

IR thermography applies to the detection of solar panel

Termografía de infrarrojos aplicada al seguimiento y detección de anomalías en paneles fotovoltaicos

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Abstract

Solar panels with photovoltaic cells that generate solar power for inclusion in the electricity grid have been installed in the south-facing wall of the Science and Technology Building in the University of Oviedo (Spain) in order to generate clean energy. We describe the application of infrared thermography to the monitoring and detection of defects in the solar panels, based on measurements made in situ between January and May 2011. The results show temperature differences in the panels attributable to panel defects, poor panel functioning or defects in panel assembly and arrangement.

Keywords: infrared thermography; photovoltaic panels; defects detection; defects monitoring; preventive maintenance

Resumen

En aplicación del empleo de energías limpias se ha dispuesto en la fachada sur del Edificio Científico Tecnológico de la Universidad de Oviedo (España) una instalación de paneles fotovoltaicos, para la obtención de energía eléctrica y su posterior entrega a la red. El presente artículo muestra la aplicación de la termografía infrarroja en el seguimiento y detección de anomalías o defectos en dichos paneles fotovoltaicos, a partir de mediciones in situ, realizadas entre los meses de enero y mayo de 2011. Los resultados obtenidos muestran diferencias de temperatura en los paneles, que pueden ser atribuidas a defectos en las placas, mal funcionamiento de las mismas o defectos en el montaje y disposición de los mismos.

Palabras Claves: termografía de infrarrojos; paneles fotovoltaicos; detección de anomalías; seguimiento de anomalías; mantenimiento preventivo.

Introduction

The estimation of the service life of the elements of a building, and the detection of possible anomalies on them are essential parts of drawing up a realistic and economically viable maintenance program (Ortega et al., 2015), (Arco et al., 2013).

In this work, we describe the use of infrared thermography (IRT) to detect anomalies in photovoltaic cell panels (ENERGY 10, 2000) used to generate electrical energy. The solar panel installation is located on the south-facing wall of the Science and Technology Building in the University of Oviedo (Spain).

IRT is an instrumental technique that converts a given spatial distribution of thermal radiation (an infrared band signal from the electromagnetic spectrum invisible to humans) into an image. This image, which represents the surface distribution of temperatures in the observed object, can then be measured and thermally analyzed.

IRT has the following advantages (Krapez & Cielo, 1991):

- It is a non-destructive technique that measures surface temperature and emissivity with no direct contact with the installation.
- As a diagnostic or preventive maintenance technique, it permits in situ analysis and control of processes and materials.
- The fact that it provides real-time information that can be stored digitally implies great flexibility in the study and temporal monitoring of data.

Physical Basis Of Thermography

All materials have the ability to absorb infrared radiation increasing their temperature. Furthermore, any material with a temperature above absolute zero emits infrared energy (Maldague, 2001). This radiant energy is directly proportional to the fourth power of the object surface temperature. Stefan-Boltzmann Law (Eq. 1).

Where R_t is the radiant energy of a body, ϵ is the emissivity ($0 \leq \epsilon \leq 1$), σ is the Stefan-Boltzmann constant ($5,67 \cdot 10^{-8} \text{ Wm}^{-2} \text{ K}^{-4}$) and T is the absolute temperature of the body. Emissivity is defined as the quotient between the radiation emitted by a body and the radiation emitted by a black body (a body that absorbs all the incident radiation) to the same temperature. This coefficient allows to classify the bodies like black ones ($\epsilon = 1$) and grey ones ($\epsilon < 1$).

Although emissivity is considered a characteristic constant of each material, in fact it is function of wavelength, temperature and emission angle. In the same way, the emitted radiation is not constant for all the wavelengths. Its spectral distribution fulfils the law of Plank (Eq. 2).

$$R_t = \epsilon \cdot \sigma \cdot T^4 \quad (\text{Wm}^{-2}) \quad (1)$$

$$dR(\lambda, T) / d\lambda = 2\pi c \epsilon(\lambda, T) / (e^{hc/\lambda kT} - 1) \quad (2)$$

From Eq. 2 it is possible to say that with a temperature around 297 °K, the maximum emitted radiation takes place at wavelengths located in the infrared spectrum band. In particular, it takes place in wavebands between 700 nm and 20000 nm.

