

¹ SunPeek: Open-Source Tool for Performance Analytics of Solar Thermal Plants

³ **Marnoch Hamilton-Jones**  ^{1,3*}, **Lukas Feierl**  ^{2*}, **Philip Ohnewein**  ^{1*¶},
⁴ **Daniel Tschopp**  ^{1,4*}, **Peter Zauner**  ¹, **Jonathan Cazco Gonzalez**  ¹, **Maria Moser**  ², **Hannes Poier**  ², **Christopher Albert**  ⁵, and **Léo Bonal**  ⁶

⁶ 1 AEE – Institute for Sustainable Technologies, Austria 2 SOLID Solar Energy Systems GmbH, Austria 3
⁷ Graz University of Technology, Institute of Software Engineering and Artificial Intelligence, Austria 4
⁸ University of Innsbruck, Unit for Energy Efficient Buildings, Austria 5 Graz University of Technology,
⁹ Institute for Theoretical Physics – Computational Physics, Austria 6 V-Research GmbH, Austria ¶
¹⁰ Corresponding author * These authors contributed equally.

DOI: [10.xxxxxx/draft](https://doi.org/10.xxxxxx/draft)

Software

- [Review](#) 
- [Repository](#) 
- [Archive](#) 



¹¹ Editor: Adam R. Jensen  

Reviewers:

- [@t-gross](#)
- [@trevorb1](#)

¹² Submitted: 28 January 2025

¹³ Published: unpublished

License

¹⁴ Authors of papers retain copyright and release the work under a Creative Commons Attribution 4.0 International License ([CC BY 4.0](#)).
¹⁵ [19](#)

Summary

¹⁶ 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. 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. 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 ([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](#)).

Availability

²⁷ 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 25,300 lines of code with 96.6% test coverage, while the JavaScript-based web interface adds around 7,400 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.
²⁸ [32](#)
²⁹ [33](#)
³⁰ [34](#)
³¹ [35](#)

³⁶ SunPeek repositories are released under open licenses: GNU LGPL for the [backend](#), BSD-3-
³⁷ Clause for the [user interface](#), CC-BY-SA 4.0 for the [open dataset](#). A curated collection of
³⁸ SunPeek-related publications, including the aforementioned dataset, technical reports, and
³⁹ peer-reviewed articles, is available on the [SunPeek Zenodo community](#).

⁴⁰ Statement of Need

⁴¹ Solar thermal collectors convert solar radiation directly into thermal energy by heating a
⁴² working fluid circulating through the collectors. Large-scale solar thermal plants provide heat
⁴³ for applications such as industries or district heating and represent a critical technology for the
⁴⁴ renewable energy transition ([Tschopp et al., 2020](#)). Assessing the performance of these systems
⁴⁵ is inherently complex and has been extensively researched for decades ([Duffie et al., 2020](#)).
⁴⁶ Key challenges include the stochastic nature of operating conditions (e.g., solar irradiance
⁴⁷ fluctuations, return temperature oscillations), heat capacity and delay effects caused by fluid
⁴⁸ transport, and lack of standardization in measurement setups of solar thermal plants.

⁴⁹ Previously, no open-source tools existed specifically for modeling and assessing solar thermal
⁵⁰ plant performance ([Tschopp, Ohnewein, Feierl, et al., 2024](#)). SunPeek fills this gap and
⁵¹ distinguishes itself from other commercial tools by combining scientifically validated, tailored
⁵² algorithms for solar thermal systems (like the ISO 24194 Power Check), adaptive performance
⁵³ modeling based on measurement data from real plant operation (unlike simulation tools), and
⁵⁴ automated data processing and analytics. Its generic modeling framework automatically adapts
⁵⁵ to various hydraulic configurations and measurement setups. Serving as the reference software
⁵⁶ implementation of the ISO 24194 Power Check ([Tschopp et al., 2025](#)), SunPeek streamlines
⁵⁷ methodological advancements in the field. As illustrated in [Figure 1](#), SunPeek addresses diverse
⁵⁸ users - technical experts (typically accessing SunPeek via the Python backend or API) and
⁵⁹ general users (via the JavaScript-based web app) - as well as external software and monitoring
⁶⁰ systems that integrate via the REST API.

