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

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DOI: 10.xxxxxx/draft

Software

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Editor: Adam R. Jensen

Reviewers:

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Submitted: 28 January 2025
Published: unpublished

Summary

SunPeek is an open-source software designed to automate the performance evaluation of solar thermal plants, with a focus on large-scale installations. Addressing both researchers and commercial plant operators, SunPeek offers an application-oriented framework for analyzing operational performance. Built on standardized methodologies, SunPeek employs scientifically validated models to compute the expected solar thermal output and integrates automated features such as data ingestion and cleaning, performance modeling, interactive data analytics, and report generation. Designed as a containerized web application, SunPeek includes a web interface and a Python backend with a REST API. All SunPeek repositories are accessible via GitLab. The backend is also available as a standalone Python package, listed on PyPI. Docker containers are available on DockerHub, and there is a public demo server. SunPeek is a NumFOCUS affiliated project and is managed by a Steering Committee, as detailed in the governance repository. Community guidelines outline how new users can contribute to SunPeek, and detailed documentation exists.

SunPeek has been developed through collaboration between research institutes and industry partners (Tschopp, Ohnewein, Hamilton-Jones, et al., 2024). It entails the first open-source implementation of the ISO 24194 Power Check (*ISO 24194 Solar energy — Collector fields — Check of performance*, 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). All SunPeek repositories are released under OSI-approved licenses, such as: 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 the focus of extensive research over the past 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.

No open-source tools have existed specifically dedicated to modeling and assessing solar thermal plant performance (Tschopp, Ohnewein, Feierl, et al., 2024). SunPeek addresses the lack of tailored open-source tools, featuring validated methods and automation: It streamlines methodological advancements in the field, provides transparent and scientifically validated algorithms, and automates performance analytics, reducing labor-intensive expert action. As illustrated in Figure 2, SunPeek is designed for a diverse user base, including general users (typically accessing the tool via the JavaScript-based web app), technical experts (leveraging the Python backend or API), and automated software systems (leveraging the REST API).

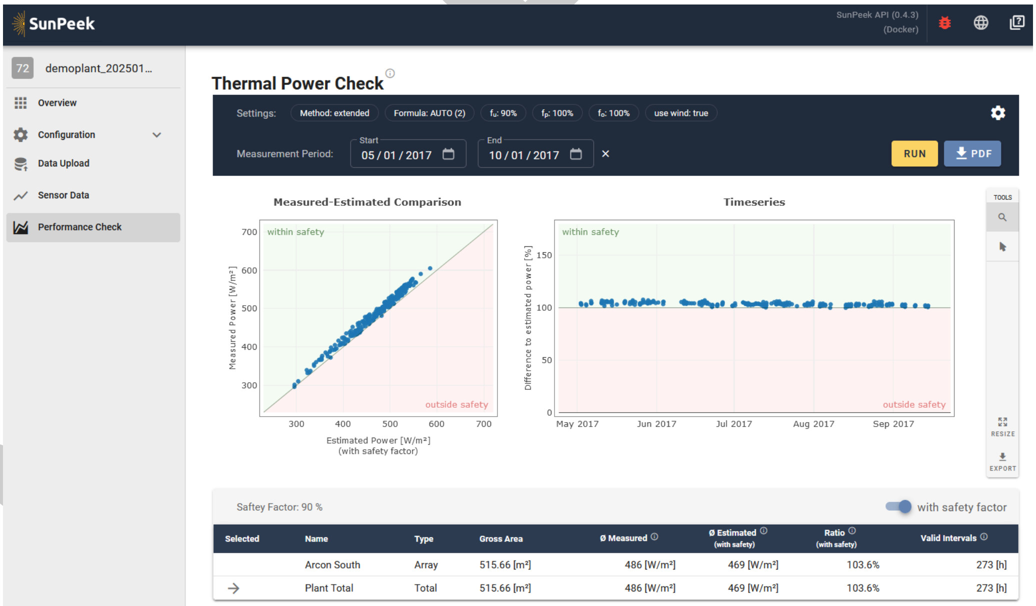

Figure 1: Screenshot of SunPeek's web user interface: Interactive display of Power Check results.