However, the radiation that reaches the receiver is not only the emitted one but also the parasitic radiation composed of the radiation emitted by other bodies and by the light sources close to the receiver. This parasitic radiation can produce an increase of the temperatures.

Measurement also depends on the angle of incidence of the observation although its influence is null with low angles. The atmosphere in which thermal radiation is transmitted also plays an important role by absorbing or scattering some of the radiation. However, there are wavelength intervals where the atmosphere is almost transparent. These ones are called transmission windows, and are located between 8 and 13 μm at room temperature.

Description of the experiment

Location and characteristics of the installation

The studied photovoltaic panels were installed in one of the outer glass south-facing walls of the Science and Technology Building in the University of Oviedo (Spain) in September 2008 (Fig. 1). Its purpose is generating electrical energy for its delivery to the network.

Fig. 1. Location of the solar panel installation. Source: Self-Elaboration.

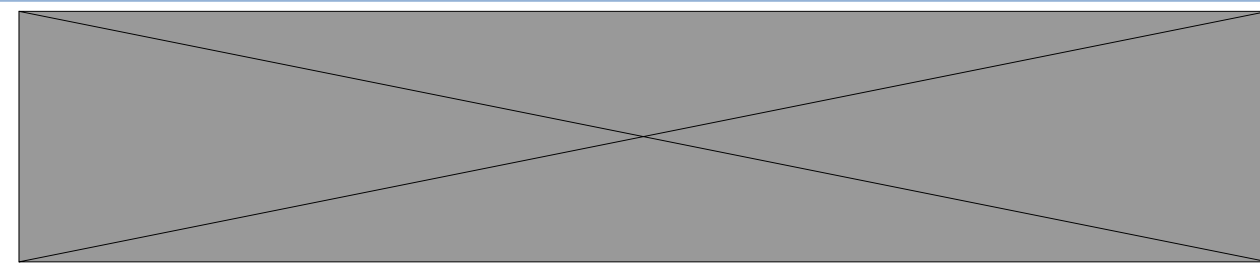


Table 1. Installation losses due to orientation and shadow. Source: Self-Elaboration from public information of SILIKEN

	Orientation and tilt	Shadow	Total
General	10%	10%	15%
Superimposition	20%	15%	30%
Architectural integration	40%	20%	50%

The photovoltaic system consists of a Photovoltaic Solar

Fig. 2. One-line wiring diagram. Source: Self-Elaboration.



Generator formed by 44 polycrystalline photovoltaic modules of two different types: 22 modules are GG25M5 of 61 Wp, and 22 ones are GG36M5 of 92 Wp. All of them are SILIKEN modules. The modules are distributed in series forming a unique group. This group is coupled to an inverter who operates in parallel with the mains. The maximum losses due to orientation and tilt, by shadow and the total losses do not exceeded the values reflected in Table 1.

The SILIKEN modules, with 13,9% conversion efficiency, provide variations in nominal characteristics for the following temperature coefficients: 127,2 mV/ $^{\circ}\text{C}$ for open-circuit voltage, 2,2 mA/ $^{\circ}\text{C}$ for short-circuit current, 0,4%/ $^{\circ}\text{C}$ for power. Real maximum power and short-circuit current fall in the range of $\pm 5\%$ of the nominal values and maximum voltage is 750 V. The two different models used are photovoltaic square polycrystalline silicon cells of high efficiency, with a size of 156 mm x 156 mm $\pm 0,5$ mm.

The cells thickness ranges between 300 μm and 270 μm . The 2 mm thick silver buses have been treated with anti-reflective silicon nitride to produce energy even at very low levels of solar radiation. This fact ensures continuous production from the dawn to the dusk, by mean of the capture of all the useful power supplied by the sun.