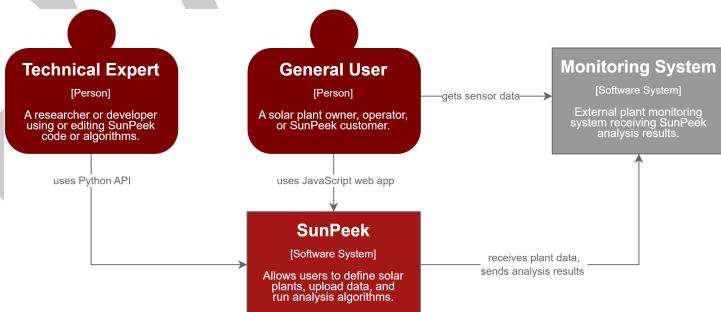


Figure 1: C4 System Context diagram of the SunPeek software system.

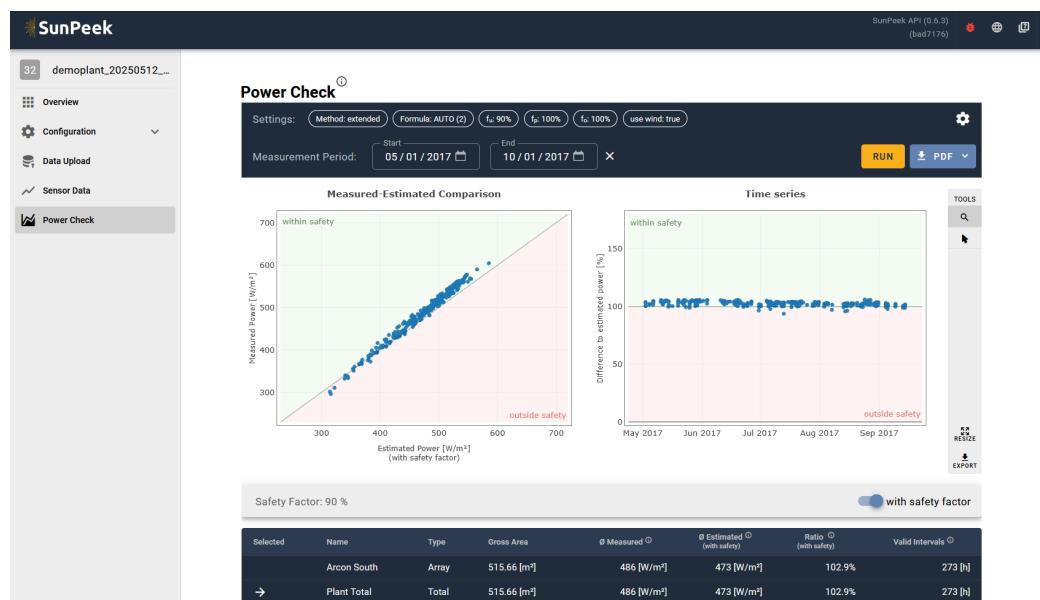


Figure 2: Screenshot of SunPeek’s web user interface: Interactive display of Power Check results.

61 Algorithms and Automation

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

69 At the core of SunPeek’s performance analysis is the “Power Check” method, a standardized
70 procedure for evaluating the power performance of solar thermal collector fields, based on ([ISO
71 24194 Solar energy — Collector fields — Check of performance, 2022](#)). This method employs
72 a grey-box model that combines measurement data with physical domain knowledge (e.g.,
73 collector efficiency parameters, collector field geometry) to model the estimated power output
74 during stable operating intervals. The primary performance metric used in the Power Check
75 is the ratio of measured-to-estimated power output, enabling a target-to-actual performance
76 analysis on an absolute scale. Tracking this metric over time can help identify faults and
77 determine whether the plant’s measured performance aligns with expectations.

78 The Power Check method factors in measured operating conditions that influence system
79 performance, such as solar radiation, temperatures, and shading. This ensures that the Power
80 Check performance metrics generalize well: they are applicable across various geographical
81 regions, collector technologies, and weather conditions. The insights derived from the Power
82 Check are valuable for plant operation and maintenance: a drop in the target-to-actual metric
83 below expected values may indicate the need for action, such as cleaning the collectors,
84 adjusting the control strategy, or performing general maintenance.

