Key Performance Indicators for PVT Systems

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What is the purpose of key performance indicators ?

- **Compare the performance of a system (or component)**

  → with its rated or optimal performance

  → with the performance of another system (or component)

  (Can be applied to measurement data or simulation results)

- **Useful both in design and operation phases**

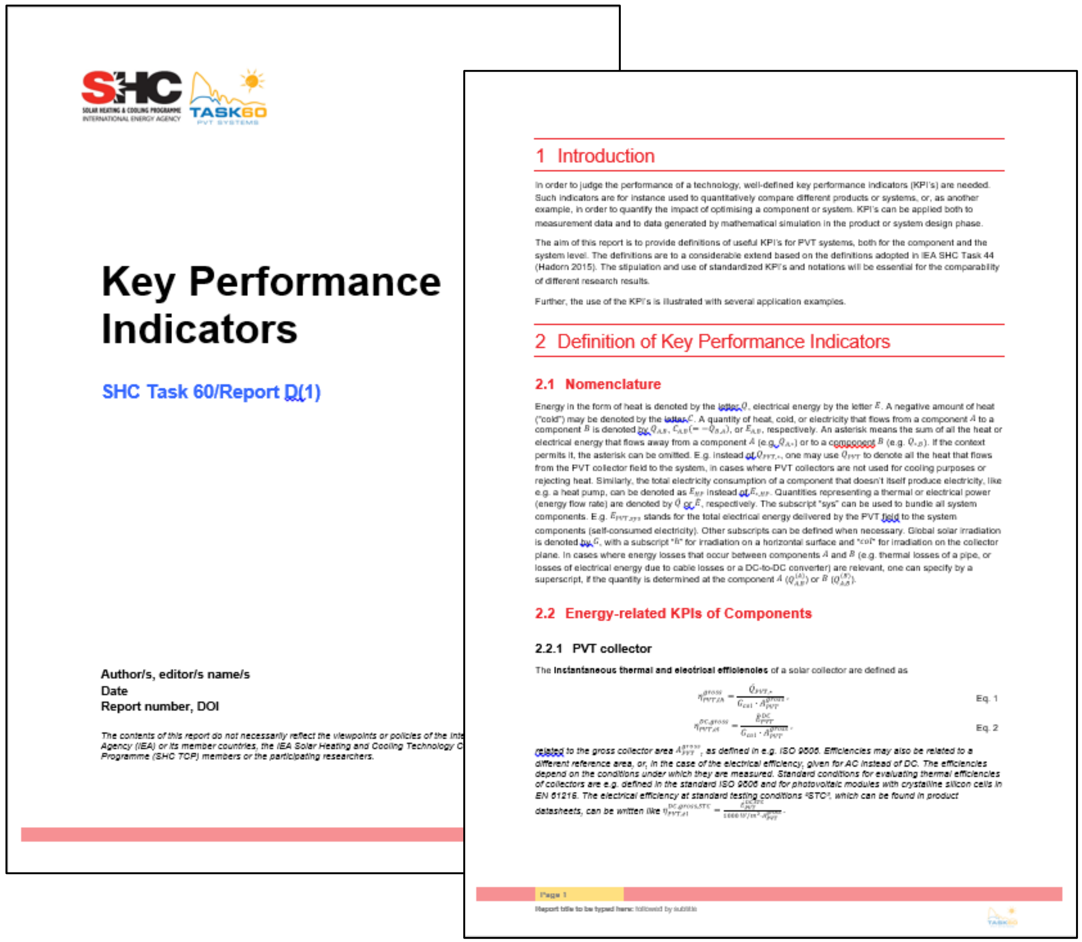
Various Key Performance Indicators

- **Three categories of KPIs**
  - Energy
  - Economics
  - Environmental impact

- **Which ones are used in a certain case depends on the purpose**

- **Goal → Everybody uses the same definitions**

KPI report draft



Key Performance Indicators

SHC Task 60/Report D(1)

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1 Introduction

In order to judge the performance of a technology, well-defined key performance indicators (KPI's) are needed. Such indicators are for instance used to quantitatively compare different products or systems, or, as another example, in order to quantify the impact of optimising a component or system. KPI's can be applied both to measurement data and to data generated by mathematical simulation in the product or system design phase.