In terms of functioning, the energy received from the sun is converted by the photovoltaic modules into electrical energy (King, 1997), (Davis, et al., 2001). This energy is leaded an inverter that transform the direct current into alternating current. This transformation let the direct connection to the mains distribution company because it is perfectly synchronous and fulfils with all standards regarding maximum allowable tolerances and distortion (Fig. 2).

The maximum discharge rate of the photovoltaic system is 4,77 kW. The supplied signal has a frequency of 50 Hz, a voltage of 250 V and a power factor ($\cos\phi$) among 0,8 to 1. These values satisfy the tolerance and quality requirements of applicable legislation. With these conditions and since it is an installation with a nominal power smaller than 20 kW, the feed-in tariff is 0,34 € per kW/h (Spanish Royal Decree 1578/2008).

Data capture

The thermography data (Thomas, 1999) were obtained using a Testo-800-3 thermal camera whose basic technical characteristics are shown in Table 2, and that confirm the data obtained for (Chrzanowski, 2001). The atmospheric conditions prevailing at the time of data acquisition were recorded by a mobile ECRON EH2325 station.

Emissivity was determined by comparison of temperatures. The temperature of the surface to analyze was moderate, first with a thermometer of contact, and later with the thermal camera with the emissivity fit to $\epsilon = 1$. These values are compared and emissivity adjusts gradually until the temperature detected by camera corresponds to that one of the contact (ASTM, 2010). The emissivity value for the panels were set to $\epsilon = 0,8$.

In situ measurements were made at the same time of day between January and May 2013. The meteorological and environmental conditions: temperature, humidity and wind, are collected in Table 3.

Table 2. Technical characteristics of the Testo 800-3 camera. Source: Self-Elaboration from public information of TESTO

INFRARED IMAGES	
Characteristic	Values
Visual field/min. focus distance	Standard objective lens: 32°x24°/0,1 m (0,33 ft) Telephoto lens: 12°x9°/0,6 m (1,97 ft)
Thermal sensitivity (NETD)	<0,1 k to 30°C (<0,18°F to 86°F)
MEASUREMENT	
Characteristic	Values
Temperature range (commutable)	-20° to 100°C/0° to 350°C (-4° to 212°F/32° to 662°F)
Accuracy	±2°C (±3°F) or ±2°C of the greatest value
Emissivity adjustment	8 materials + 1 personalized (freely defined between 0,01 and 1,00)
ENVIRONMENT CONDITIONS	
Characteristic	Values
Operational temperature	-15° to 40°C (5° to 113°F)
Environment humidity	20% to 80% relative humidity with no condensation

Table 3. Atmospheric conditions. Source: Self-Elaboration.

Date	Time	Temperature °C	Humidity %	Wind
11-01-2013	12:00	6,5	75	Null
09-02-2013	12:00	11,0	70	Null
09-03-2013	12:00	15,0	75	Null
06-04-2013	12:00	16,0	80	Null
06-05-2013	12:00	17,0	88	Null

Data management and processing

Once the data were collected they were computerized and processed (Krapez & Cielo, 1991) using the Testo IRSoft® software. This tool allows to plot, from the thermal image, different graphs of profiles and histograms of temperatures (International Organization for Standardization, 1983), (Kaplan, 2001) as much of the complete installation as of zones that show stranger values. These zones will be named critic zones.

The processed thermography data were analyzed and evaluated in terms of three aspects: general installation, groups of panels, localized areas or critic zones. In all the cases, examples of the results are given below and in them are included the thermal and real image and the temperature profile.

General installation

The thermography image (Fig. 3a) shows a very uniform temperature distribution with a 95% of the surface with temperatures between 18,5° and 21°C, and some isolated points with temperatures above 22,5°C. The same results are obtained from the vertical temperature profile (Fig. 3c). In addition, in this case the image shows a very light reduction of the temperature from the highest zone of the building to the lowest one. This behavior is caused by the lean of the building.