85 In addition to the standard Power Check, SunPeek features an “Extended Power Check”,
86 with improved data filtering ([Tschopp, Ohnewein, Hamilton-Jones, et al., 2024](#)). This
87 enhancement uses a moving-window method combined with a minimum-noise selection criterion
88 to improve result accuracy. Beyond Power Check analysis, the SunPeek platform is designed to
89 accommodate additional performance analysis methods, including D-CAT (Dynamic Collector
90 Array Test), discussed in Future Work.

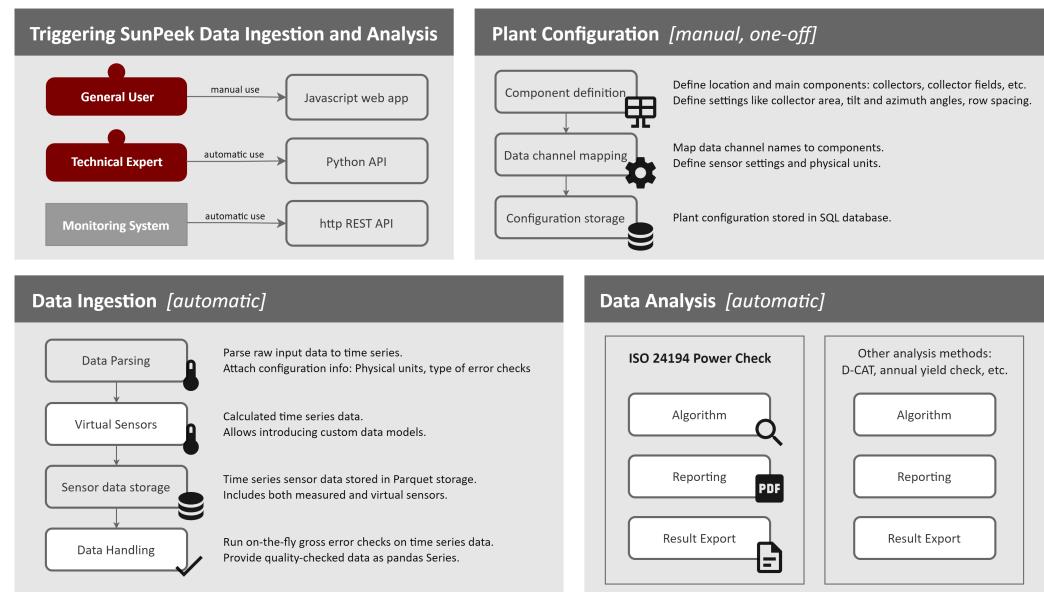


Figure 3: SunPeek automation framework for executing the Power Check and other analysis methods. Customizable modules (white boxes) include data handling, modeling, and visualization.

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

- 93 ▪ **Collector parameterization:** SunPeek supports collector efficiency parameters derived from
 94 the widely used QDT (quasi-dynamic test) of ([ISO 9806 Solar energy — Solar thermal](#)
 95 [collectors — Test methods, 2025](#)). Parameters from various testing procedures (e.g.,
 96 earlier versions of ISO 9806, steady-state tests, and different incidence angle modifier
 97 models) are also accepted and automatically converted as needed. The tool includes
 98 pre-configured collectors and allows users to define custom collectors. Development of
 99 an automated interface to the extensive [Solar Keymark collector database](#) is currently
 100 ongoing.
- 101 ▪ **Robust data quality checks:** Great care has been taken to check that plant configurations
 102 and time series data are reasonable and compatible with the chosen analysis methods.
 103 These built-in checks eliminate the need for data preprocessing using external tools.
- 104 ▪ **Heat transfer fluids:** SunPeek uses [CoolProp](#) to compute fluid properties if required for
 105 the performance calculations (e.g., temperature- and concentration-dependent density
 106 and heat capacity). The software comes with pre-defined heat transfer fluids commonly
 107 used in solar thermal plants.
- 108 ▪ **Virtual sensors:** Virtual sensors derive unmeasured quantities (e.g., solar position, collector
 109 field shading, or fluid properties), enabling or enhancing modeling. Virtual sensors are
 110 computed from measured sensor data and parameters, enhancing SunPeek's adaptability
 111 to the diverse and non-standardized measurement setups found in solar thermal plants.
- 112 ▪ **Unit awareness:** All physical parameters and measurement data in SunPeek are encoded
 113 as unit-aware quantities, leveraging the [pint](#) and [pandas](#) libraries. This ensures consistent
 114 and reliable handling of units across all calculations and analyses.

