SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

2023 HIGHLIGHTS

Task 68 - Efficient Solar District Heating Systems

THE ISSUE

Heat is the largest energy end-use, accounting for 50% of global final energy consumption in 2021 and contributing to 40% of global carbon dioxide (CO2) emissions. Of the total heat produced, about 46% was consumed in buildings for space and water heating. Regarding the heat supply of buildings, district heating systems play an important role and are well-established in many countries since they typically enable efficient resource utilization. However, most district heating networks in Europe and worldwide still operate with supply temperatures over 80 to 120°C (medium-high temperature), which is still typically produced by caloric power plants. Currently operating solar district heating (SDH) systems are typically installed with flat-plate collectors providing either heat at lower temperatures or lower efficiency in case of higher temperatures. SHC Task 68 is therefore investigating how to increase the efficiency of SDH systems further and support the dissemination of such systems.

OUR WORK

SHC Task 68 provides a high-quality and powerful platform for practitioners and scientists to elaborate on the latest benefits and challenges of SDH systems. It elaborates on options and measures how to further increase the efficiency of solar district heating (SDH) systems when providing the desired temperatures needed by currently operated district heating systems by investigating how:

- To provide the heat most efficiently at the desired temperature level either directly by solar (e.g., combining flat-plate collectors with other solar collectors) or indirectly by solar by combining solar collectors with other technologies (e.g., solar collectors with heat pumps).
- To take the next step in digitalization measures to allow for more efficient data preparation and utilization.
- To make SDH systems more competitive and more appealing by exploring new business models and ways to reduce costs.
- To raise awareness of solar technologies and disseminate the knowledge.

Finally, SHC Task 68 aims to create synergies between the IEA Technology Collaboration Programme on District Heating and Cooling, including Combined Heat and Power (IEA DHC).

Participating Countries

Austria
China
Denmark
Germany
Italy
Netherlands
Spain
Sweden
United Kingdom

Task Period	2022 – 2025
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KEY RESULTS IN 2023

Self-learning algorithm to forecast the expected energy yield of flat-plate solar collector systems

The number of large-scale solar thermal installations has increased rapidly in Europe in recent years, with 70% of these systems operating with flat-plate solar collectors. Since these systems cannot be easily switched on and off and directly depend on solar radiation, they must be combined with other technologies or integrated into large energy systems. To most efficiently integrate and operate solar systems, it is important to consider their expected energy yield to better schedule heat production, storage, and distribution. To do so, the availability of accurate forecasting methods for the future solar energy yield is essential. Currently, available forecasting methods do not meet three important practical requirements: simple implementation, automatic adaption to seasonal changes, and wide applicability. For these reasons, a simple and self-learning forecasting method is presented in this contribution, which allows us to accurately forecast the solar heat production of flat-plate collector systems considering weather forecasts. The method is based on a modified collector efficiency model where the parameters are continuously redetermined to specifically consider the influence of the time of the day. To show the wide applicability, the method is extensively tested with measurement data of various flat-plate collector systems covering different applications (below 200 degrees Celsius), sizes, and orientations. The results show that the method can accurately forecast the solar yield with a Mean Absolute Range Normalized Error (MARNE) of about 5% using actual weather forecasts as inputs and outperforms common forecasting methods by being nearly twice as accurate.