However, from this previous analysis it is possible to divide the area of study in three anomalous different zones:

- Zones with lower temperatures, between 17° and 18° C. These ones come from the metal supports.
- Zones with higher temperatures. These ones come from the panels near to the metal supports. In this case the metal sections increase the temperature due to the solar radiation reflected (Lyberg, Mattsson, & Sundberg, 1990), (Seeber, 1984).
- Critic zones. These points display very high temperatures (23°C) with respect to the average one. These values can be the result of damages in some cells or damage inside the circuit of transport, and they must be analyzed.

Groups of panels

In the same way that the analysis previous, the study of the different panels shows that a great percentage of the surface has temperatures with values near to the average one. As it was previously mentioned, the lean of the building produce changes in the temperature so the average value of the panel depends on its situation. However, in all the panels it was found that the average value is bigger that the gotten in the general installation. This increase is because of the exclusion from the analysis, of the metal supports and the gaps between panels.

But although the metal supports are outside the analyzed area, they cause that the nearest cells display higher temperatures (Fig. 4a). In the panels there are also areas with lower temperatures than the average one. These areas are the separations between panels (Fig. 4c).

Fig. 3. General installation. Source: Self-Elaboration.

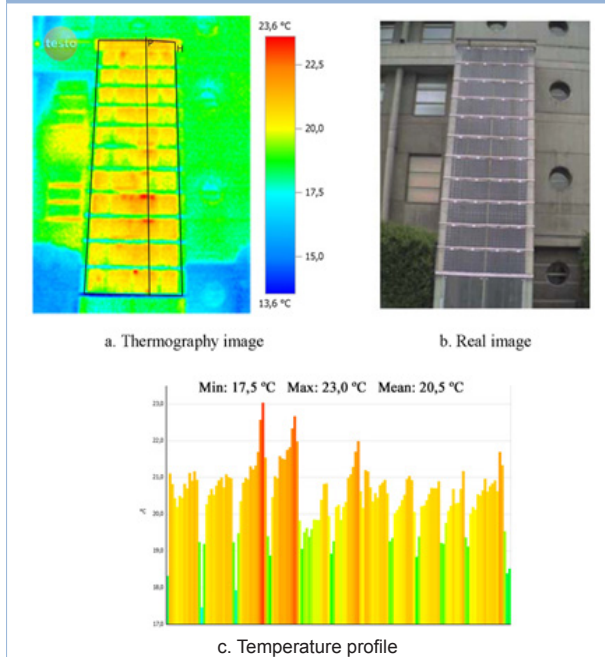


Fig. 4. Groups of panels. Source: Self-Elaboration.

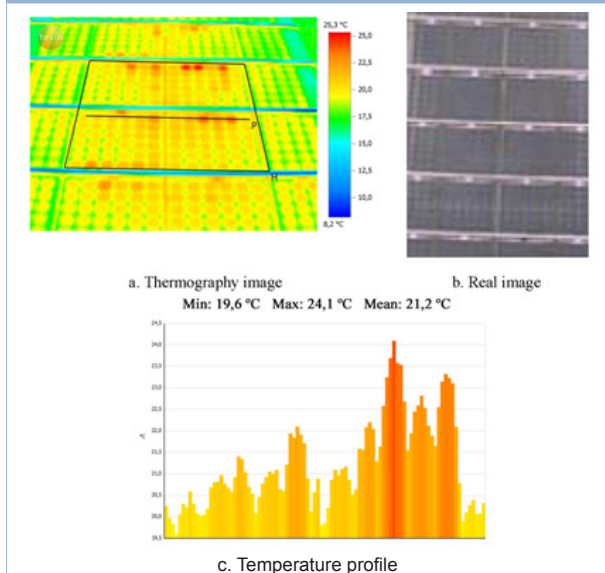
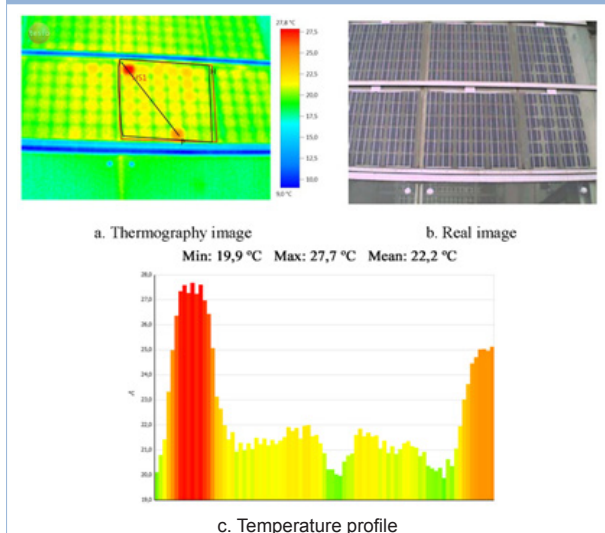


