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CHALLENGES AND LESSONS LEARNED FROM LONG-TERM MONITORING OF SWISS SHIP PLANTS

Summary

Long-term monitoring (up to 12 years) of six Swiss Solar Heat for Industrial Processes (SHIP) plants, as well as the solar thermal system at Geneva University Hospital, shows that robust solar process heat delivery is achievable, but strongly dependent on system integration, maintainable hydraulics, and monitoring/data ownership. Low and medium-temperature water(-glycol) thermal systems demonstrate stable operation and high availability, while medium-temperature thermal-oil/steam concepts face higher operational burden (oil leaks, inert gas management) and longer downtimes. Several discontinuities in the operation of the seven SHIP plants were driven by continuous repairability and supply-chain constraints rather than by collector ageing. A combined workflow of monitoring-based KPIs (with a MATLAB script) and dynamic simulation (pytrnsys/TRNSYS) supports root-cause diagnosis and retrofit/design screening, with dynamic simulations applied selectively to systems requiring detailed modelling to reproduce existing problems and evaluate potential solutions.

Keywords: solar process heat, SHIP, monitoring, reliability, integration, TRNSYS, pytrnsys

Field of application for the findings: industrial heat, large-scale solar thermal system design and O&M

Addressed audience: planners, plant owners/operators, EPC/integrators, collector manufacturers, policy makers

1. Introduction

Solar Heat for Industrial Processes (SHIP) can contribute to decarbonising industrial heat demand across a broad temperature range. In practice, however, the perceived technical risk remains high because performance and availability depend on system integration, operation, and maintainability rather than on collector efficiency alone. This extended abstract summarises lessons learned from a multi-year monitoring (up to 12 years) of seven different solar thermal plants -most of them SHIP systems-, focusing on recurrent challenges, successful implementation patterns, and technology-dependent robustness.

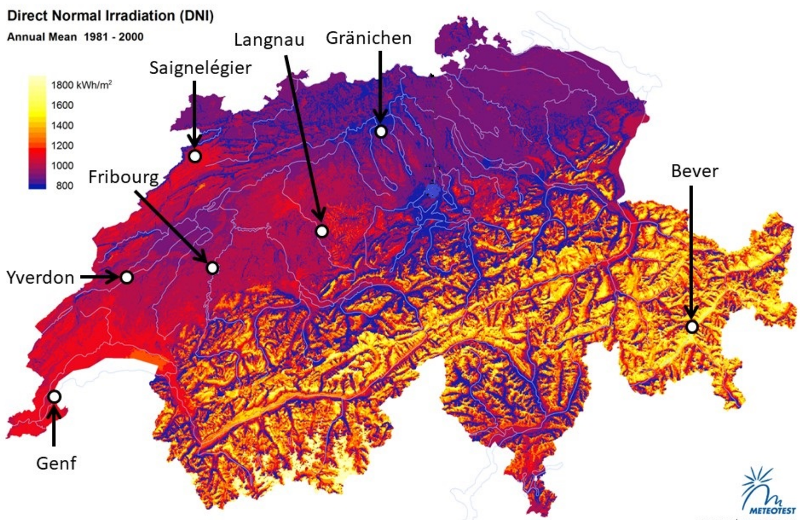

Fig. 1: Location of the seven Swiss solar thermal systems, illustrated on a direct normal irradiance map courtesy of Meteotest.

Tab. 1: Overview of the evaluated Swiss solar thermal plants. CIP: Clean-In-Place; Tcol: Operational temperature of the solar thermal collector; PTC: parabolic trough collector; VFPC: vacuum flat plate collector; VTC: vacuum tube collector; HTF: heat transfer fluid.

Plant (Loc.)	Sector; Process	Tcol [°C]	Collector, Area	HTF	Operation period
Emmi (Saignelégier)	Dairy; CIP and production heat	110	PTC, 627 m^2	Water–glycol mixture	2012–Today
Cremo (Fribourg)	Dairy; CIP and production heat	120 / 160	PTC, 581 m^2	Water	2014–Not available
Lesa (Bever)	Dairy; CIP and production heat	190	PTC, 115 m^2	Thermal oil	2011–2018
Colas (Yverdon)	Road construction; bitumen process heat	90 / 160	VFPC, 184 m^2	Thermal oil	2014–2022
Emmi (Langnau)	Dairy; CIP and production heat	120	VFPC, 214 m^2	Water–glycol mixture	2022–Today[a]
Zehnder (Gränichen)	Manufacturer; space heating and varnish bath preheating.	90	VTC, 360 m^2	Water–glycol mixture	2012–Today[b]
HUG (Geneva)	Hospital; Sterilisation and DHW	105 / 140	VTC, 360 m^2	Thermal oil	2018–Today[c]

[a] Plant was temporarily dismantled in Sep. 2023 and put back in operation in Aug 2024.
[b] Production at the site is planned to cease from 2026 onwards; the plant will be rented, and the future tenant's use remains unclear.
[c] The system is highly prone to malfunctions and has been largely non-operational for extended periods. Hardly any steam production. Last time in operation: May 2025.

2. Methodology

Seven Swiss solar thermal plants delivering process heat are evaluated using a methodology combining long-term monitoring, on-site assessment, and operator feedback. First, plant-specific time series of irradiance, temperatures, flow rates, and heat-metered energy are consolidated across the available monitoring years. Data-quality and plausibility screening is applied to identify missing signals, out-of-range values, inconsistent flow–ΔT pairs, and deviations between heat-meter readings and calculated energy with the help of temperatures, flow rates and irradiation if available. The plant operators provide measurement data (usually in minute-by-minute resolution) for this purpose, which is then evaluated using a Matlab routine. In addition to temperatures and mass flows, this data can also includes data from weather stations, valve positions and aggregated energy values.

