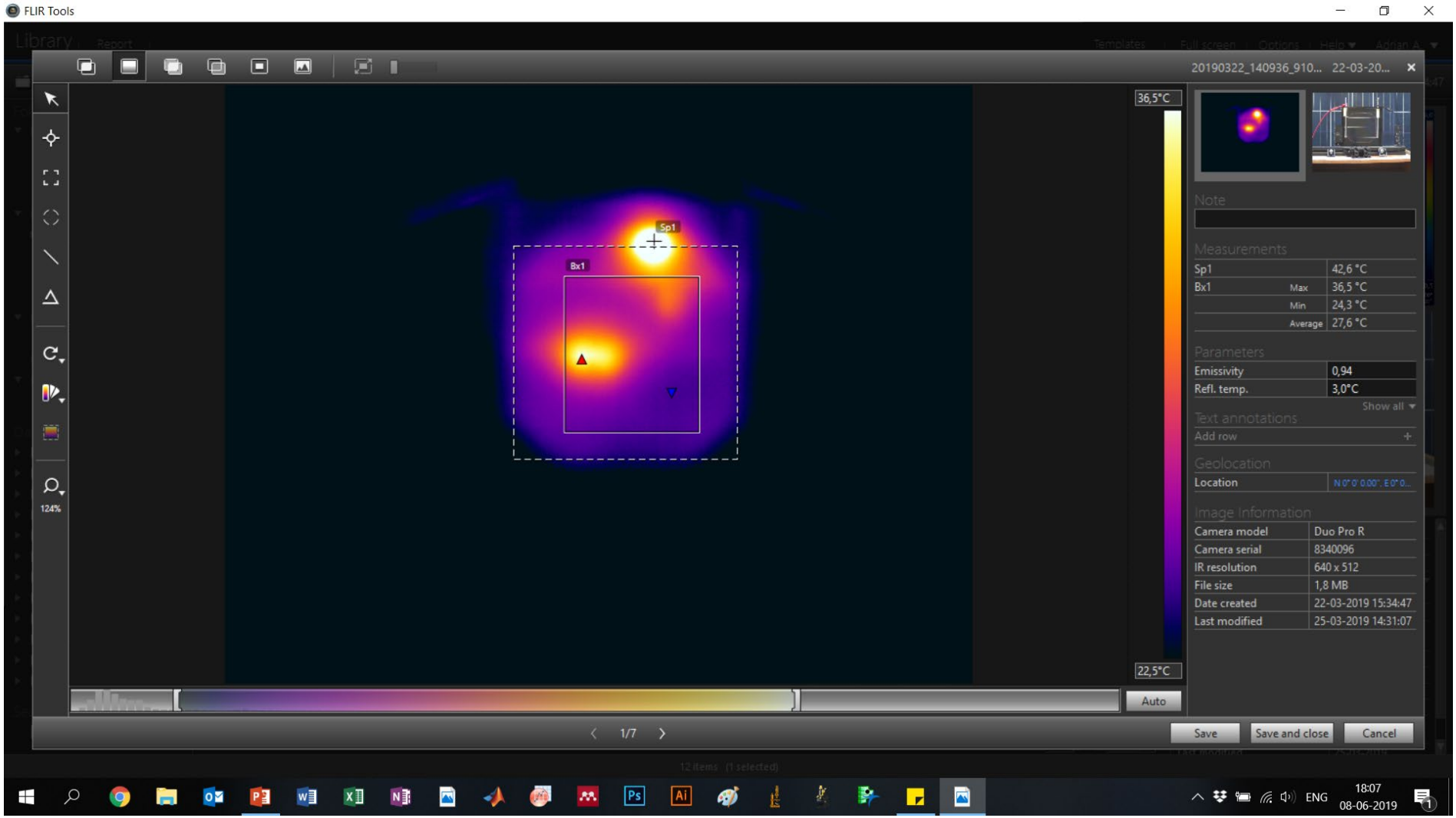
Add Temperature Box



Set Adjust Region



Set Adjust Region



Save and use the images in your report

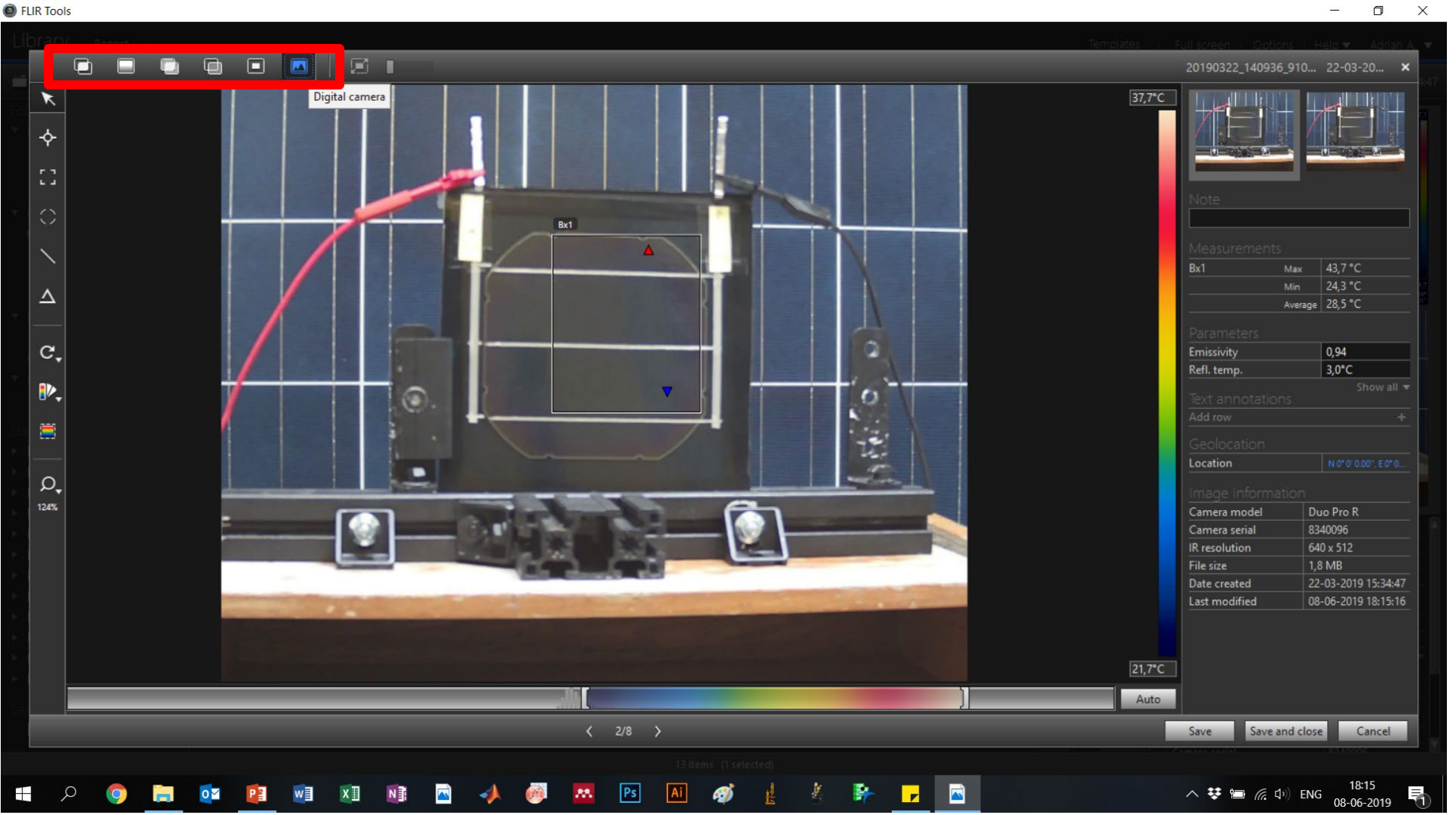


Image processing – FLIR Tools

- Note:
  - Note that the IRT and Visual image are embedded in the same file (it can be changed in FLIR UAS).
  - Check how FLIR Tools save the images in the source folder
  - You might need to duplicate the image to save both IRT and Visual image.