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Infrared imaging method for flyby assessment of solar thermal panel operation in field settings

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HIGHLIGHTS

- We describe a remote method to find non-operational solar thermal collector panels.
- Long-wave infrared imaging is a robust primary diagnostic.
- The method is suitable for aerial flyby inspection of residential solar systems.
- Identification reliability is tested for several commonly used solar thermal panels.
- Same method might be used to detect non-functional photovoltaic panels.

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ABSTRACT

We describe a remote, non-intrusive method of identifying whether a solar thermal collector panel is operational. This method is tested for several commonly used solar thermal panels. Suitability of the proposed method for aerial flyby inspection of residential solar systems is discussed. It is found that non-operating panels are easily identifiable, as their temperature is appreciably higher than that of panels in operation, and that the expected variability of lighting, weather conditions, and distance between the panel and the imaging device do not significantly impede the diagnostic. Suitability of a similar method for identification of non-working photovoltaic collectors is also discussed.

1. Introduction

In recent years, tax incentives both on the federal [1] and state [2] levels, as well as the utility rebate programs [3,4] have led to significantly increased consumer interest in residential solar power, specifically solar hot water (SHW) and photovoltaic (PV) systems. Thousands of new systems have been installed in some utility districts, with rooftop solar systems responsible for most of the estimated 44% surge in new solar installations between the third quarters of 2011 and 2012 [5]. As the number of installed systems increases, concern is growing about the systems dependability. Planners in both electric and gas utilities are concerned because if SHW systems fail in the field, the responsible utility must supply customer loads. Moreover, installation rebates are frequently based on the assumption that all of the SHW systems will perform robustly for a 20-year period. If a sufficient number of systems fail prematurely, then the utilities will have overpaid for grid-energy reduction performance that is unrealized.

Two studies have been recently conducted to quantify SHW reliability [6,7]. The 2011 investigation by Menicucci [6] found the existing data to be insufficient to properly characterize the reliability of fielded systems and made a number of recommendations for generating reliability data and information, including use of infrared aerial photography to identify solar thermal collectors that are non-operational, thus showing a hotter glazing temperature than ones cooled by liquid flowing through their collector tubes.

Flyby aerial surveys of residential areas with thermal imaging to visualize energy losses and promote energy conservation have a long history. On a large scale, such surveys have been conducted since the 1970s [8]. In these studies, the typical per-building cost of assessment While early surveys relied on human interpretation of analog thermograms, digital imaging and computer analysis have been successfully applied to assess surface temperatures in urban areas since the 1990s [9].

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The concept of using infrared (IR) photos to assess performance of residential solar systems has a threefold appeal. First, it is advantageous for the utility companies. Thousands of installations could be assessed in a single aerial flyover over an area with multiple solar installations, generating much data without intrusive and expensive field surveys. Second, once non-operating systems are identified, they could be traced back to their dates of installation based on a record of rebates. Thus a meaningful reliability database could be developed that could lead to development of statistics that the utilities are seeking. Such statistical measures include the mean time to failure, a key engineering reliability metric. Third, this database could be useful to the SHW industry to improve their products.

A recent collaborative effort between Sandia National Laboratories and the University of New Mexico [7] gave promising results regarding the feasibility of the idea to use IR photography to check the operation of residential-scale solar panel installations. Here we describe an experiment that was designed and conducted to test whether differences in SHW collector glazing temperatures can be discerned by infrared camera imaging. In addition, an analytic model was developed for the Transient System Simulation Program (TRNSYS) that can be used to predict the expected glazing temperature as a function of ambient conditions. The expected glazing temperature range is needed to properly configure the operational parameters for the IR camera prior to conducting aerial photography of an area containing SHW systems.

Here we describe the results of this collaborative effort pertaining to the feasibility of the use of aerial infrared imaging to identify whether rooftop solar thermal panels are operating properly.