The aim of this report is to provide definitions of useful KPI's for PVT systems, both for the component and the system level. The definitions are to a considerable extend based on the definitions adopted in IEA SHC Task 44 (Hadorn 2015). The stipulation and use of standardized KPI's and notations will be essential for the comparability of different research results.

Further, the use of the KPI's is illustrated with several application examples.

2 Definition of Key Performance Indicators

2.1 Nomenclature

Energy in the form of heat is denoted by the letter Q, electrical energy by the letter E. A negative amount of heat ("cold") may be denoted by the letter C. A quantity of heat, cold, or electricity that flows from a component A to a component B is denoted by $Q_{A,B}$, $C_{A,B}(=-Q_{B,A})$, or $E_{A,B}$, respectively. An asterisk means the sum of all the heat or electrical energy that flows away from a component A (e.g. $Q_{A,*}$) or to a component B (e.g. $Q_{*,B}$). If the context permits it, the asterisk can be omitted. E.g. instead of $Q_{PVT,*}$, one may use Q_{PVT} to denote all the heat that flows from the PVT collector field to the system, in cases where PVT collectors are not used for cooling purposes or rejecting heat. Similarly, the total electricity consumption of a component that doesn't itself produce electricity, like e.g. a heat pump, can be denoted as E_{HP} instead of $E_{*,HP}$. Quantities representing a thermal or electrical power (energy flow rate) are denoted by $\dot{Q}$ or $\dot{E}$, respectively. The subscript "sys" can be used to bundle all system components. E.g. $E_{PVT,sys}$ stands for the total electrical energy delivered by the PVT field to the system components (self-consumed electricity). Other subscripts can be defined when necessary. Global solar irradiation is denoted by G, with a subscript "h" for irradiation on a horizontal surface and "col" for irradiation on the collector plane. In cases where energy losses that occur between components A and B (e.g. thermal losses of a pipe, or losses of electrical energy due to cable losses or a DC-to-DC converter) are relevant, one can specify by a superscript, if the quantity is determined at the component A ($Q_{A,B}^{(A)}$) or B ($Q_{A,B}^{(B)}$).

2.2 Energy-related KPIs of Components

2.2.1 PVT collector

The **instantaneous thermal and electrical efficiencies** of a solar collector are defined as

$$\eta_{PVT,th}^{gross} = \frac{\dot{Q}_{PVT,*}}{G_{col} \cdot A_{PVT}^{gross}}, \quad \text{Eq. 1}$$

$$\eta_{PVT,el}^{DC,gross} = \frac{\dot{E}_{PVT}^{DC}}{G_{col} \cdot A_{PVT}^{gross}}, \quad \text{Eq. 2}$$

related to the gross collector area A_{PVT}^{gross}, as defined in e.g. ISO 9806. Efficiencies may also be related to a different reference area, or, in the case of the electrical efficiency, given for AC instead of DC. The efficiencies depend on the conditions under which they are measured. Standard conditions for evaluating thermal efficiencies of collectors are e.g. defined in the standard ISO 9806 and for photovoltaic modules with crystalline silicon cells in EN 61215. The electrical efficiency at standard testing conditions "STC", which can be found in product datasheets, can be written like $\eta_{PVT,el}^{DC,gross,STC} = \frac{\dot{E}_{PVT}^{DC,STC}}{1000\,W/m^2 \cdot A_{PVT}^{gross}}$.