Performance is then quantified using KPIs such as useful heat yield, specific yield (e.g., per aperture area), collector-field efficiency, and operational availability. For long-term comparisons, quasi-stationary time windows (e.g., short sequences around midday under similar boundary conditions) are used to perform like-for-like efficiency checks between selected years.

In parallel, site visits are conducted where feasible to document system condition, hydraulic integration and control implementation, maintenance actions, and any major modifications. Interviews with operators and maintenance staff complement the monitoring analysis and help evaluate irregularities in the monitoring data.

Finally, for selected plants, dynamic system simulations in *pytrnsys* (based on TRNSYS) are conducted using measured weather and demand boundary conditions to explain performance gaps and to assess potential control or integration enhancements (e.g., storage temperature strategy, heat-exchanger fouling and redimensioning or recooler control logic) before costly retrofit decisions are made.

3. Results and Conclusions

While it is true that the number of systems experiencing operational problems outweighs those performing reliably —of the seven thermal plants examined, at least two have shut down and one operates only partially— these systems represent pioneering projects in medium-temperature solar thermal applications implemented under demanding industrial boundary conditions. Some of the challenges encountered, therefore, reflect the innovative and exploratory character of these systems and do not call into question the general technical viability of solar thermal energy for industrial process heat.

The main findings and observations, as well as the current status of the solar thermal plants, are listed in the following table.

Tab. 2: Summary of main findings and status by plant. (Cremo (Fribourg) is excluded as no data is available).

Plant	Main findings / observations	Status
Emmi (Saignelégier)	Seasonal availability limited in winter period due to snow loads in PTC; HTF leakages in primary loop and software-related downtime reported; some visible ageing effects (soiling/corrosion) without compromising performance.	Operating with a mean high availability of around 95 % and energy yield 220 - 370 kWh/m^2.y.
Lesa (Bever)	Medium-temperature thermal-oil operation with repeated leakage events (hoses/fittings) and extended outages. High operational burden and corrective maintenance effort.	Operation discontinued due too high corrective maintenance costs. *Replaced* with PV.
Colas (Yverdon)	Often unable to reach needed temperature level; air in circuits / hydraulic issues leading to low effective yields; limited repairability due to collector availability (collector production discontinued).	Operation discontinued due to high maintenance costs and no spare parts (collectors) available.
Emmi (Langnau)	Plant temporarily dismantled due to installation errors, later recommissioned; separate responsibilities between solar field and different subsystems (waste heat recovery and plant heat generation) resulting in a suboptimal integration of the solar system; soiling of the heat reducing heat transfer capacity.	Operating with availability of around 80 % but only 50% of expected yield, resulting in 210 - 370 kWh/m^2·y due to non-optimal integration.
Zehnder (Gränichen)	Most reliable system among the analysed plants, based on VTC technology and water-glycol mixture as HTF, showing the highest operational availability and achieving an energy yield exceeding initial expectations.	Uncertain future operation. High availability (> 95 %) and high energy yield 460 - 490 kWh/m^2·y until 2025.
HUG (Geneva)	Recurrent HTF leaks led to costly maintenance, together with monitoring outages requiring temporary disconnections during repairs; complexity of the thermal oil operation and nitrogen-related issues in the solar field were reported; repair works resulted in $\sim$ 40% of VTC being permanently disconnected.	Intermittent / suspended operation. Almost no steam production. Reduced collector area. Low availability (20 %) and low energy yield (160 kWh/m^2·y).

The comparative evaluation of the monitored plants highlights a series of recurrent technical, operational, and integration-related challenges that largely explain differences in performance and operational status. The main findings can be summarised as follows:

- **Reliability strongly depends on fundamental system design choices.** Plants operating with water or water–glycol mixtures generally demonstrated higher robustness, lower maintenance requirements, and more stable long-term availability. In contrast, systems using thermal oil as the HTF experienced increased operational complexity, and higher corrective maintenance. In some cases this higher operational cost rendered solar system operation economically unviable, leading to temporary disconnections or even plant dismantling.
- **Thermo-hydraulic integration and system design.** Poor hydraulic integration of the solar system into the whole generation system, or not consideration of operational constraints led to reduced energy yields despite technically functional solar system. Systems performed best when the solar installation was treated as an integral part of the overall heat generation system rather than as an independent add-on. Designs must consider real physical operational conditions, including temperatures, pressures and flow rates.
- **Dynamic simulation is essential not only for diagnosis or optimisation, but also for integration design.** Transient simulations capture hourly variations in boundary conditions, including temperatures and flow rates, enabling the adequate integration of the solar system considering the real constraints, the assessment of operational changes, and root-cause analysis of performance deviations.
- **Responsibility model definition.** Clearly defined operational responsibilities, coordinated system management in parallel to harmonised integration of all subsystems proved essential for long-term reliable operation. Clear ownership and responsibility models are particularly important for industrial process heat applications.

Despite the shortcomings of several demonstrations, the observed failure mechanisms are now better understood. Lessons learned indicate that reliable solar process heat systems can be achieved through: robust design choices, system-level integration according to boundary conditions, clearly defined responsibilities and the use of dynamic simulation tools in different project phases. Applying these insights is expected to improve the reliability, performance, and stakeholder confidence in future solar heat for industrial processes (SHIP) installations.