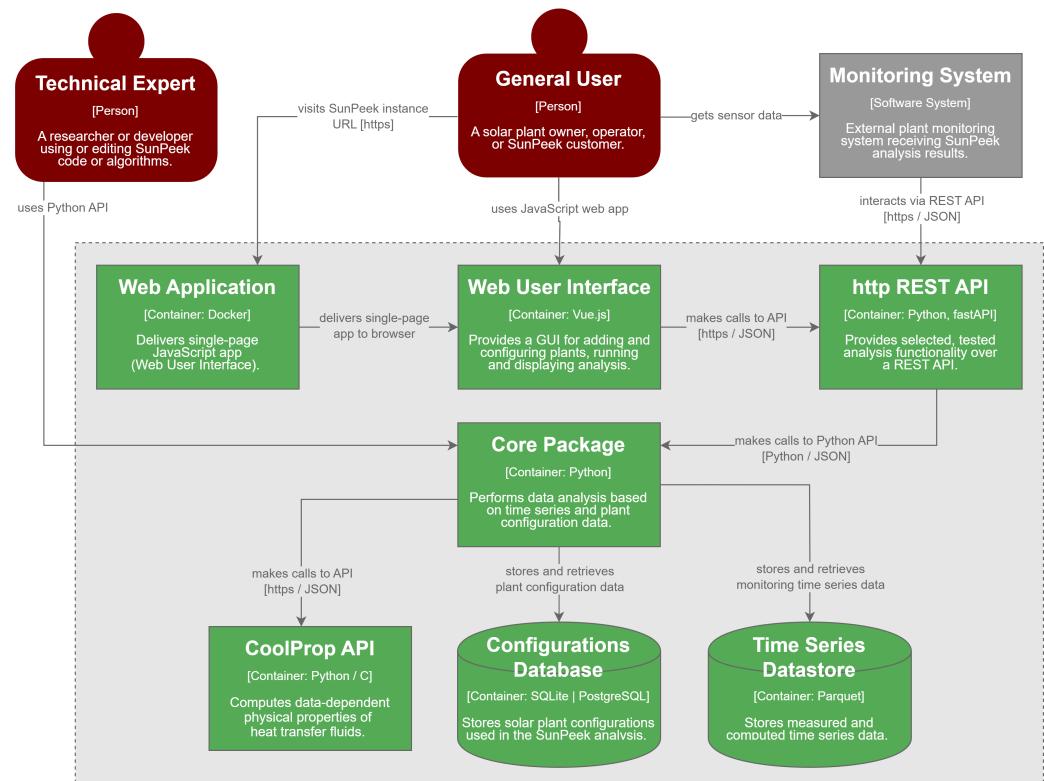


Figure 4: C4 container diagram of the SunPeek software system.

115 Usage and Community

116 The [IEA SHC Task 68 Guide to the Power Check](#) ([Tschopp et al., 2025](#)) documents use cases
 117 and successful deployments of SunPeek in large-scale solar plants. The development team
 118 maintains active collaboration with the solar thermal community, including both industry and
 119 academia, and with the technical committee ISO/TC 180/SC4 responsible for developing the
 120 ISO 24194 standard. By operationalizing ISO 24194 and clarifying important shortcomings
 121 and ambiguities, SunPeek serves as a reference implementation, encouraging collaboration
 122 among researchers, industry partners, and technical committees. The SunPeek implementation,
 123 proposed method enhancements and directions for future work, are comprehensively described
 124 in ([Tschopp et al., 2025](#)). A curated collection of SunPeek-related publications is hosted on
 125 [Zenodo](#), providing a centralized resource for further reading and reference.