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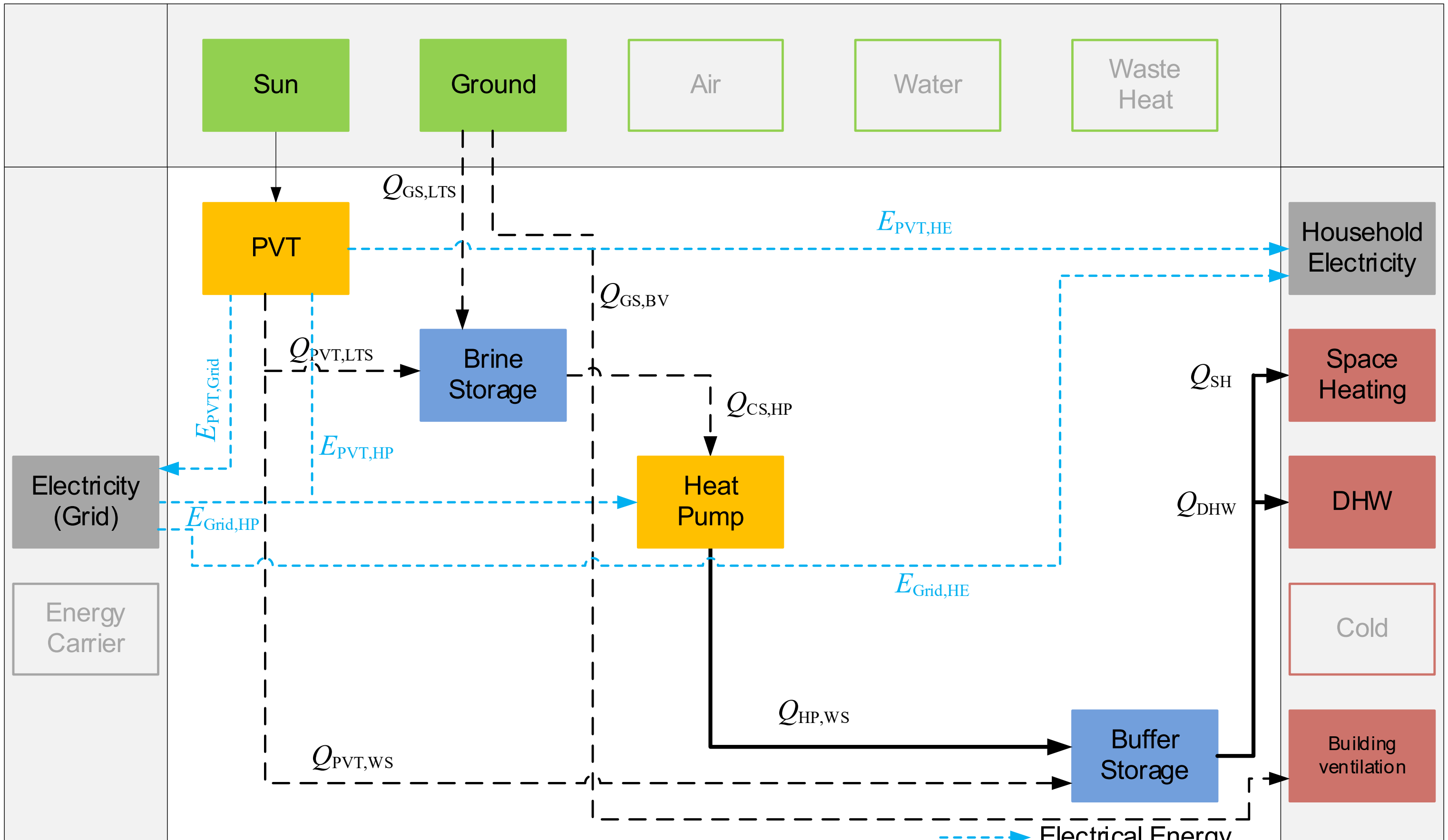
System square view and nomenclature



P&D Project Sotchà, building B, PVT+GSHP

Orig: Combined Solar Thermal and Ground Source Heat Pump System - Parallel: SGSHP-P

SHP/P

KPIs for Systems in Operation - Selection

Energy

- **Area-specific thermal yield**
- **Area-specific electrical yield AC**
- **Thermal and electrical utilisation ratio**
- **Solar thermal fraction (secondary)**
- **Solar electrical fraction**
- **Electrical self-consumption fraction**
- **Seasonal performance factor of system (for heat pump systems)**

