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Correction Factors for Modelling Start-up of Process Heat Plants

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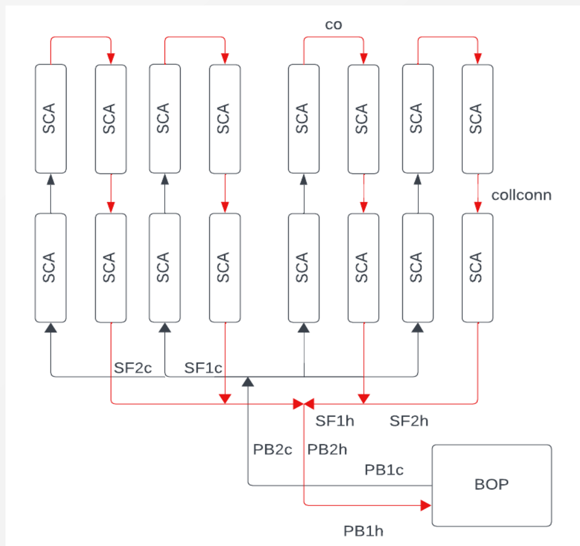
Main idea

Early-stage projects rely heavily on annual simulation models to inform decision-making processes, underscoring the critical need for accurate solar plant energy yield predictions. To address this, a methodology has been developed to enhance the precision of heat production estimates in annual **steady-state modelling** by integrating **dynamic effects** by introducing a **heat-up factor**.

Reference solar heat plant



- Reflective area of 13,848 m^2
- Nominal power of 1.5 MW
- Parabolic trough collector
- Each SCA contains 10 collectors
- Aperture wide 5.77 m
- SCA length 150 m
- Peak optical efficiency 0.75
- Receiver PTR70 (diameter 66 mm)

Weather data

- 12 days from the available ASI data obtained at the DLR solar tower facility in Jülich, Germany.
- Spatially inhomogeneous DNI information, with 30 seconds temporal resolution and 23x23 m special resolution
- Days variability classification

Categories	ΔDNI_{avg}	ΔDNI_{std}	ΔDNI_{max}
HDNILV	2 – 21	1 – 34	3.6 - 137
Clouds	40 – 114	36.6 – 118	137 - 424