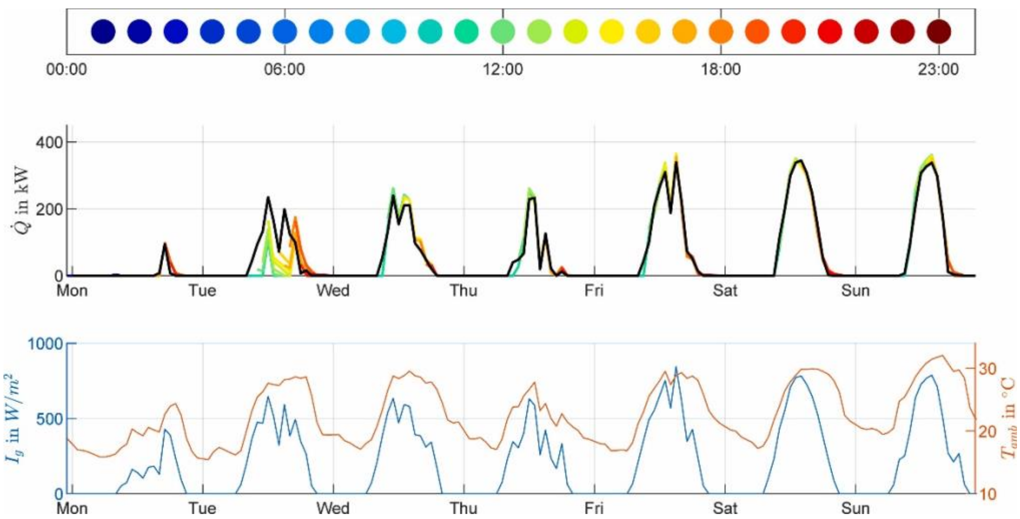

Figure 1: Evaluation of the forecasting method for a week in July of a medium-sized heat producer in Austria. The upper graph shows the measured (black) and the forecast (color) solar yield, with the colors indicating the hour of the day the respective forecast starts. The lower graphs show the corresponding measured global radiation and ambient temperature.

(Reference: Viktor Unterberger, Klaus Lichtenegger, Valentin Kaisermayer, Markus Gölles and Martin Horn, An adaptive short-term forecasting method for the energy yield of flat-plate solar collector systems, Applied Energy, Volume 293, 2021, 116891, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2021.116891.)

Automatic fault-detection for solar thermal systems based on artificial intelligence

Fault-Detection (FD) is essential to ensure the performance of solar thermal systems. However, manually analyzing the system can be time-consuming, error-prone, and requires extensive domain knowledge. On the other hand, existing FD algorithms are often too complicated to set up, limited to specific system layouts, or have only limited fault coverage. Hence, a new FD algorithm called *Fault-Detective* is presented in this paper, which is purely data-driven and can be applied to a wide range of system layouts with minimal configuration effort. It automatically identifies correlated sensors and models their behavior using Random-Forest-Regression. Faults are then detected by comparing predicted and measured values.

The algorithm is tested using data from three large-scale solar thermal systems to evaluate its applicability and performance. The results are compared to manual fault detection performed by a domain expert. The evaluation shows that *Fault-Detective* can successfully identify correlated sensors and model their behavior well, resulting in coefficient-of-determination scores between $R^2=0.91$ and $R^2=1.00$. In addition, all faults detected by the domain experts were correctly spotted by *Fault-Detective.* The algorithm even identified some faults that the experts missed. However, the use of *Fault-Detective* is limited by the low precision score of 30% when monitoring temperature sensors. The reason for this is a high number of false alarms raised due to anomalies (e.g., consecutive days with bad weather) instead of faults. Nevertheless, the algorithm shows promising results for monitoring the thermal power of the systems, with an average precision score of 91%.

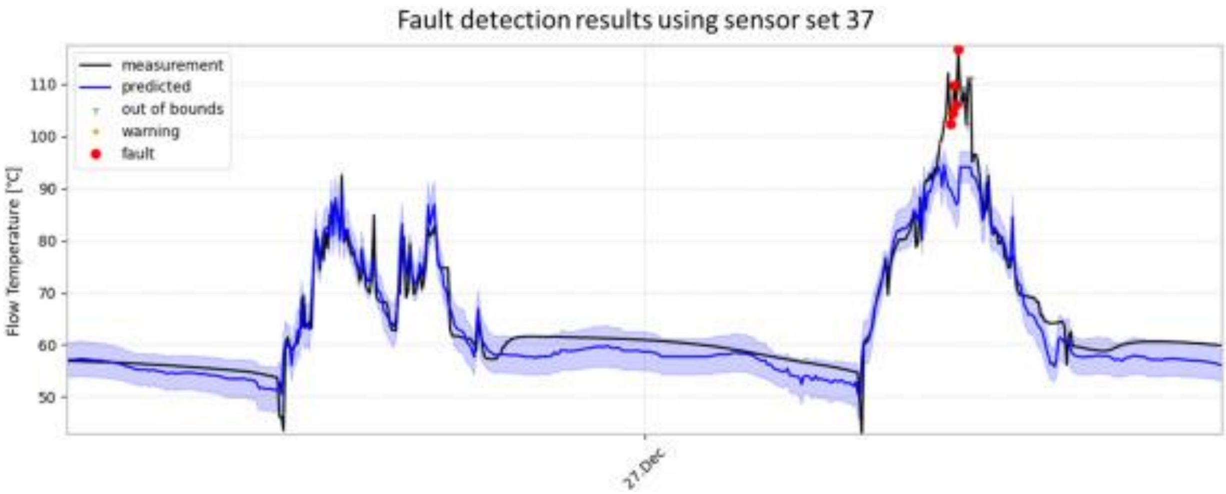

Figure 2: Due to the limited heat extracted from the storage, the collector temperatures increase for a short time. The fault was detected even though the temperatures did not reach critical levels.