Fig. 5. Critic zones. Source: Self-Elaboration.



Critic zones

The study of the general installation has showed one critic zone in the lower panel of the building (Fig. 3a). The analysis of this zone has displayed two hot spots (Fig. 5a) with temperatures around 26 and 28 °C against an average temperature of 21 °C (Fig. 5c). Their visual inspection (Fig. 6) has revealed that these high temperatures were due to deterioration in the cell-to-junction box transmission circuit that generated a positive temperature gradient.

Fig. 6. Visual inspection. Source: Self-Elaboration



General methodology for the procedure

After the study carried out, it was established the criteria to be followed for a correct implementation of the steps of the procedure. These criteria can be applied in buildings where integrated panels in roofs or facades can be assessed. The objective is to ensure repeatability when it comes to gathering data (obtaining thermograms). These criteria are:

Location and signage. This phase entails the selection and identification of the points for taking the samples, based on criteria such as accessibility, repeatability and the operational requirements of the operation itself. Once they have been selected and identified, the points are marked using markers that can be identified on site, their geodesic coordinates are recorded, and the frequency with which data will be collected is determined. This phase can be summarized as: choosing and identifying the points for taking samples, applying signage to the points for taking samples, preparing the file for location and signage

Data collection. Once the points have been selected and identified, the data are collected on site, or rather the thermograms are taken and the physical and environmental parameters are determined at that point. The majority of the thermographic cameras on the market store the information on digital memory, which facilitates its subsequent processing and management. The steps of this phase are: frequency of data collection, determining the physical and environmental parameters (for example ambient temperature, reflected temperature or relative humidity), taking the thermograms, preparing the file for data collection

Data management and analysis. The information gathered on site is transferred to a database for management and analysis. The existence and maintenance of this database makes it possible to determine not just the actual state of the areas being studied but also their behavior and evolution over time. The protocol for the procedure for managing and handling data essentially consists of: identifying the areas with

possible anomalies, analyzing the current state, comparing the current state with previous states, preparing the analysis and management file

Based on the previous analysis it is possible to identify and evaluate the areas with anomalies. Three levels are established with different protocols for action (Fig. 7).

- No anomalies: continue gathering and monitoring data with the established frequency
- Possible anomalies: increase the frequency for gathering and monitoring data.
- Anomalies: proceeded to carry out the required operations to eliminate the failure

Conclusions

The infrared thermography is a reliable, economic and easily applied technique for the monitoring and preventive maintenance of photovoltaic installations. The profile of temperatures let to recognize hot spots that reflect the damages in some cells or damages inside the circuit of transport without having access to the installation. It is possible to establish a methodology with the end of ensuring the repeatability of the procedure. It can be concluded that the solar panels, after almost three years of operation, are in a satisfactory condition, except for some minor flaws that can easily be corrected.

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Fig. 7. General schema for the procedure. Source: Self-Elaboration