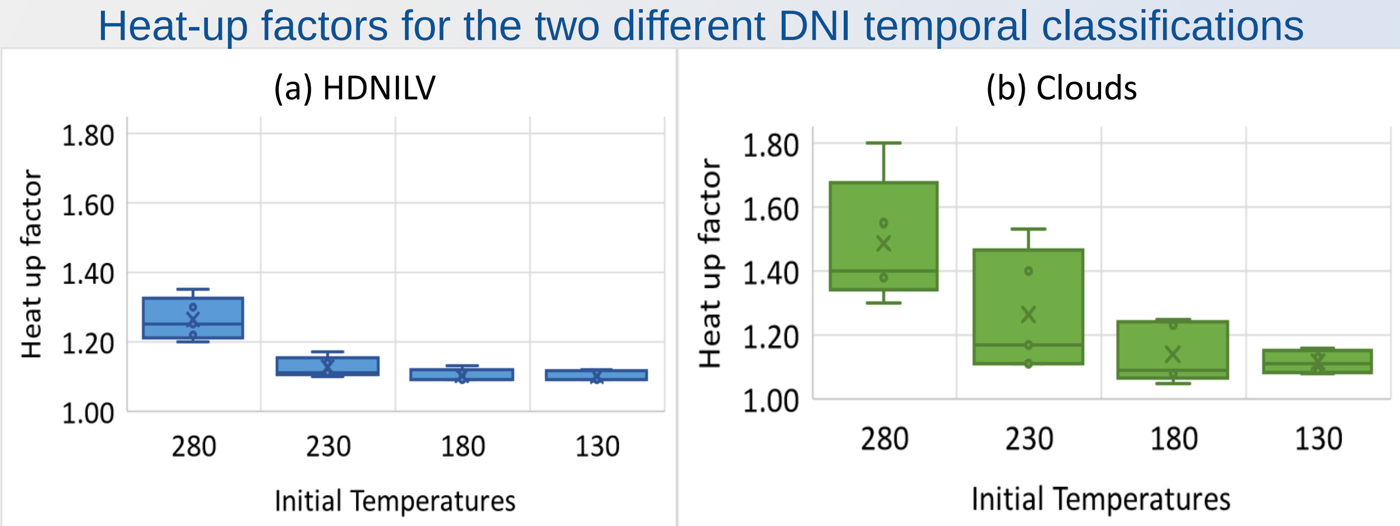
YACOP quasi-dynamic model

Python based on the SolarPACES Guideline for bankable STE Yield Assessment. The solar field has **four distinct modes**: operation, temperature hold, heat up and cool down, and forced defocus. Start-up is always in recirculation. During **start-up**, the **thermal inertia** of the solar field plays an important role. Therefore, in the **heat-up mode**, a quasi-dynamic approach is implemented to calculate the **mean temperature** of the solar field. This approach considers the HTF mass of the loops and the headers of the solar field (m_{tot}), and the mass of the steel in the piping m_s .The **heat-up factor f_{hu}**, which accounts for the dynamic effects of the start-up, is introduced in this equation. The required **start-up energy** is calculated considering the start-up begins when the temperature gradient is higher to zero and ends when the setpoint is achieved. This energy describes the amount of energy needed to bring the solar field from the initial temperature to the set outlet temperature, based on the thermal losses and the current irradiation. This quasi-dynamic approach is then compared with the energy calculated from a simulation using a **dynamic simulation tool.**

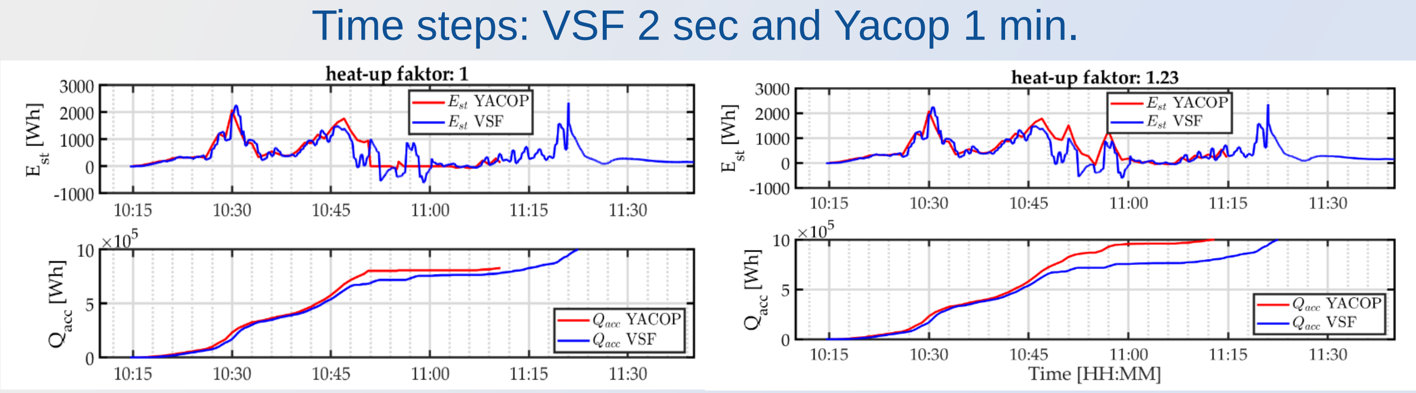
$$T_{mean,t} = T_{mean,t-1} + \frac{\Delta t}{(Cp \cdot m_{tot} + Cp_s m_s) \cdot f_{hu}} \cdot (Q_{abs,t} - Q_{loss,rec,t} - Q_{loss,pipe,})$$

Heat-up factor

Heat-up factors for the two different DNI temporal classifications



Time steps: VSF 2 sec and Yacop 1 min.



Lower $E_{start-up}$ in YACOP. With the f_{hu} $E_{start-up}$ is equal.

VSF dynamic model

- Mass flow distribution depends on the pressure loss in each piping element.
- Spatially variant irradiance can be modelled.
- Control of the temperature gradient during the start-up at 5 K/min by adjusting the mass flow
- Defocusing by the control system when the outlet temperatures are too high
- The solar field is recirculated until 280 ºC.
- Control and clouds are modelled in VSF and have an influence on the start-up behavior of the solar field.
- The energy required to bring the solar field up to the set temperature can be calculated using the dynamic model.
- Differences between the two models can be calculated and then used in YACOP.

Main findings

- The f_{hu} corrects energy available for the start-up and thus slows down the heat-up in the quasi-dynamic model.
- With low DNI and clouds not accounting, f_{hu} can overestimated the energy production due to controller-induced limitation of temperature gradients and partial defocusing events especially under cloudy conditions
- The f_{hu} for HDNILV can be estimated with: $f_{hu} = 1 + \frac{E_{yacop}}{E_{vsf}}$
- For Clouds the f_{hu} is higher than the calculated for HDNILV.

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