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SunPeek: Open-Source Tool for Performance Analytics of Solar Thermal Plants

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Software

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Summary

SunPeek is an open-source software designed to automate the performance evaluation of solar thermal plants, focusing on large-scale installations. Addressing both researchers and plant operators, SunPeek provides a practical framework for operational performance analysis. SunPeek computes expected solar thermal output using models based on ISO 24194 and automates data ingestion and cleaning, performance modeling and data analysis, result visualization, and report generation. SunPeek emerged from collaboration between research institutes and industry partners (Tschopp, Ohnewein, Hamilton-Jones, et al., 2024; Tschopp et al., 2025). To our knowledge, it provides the first open-source implementation of the ISO 24194 Power Check (International Organization for Standardization, 2022), a standardized methodology for evaluating the power performance of solar thermal collector fields. SunPeek also integrates an open dataset, comprising a full year of measurement data from a real-world, large-scale solar plant, as described in a journal article (Tschopp et al., 2023).

Availability

Designed as a containerized web application, SunPeek includes a web interface and a Python backend with a REST API, and a few auxiliary repositories. The Python backend comprises approximately 27,500 lines of code with 96.3% test coverage, while the JavaScript-based web interface adds around 7,950 lines (both including tests, excluding blank lines and comments). All SunPeek repositories are accessible via GitLab. Docker containers are available on DockerHub, and there is a public demo server. The backend is also available as a standalone Python package, listed on PyPI. SunPeek is a NumFOCUS affiliated project and is managed by a Steering Committee, as detailed in the governance repository. Community guidelines outline how to contribute to SunPeek, and detailed documentation is available.

SunPeek repositories are released under open licenses: GNU LGPL for the backend, BSD-3-Clause for the user interface, CC-BY-SA 4.0 for the open dataset. A curated collection of

SunPeek-related publications, including the aforementioned dataset, technical reports, and peer-reviewed articles, is available on the SunPeek Zenodo community.

Statement of Need

Solar thermal collectors convert solar radiation directly into thermal energy by heating a working fluid circulating through the collectors. Large-scale solar thermal plants provide heat for applications such as industries or district heating and represent a critical technology for the renewable energy transition (Tschopp et al., 2020). Assessing the performance of these systems is inherently complex and has been extensively researched for decades (Duffie et al., 2020). Key challenges include the stochastic nature of operating conditions (e.g., solar irradiance fluctuations, return temperature oscillations), heat capacity and delay effects caused by fluid transport, and lack of standardization in measurement setups of solar thermal plants.

Before SunPeek, no open-source tools existed for modeling and assessing solar thermal plant performance (Tschopp, Ohnewein, Feierl, et al., 2024). SunPeek addresses this and distinguishes itself from commercial tools by combining scientifically validated, tailored algorithms for solar thermal systems (like the ISO 24194 Power Check), adaptive performance modeling based on measurement data from real plant operation (unlike simulation tools), and automated data processing and analytics. Its modeling framework adapts to various hydraulic configurations and measurement setups. Serving as the reference software implementation of the ISO 24194 Power Check (Tschopp et al., 2025), SunPeek streamlines methodological advancements in the field. As illustrated in Figure 1, SunPeek addresses diverse users - technical experts (typically accessing SunPeek via the Python backend or API) and general users (via the JavaScript-based web app) - as well as external software and monitoring systems that integrate via the REST API.

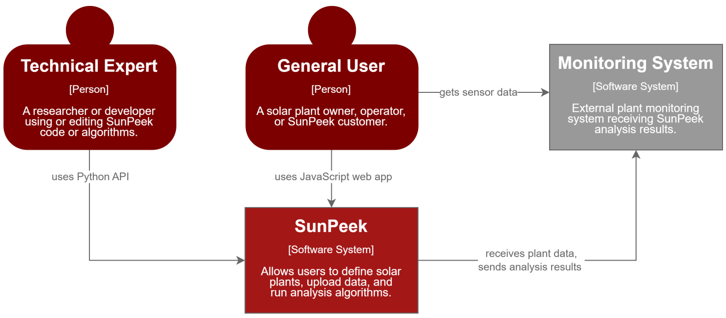

Figure 1: C4 System Context diagram of the SunPeek software system.