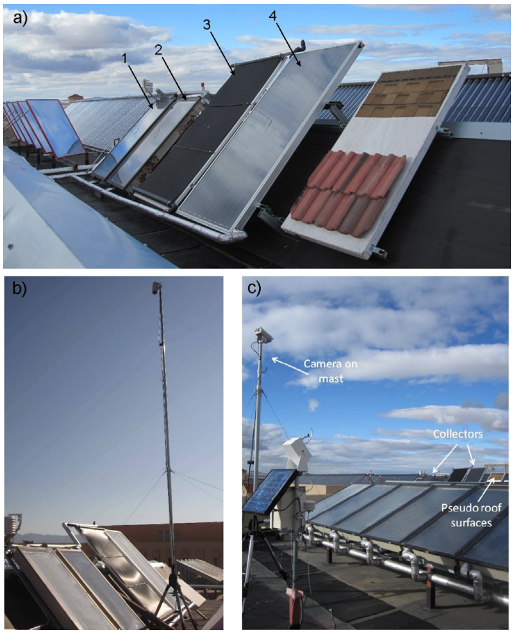

Fig. 1. Experimental arrangement of the solar collectors and the IR camera in the weatherproof enclosure mounted on the mast. a) shows the collectors: 1 – double-glazed Lennox LSC-18, 2 – single-glazed Lennox LSC-18, 3 – Fafco Sun Saver, 4 – Sun Earth SB-32. To the right of the last collector are the roofing material samples. b) shows the mast extended above the collectors ("near-field" configuration). c) shows the mast and the collectors in the "far-field" configuration. In the background are solar collectors and booster mirrors of the UNM solar power plant [11].

2. Experimental setup and data acquisition

The experiment was conducted at the SHW Reliability Testbed [10] located in the Mechanical Engineering building at UNM. This well-instrumented facility models a residential-sized solar hot water system. The creation of the testbed was co-funded by Sandia and UNM. For the experiments described here, the system was connected to four different SHW collectors representing the most popular commercially available collector types (Fig. 1):

1. Lennox LSC-18 with a steel fin collector, copper riser tubes, black chrome selective coating, and double glazing on the front surface.
2. Lennox LSC-18 with a steel fin collector, copper riser tubes, black chrome selective coating, and single glazing on the front surface.
3. Fafco Sun Saver unglazed polymer collector.
4. Sun Earth SB-32 single glazed collector with a copper fin collector coated with a non-selective paint.

The high-performance selective surface collectors are relatively expensive and not in wide use presently. The other collectors cost less per unit area and constitute the majority of thermal collectors currently in use. For example, 97.2% of all thermal installations listed in Arizona Public service database [12] are solar water heaters, and for these, the most commonly used type of collector is the non-selective surface flat-plate [13]. They were also the primary focus of the experimental efforts.

The testbed is setup to represent a typical residential solar thermal panel installation – south-facing, with a 45° slope. It can use any single collector or any grouping of collectors as its solar heat source. The solar panel array was visualized with an infrared camera mounted on a movable telescoping mast. The camera used for the experiments was the small, lightweight, Photon 320 from FLIR [14]. It is a commercially developed, military-qualified 320 × 240 Long-Wave (7–13 μm) Infrared (LWIR) thermal imager. The Photon 320 achieves superior LWIR image quality using an un-cooled vanadium-oxide micro-bolometer array that provides a broad spectral response and operates over a temperature range of −40 to 80 °C. The compact size, modest mass, and robustness of this camera make it a suitable candidate for mounting on an unmanned aerial vehicle (UAV) for flyby inspections. For our experiment, the camera was used with a fixed 14.25 mm lens that provided a 46° horizontal field of view and a 36° vertical field of view. The Photon 320 acquires images at 30 frames per second and camera settings, including automatic gain control (AGC) mode, can be controlled and set via a standard RS-232 serial communication interface. The vanadium-oxide micro-bolometer array inside the camera has a broad spectral response. A short-wave blocking filter incorporated within the lens blocks wavelengths less than 7 μm.

Our goal was to determine if in the 7–13 μm band visible to the camera operational solar-thermal collectors emit amounts of energy measurably different from the non-operational ones. The camera was placed in a standard security-camera enclosure with the glass face plate removed to enable imaging of thermal wavelengths. The camera in the enclosure was mounted on the telescoping mast, whose height was adjustable up to 5.3 m (Fig. 1). Its location relative to the collectors was varied during the experiments. The mast could be located directly above the collectors (we will refer to this location as the near-field), or up to 16.3 m to the south and east of them collector array (this location will be referred to as the far-field location).

Along with the collectors, two common types of roofing surfaces were mounted on a platform within the field of view of the camera, to serve as temperature references. These surfaces included concrete barrel tiles and standard 90 lb (40.8 kg) 3-tab roofing shingles.

The testbed data collection system includes thermocouples that sense temperatures of various components, such as the glazing and collector fin temperatures of all of the collectors and the fluid