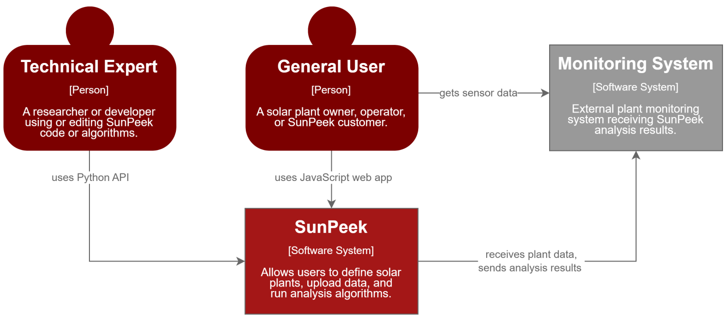

Figure 2: C4 System Context diagram of the SunPeek software system.

Algorithms and Automation

SunPeek offers a range of interactive features, including plant configuration, Power Check analysis (see screenshot in Figure 1), 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, allowing seamless automation. 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 (*ISO 24194 Solar energy — Collector fields — Check of performance*, 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, a figure which enables 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.

Notably, 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 and are applicable across various geographical regions, collector technologies, and weather conditions. The insights derived from the Power Check are valuable for plant operation and maintenance: a drop in the target-to-actual metric below expected values may indicate the need for actions on the solar plant, such as cleaning the collectors, adjusting the control strategy, or performing 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 accommodate additional performance analysis methods, including D-CAT (Dynamic Collector Array Test), with development plans discussed in the Future Work section.

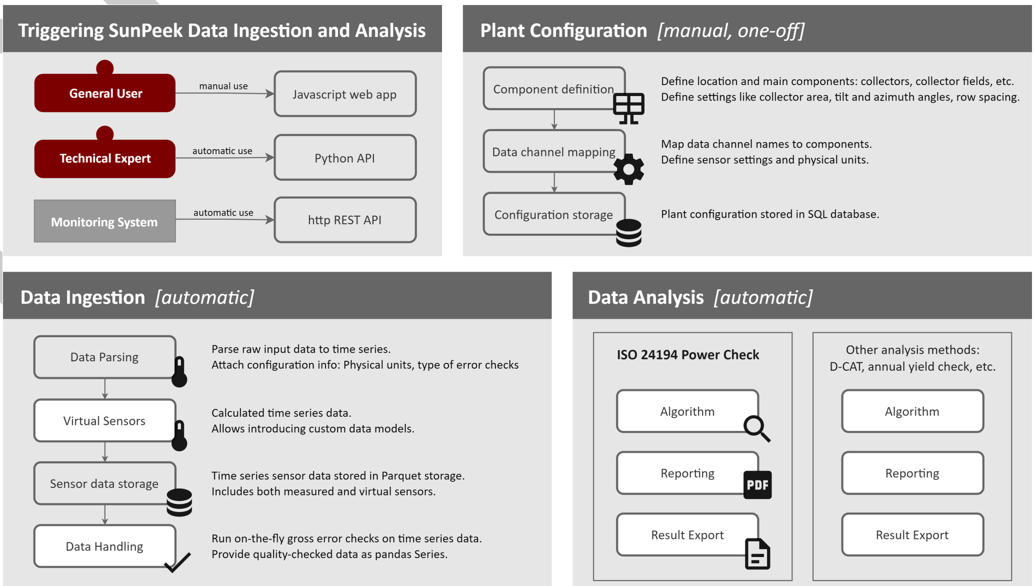

Figure 3: SunPeek automation framework for executing the Power Check and other analysis methods. Customizable modules (white boxes) include data handling, modeling, and visualization.

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

- *Collector parameterization*: SunPeek supports collector efficiency parameters derived from the widely used QDT (quasi-dynamic test) of (*ISO 9806 Solar energy — Solar thermal collectors — Test methods*, 2017). 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:* Great care has been taken to check that plant configurations and time series data are reasonable and compatible 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.
- *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 and enhance SunPeek's adaptability to the diverse and non-standardized measurement setups found in solar thermal plants.
- *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.