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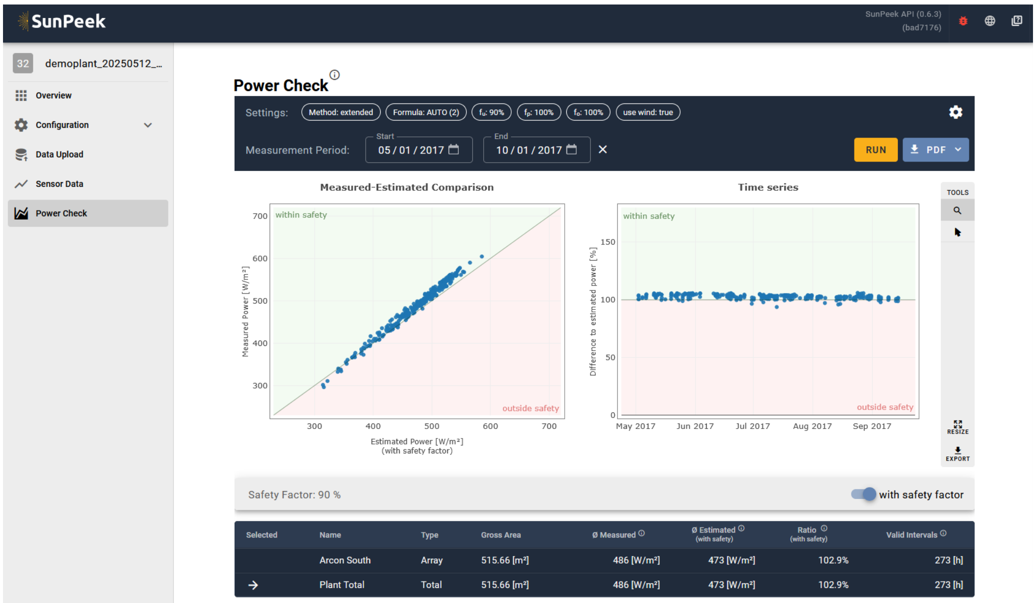

Figure 2: Screenshot of SunPeek's web user interface: Interactive display of Power Check results.

Algorithms and Automation

SunPeek offers a range of interactive features, including plant configuration, Power Check analysis (see screenshot in Figure 2), automated generation of PDF reports, and CSV export of calculation results. A fully documented REST API enables programmatic access to all configuration and analysis functionalities, enabling automation of all configuration and analysis tasks. Figure 3 illustrates the automation framework for executing the Power Check, including the key steps in modeling, data handling, and visualization. Figure 4 presents an overview of SunPeek's software architecture, highlighting the technologies employed and the interactions between core components.

At the core of SunPeek's performance analysis is the "Power Check" method, a standardized procedure for evaluating the power performance of solar thermal collector fields, based on (International Organization for Standardization, 2022). This method employs a grey-box model that combines measurement data with physical domain knowledge (e.g., collector efficiency parameters, collector field geometry) to model the estimated power output during stable operating intervals. The primary performance metric used in the Power Check is the ratio of measured-to-estimated power output, enabling a target-to-actual performance analysis on an absolute scale. Tracking this metric over time can help identify faults and determine whether the plant's measured performance aligns with expectations.

The Power Check method factors in measured operating conditions that influence system performance, such as solar radiation, temperatures, and shading. This ensures that the Power Check performance metrics generalize well: they are applicable across various geographical regions, collector technologies, and weather conditions. The insights derived from the Power Check can be valuable for plant operation and maintenance: a drop in the target-to-actual metric below expected values can indicate issues requiring action, such as collector cleaning, control adjustments, or general maintenance.

In addition to the standard Power Check, SunPeek features an "Extended Power Check", with improved data filtering (Tschopp, Ohnewein, Hamilton-Jones, et al., 2024). This enhancement uses a moving-window method combined with a minimum-noise selection criterion to improve result accuracy. Beyond Power Check analysis, the SunPeek platform is designed to

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accommodate additional performance analysis methods, including D-CAT (Dynamic Collector Array Test), discussed in Future Work.