(Reference: L. Feierl, V. Unterberger, C. Rossi, B. Gerardts, M. Gaetani, Fault detective: Automatic fault-detection for solar thermal systems based on artificial intelligence, Solar Energy Advances, Volume 3, 2023, 100033, ISSN 2667-1131, https://doi.org/10.1016/j.seja.2023.100033).

One year of high-precision operational data from solar thermal collector array publicly available

The contribution presents operational data of a large-scale solar thermal collector array. The collector array deploys flat plate collectors with a total gross collector area of 516 m^2 (361 kW nominal thermal power). Measurement data was collected in situ using high-precision measurement equipment and implementing extensive data quality assurance measures. Data compromises one full operational year (2017) in a 1-minute sampling rate with a share of missing data of 8.2%. Several files are provided, including data files and Python scripts for data processing and plot generation. The main dataset contains the measured values of various sensors, including volume flow, inlet and outlet temperature of the collector array, outlet temperatures of single collector rows, global tilted and global horizontal irradiance, direct normal irradiance, and weather data (ambient air temperature, wind speed, ambient relative humidity) at the plant location. Beyond the measurement data, the dataset includes additional calculated data channels, such as thermal power output, mass flow, fluid properties, solar incidence angle, and shadowing masks. The dataset also provides uncertainty information in terms of the standard deviation of a normal distribution, based either on sensor specifications or on error propagation of the sensor uncertainties. Uncertainty information is provided for all continuous variables, with some exceptions, such as the solar geometry, where uncertainty is negligible. The data files include a JSON file containing metadata (e.g., plant parameters, data channel descriptions, physical units, etc.) in both human and machine-readable formats. The dataset is suitable for detailed performance and quality analysis and for modeling flat plate collector arrays.

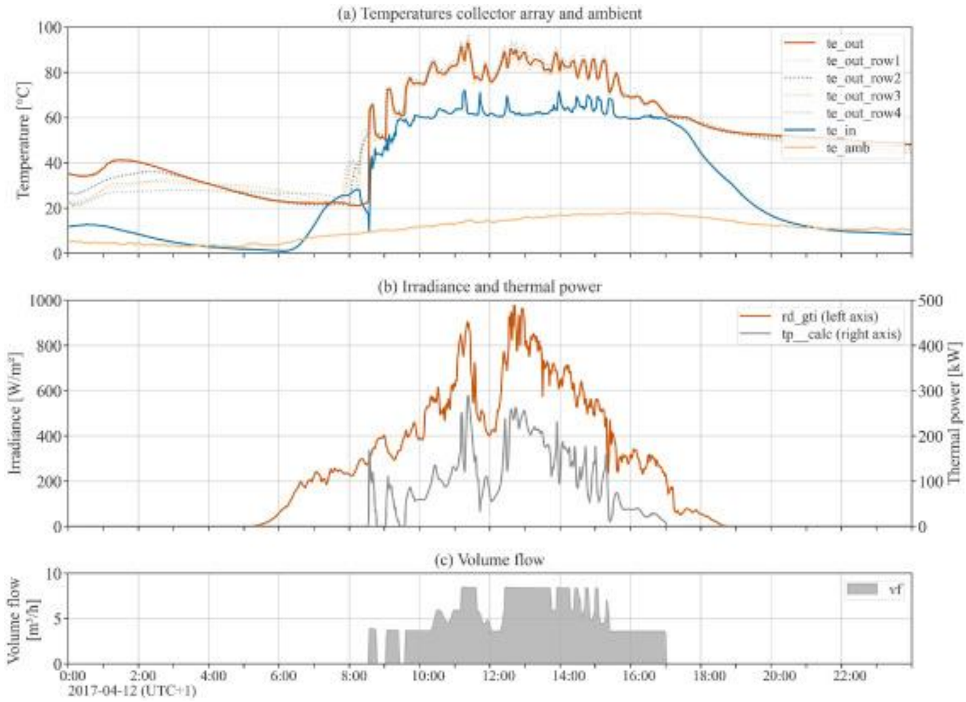

Figure 3: Example day plot of selected data channels related to collector array operation and global tilted irradiance.

(Reference: D. Tschopp et al., One year of high-precision operational data including measurement uncertainties from a large-scale solar thermal collector array with flat plate collectors, located in Graz, Austria, Data in Brief, Volume 48, 2023, 109224, ISSN 2352-3409, https://doi.org/10.1016/j.dib.2023.109224.)