126 Future Work

127 Ongoing work is focused on integrating D-CAT (Dynamic Collector Array Test), a performance
 128 analysis method based on high-resolution models of solar plant behavior. D-CAT extends the
 129 ISO 9806 collector model by explicitly incorporating transport effects in collector fields. It
 130 can be used for fault diagnostics and solar energy yield assessment, relevant for the financial
 131 performance of a solar plant. The D-CAT method has been developed through several research
 132 projects; see ([Ohnewein et al., 2020](#)) for additional background. The implementation is being
 133 developed in a [SunPeek fork](#) and is planned to be merged with the main project later.

134 Other planned developments include enhancements to the Power Check method, as outlined
 135 in ([Tschopp et al., 2025](#)), and implementation of the Annual Yield Check, defined in a new
 136 revision of ISO 24194 targeted for 2026. Longer-term goals are summarized in the [project](#)

137 roadmap and include several key features: integrating an automatic interface with the Solar
138 Keymark collectors database, adding data integration with common SCADA systems, and
139 developing a cloud-based SunPeek solution to enable software-as-a-service (SaaS) offerings.

140 Acknowledgements

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

146 References

- 147 Duffie, J. A., Beckman, W. A., & Blair, N. (2020). *Solar engineering of thermal processes,
148 photovoltaics and wind, 5th edition*. John Wiley & Sons. <https://doi.org/10.1002/9781119540328>
- 150 ISO 24194 *Solar energy — Collector fields — Check of performance*. (2022). [Standard].
151 International Organization for Standardization.
- 152 ISO 9806 *Solar energy — Solar thermal collectors — Test methods*. (2025). [Standard].
153 International Organization for Standardization.
- 154 Ohnewein, P., Tschopp, D., Hausner, R., & Doll, W. (2020). *Dynamic Collector Array Test
(D-CAT). Final report FFG project 848766 - MeQuSo. Development of methods for quality
155 assessment of large-scale solar thermal plants under real operating conditions*. AEE INTEC.
156 <https://doi.org/10.5281/zenodo.7615252>
- 158 Tschopp, D., Ohnewein, P., Feierl, L., & Hamilton-Jones, M. (2024). *Digital tools for solar
159 thermal plant monitoring. A handbook for plant operators and associated stakeholders.
160 Version 1.0 (june 2024)*. DIH Süd. <https://doi.org/10.5281/zenodo.12523699>
- 161 Tschopp, D., Ohnewein, P., Hamilton-Jones, M., Zauner, P., Feierl, L., Moser, M., Zellinger,
162 M., Kloibhofer, C., Koren, M., Mehnert, S., Duret, A., Jobard, X., Pauleta, S., Giovannetti,
163 F., & Schiebler, B. (2024). SunPeek open-source software for ISO 24194 performance
164 assessment and monitoring of large-scale solar thermal plants. *International Sustainable
165 Energy Conference - Proceedings, 1*. <https://doi.org/10.52825/isec.v1i.1248>
- 166 Tschopp, D., Ohnewein, P., Mehnert, S., & Emberger, L. (Eds.). (2025). *Guide to ISO
167 24194:2022 Power Check - procedure for checking the power performance of solar thermal
168 collector fields* [Report RB2 from IEA SHC Task 68]. <https://doi.org/10.5281/zenodo.16954914>
- 170 Tschopp, D., Ohnewein, P., Stelzer, R., Feierl, L., Hamilton-Jones, M., Moser, M., & Holter, C.
171 (2023). One year of high-precision operational data including measurement uncertainties
172 from a large-scale solar thermal collector array with flat plate collectors, located in Graz,
173 Austria. *Data in Brief, 48*, 109224. <https://doi.org/10.1016/j.dib.2023.109224>
- 174 Tschopp, D., Tian, Z., Berberich, M., Fan, J., Perers, B., & Furbo, S. (2020). Large-scale
175 solar thermal systems in leading countries: A review and comparative study of Denmark,
176 China, Germany and Austria. *Applied Energy, 270*, 114997. <https://doi.org/10.1016/j.apenergy.2020.114997>