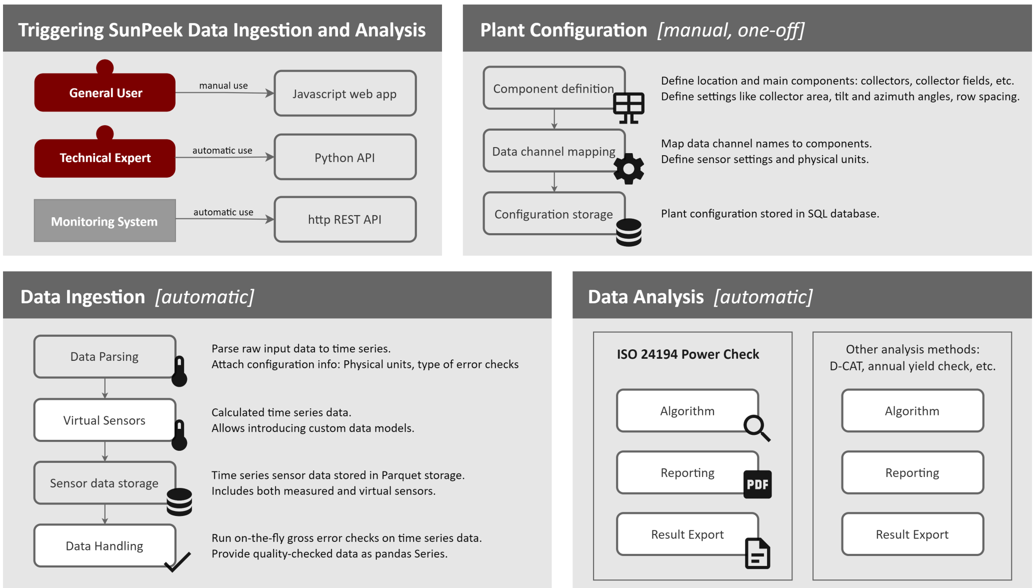

Figure 3: SunPeek automation framework for executing the Power Check and other analysis methods. Customizable modules (white boxes) include data handling, modeling, and visualization.

Figure 3 illustrates SunPeek's framework for automating performance evaluations of solar thermal plants, after an initial plant configuration step. Automation concepts include:

- *Collector parameterization*: SunPeek supports collector efficiency parameters derived from the widely used QDT (quasi-dynamic test) of (International Organization for Standardization, 2025). Parameters from various testing procedures (e.g., earlier versions of ISO 9806, steady-state tests, and different incidence angle modifier models) are also accepted and automatically converted as needed. The tool includes pre-configured collectors and allows users to define custom collectors. Development of an automated interface to the extensive Solar Keymark collector database is currently ongoing.
- *Robust data quality checks:* SunPeek validates plant configurations and time series data for consistency and compatibility with the chosen analysis methods. These built-in checks eliminate the need for data preprocessing using external tools.
- *Heat transfer fluids*: SunPeek uses CoolProp to compute fluid properties if required for the performance calculations (e.g., temperature- and concentration-dependent density and heat capacity). The software comes with pre-defined heat transfer fluids commonly used in solar thermal plants.
- *Collector field mounting types*: SunPeek supports fixed-mounted and single-axis tracking collector fields, covering two main mounting configurations in large-scale solar thermal plants.
- *Virtual sensors*: Virtual sensors derive unmeasured quantities (e.g., solar position, collector field shading, or fluid properties), enabling or enhancing modeling. Virtual sensors are computed from measured sensor data and parameters, accommodating the diverse and non-standardized measurement setups found in solar thermal plants. SunPeek uses pvlib (Anderson et al., 2023) for solar position and angle of incidence calculations, incidence angle modifiers, shading fraction estimation, and single-axis tracking geometry and shading.

- *Unit awareness*: All physical parameters and measurement data in SunPeek are encoded as unit-aware quantities, leveraging the pint and pandas libraries. This ensures consistent and reliable handling of units across all calculations and analyses.