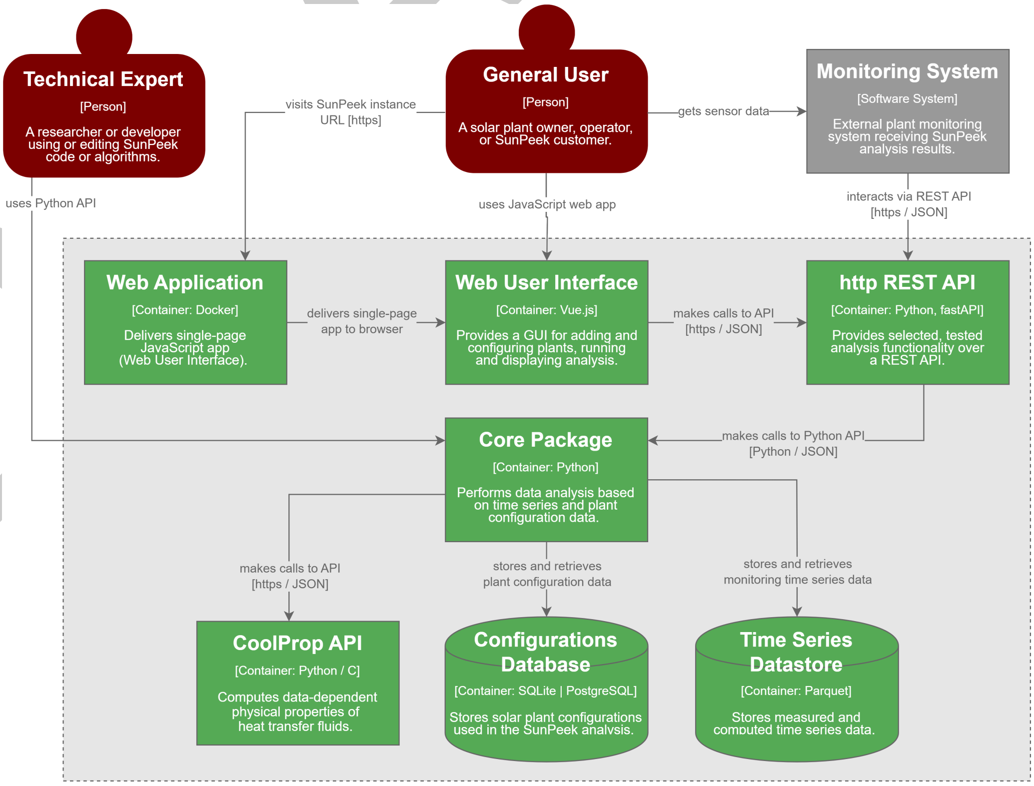

Figure 4: C4 container diagram of the SunPeek software system.

Usage and Community

Use cases and successful deployments of SunPeek in large-scale solar plants are documented in (Tschopp, Ohnewein, Hamilton-Jones, et al., 2024). 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. By operationalizing ISO 24194 and clarifying important shortcomings and ambiguities, SunPeek serves as a reference implementation, encouraging collaboration among researchers, industry partners, and technical committees. The SunPeek implementation, proposed method enhancements and directions for future work, are comprehensively described in the Guide to the Power Check (Tschopp, Mehnert, et al., 2024). A curated collection of SunPeek-related publications is hosted on Zenodo, providing a centralized resource for further reading and reference.

Future Work

Ongoing work is focused on integrating D-CAT (Dynamic Collector Array Test), a performance analysis method based on high-resolution models of solar plant behavior. D-CAT extends the ISO 9806 collector model by explicitly incorporating transport effects in collector fields. It can 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, Mehnert, et al., 2024). 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 integration with common SCADA systems, and developing a cloud-based SunPeek solution to enable a software-as-a-service (SaaS) model.

Acknowledgements

SunPeek development was partially funded by the Austrian Research Promotion Agency (grant no. FO999887648, FO999890460, FO999908366), Austrian Federal Ministry of Labour and Economy (grant no. SP-2024-02), and the European Commission (grant no. 101136140). The authors acknowledge and thank all contributors to the project, with special recognition to Michael Zellinger, Christian Kloibhofer, Alexander Thür, Wolfgang Streicher and Martin Koren.

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