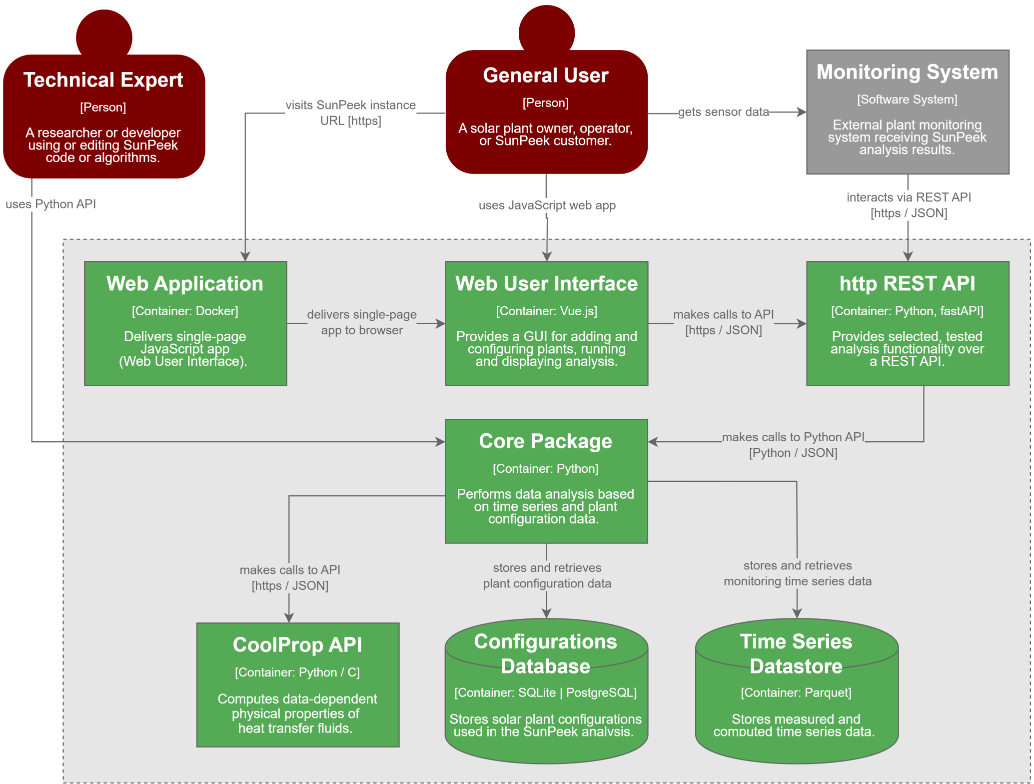

Figure 4: C4 container diagram of the SunPeek software system.

Usage and Community

The IEA SHC Task 68 Guide to the Power Check (Tschopp et al., 2025) documents use cases and successful deployments of SunPeek in large-scale solar plants. The development team maintains active collaboration with the solar thermal community, including both industry and academia, and with the technical committee ISO/TC 180/SC4 responsible for developing the ISO 24194 standard. As the reference implementation of ISO 24194, SunPeek has helped identify important shortcomings and ambiguities in the standard, encouraging collaboration among researchers, industry partners, and technical committees. The SunPeek implementation, proposed method enhancements and directions for future work, are comprehensively described in (Tschopp et al., 2025). A curated collection of SunPeek-related publications is hosted on Zenodo.

Future Work

We are integrating D-CAT (Dynamic Collector Array Test), a dynamic performance analysis method that extends the ISO 9806 collector model by incorporating transport effects in collector fields. It could be used for fault diagnostics and solar energy yield assessment, relevant for the financial performance of a solar plant. The D-CAT method has been developed through several research projects; see Ohnewein et al. (2020) for additional background. The implementation is being developed in a SunPeek fork and is planned to be merged with the main project later.

Other planned developments include enhancements to the Power Check method, as outlined in Tschopp et al. (2025), and implementation of the Annual Yield Check, defined in a new revision of ISO 24194 targeted for 2026. Longer-term goals are summarized in the project roadmap and include several key features: integrating an automatic interface with the Solar Keymark collectors database, adding data integration with common SCADA systems, and developing a cloud-based SunPeek solution to enable software-as-a-service (SaaS) offerings.

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