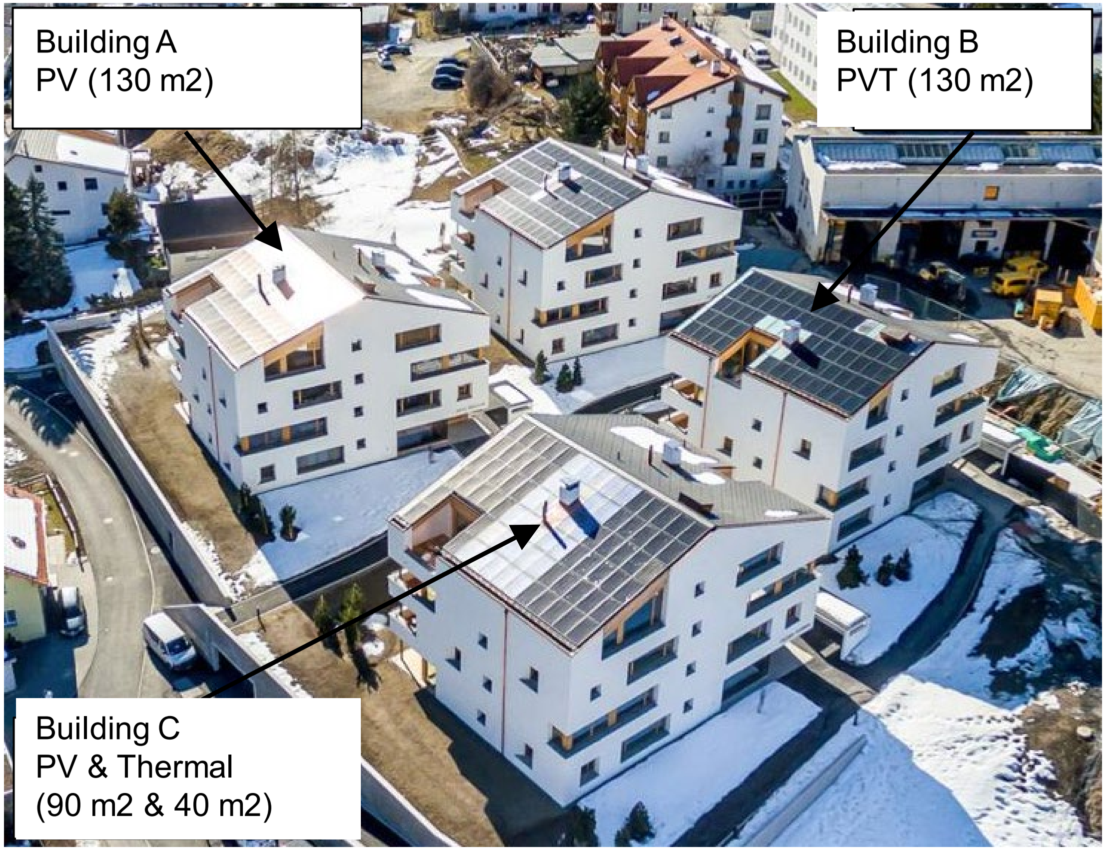
Economics

- **Cost per square meter collector area**
- **Levelized cost of heat and electricity**

Environment

- **Avoided global warming impact**
- **Avoided primary energy depletion**

Example Sotchà - System



- **Each system with a 30 kW heat pump and 5 x 170 m boreholes**
- **Solar heat in buildings B and C for borehole regeneration DHW and SH**

Utilization ratio

- **Solar thermal / electrical / energy utilization ratio ω**

	Individual component	Complete solar installation
Thermal	$\omega_{PVT/T,th}^{gross} = \frac{Q_{PVT/T}}{G_{col} \cdot A_{PVT/T}^{gross}}$	$\omega_{sol,th}^{gross} = \frac{Q_{PVT} + Q_T}{G_{col} \cdot (A_{PVT}^{gross} + A_{PV}^{gross} + A_T^{gross})}$
Electrical	$\omega_{PVT/PV,el}^{AC,gross} = \frac{E_{PVT/PV}^{AC}}{G_{col} \cdot A_{PVT/PV}^{gross}}$	$\omega_{sol,el}^{AC,gross} = \frac{E_{PVT}^{AC} + E_{PV}^{AC}}{G_{col} \cdot (A_{PVT}^{gross} + A_{PV}^{gross} + A_T^{gross})}$
Energetic	$\omega_{PVT,en}^{AC,gross} = \frac{Q_{PVT} + E_{PVT}^{AC}}{G_{col} \cdot A_{PVT}^{gross}}$	$\omega_{sol,en}^{AC,gross} = \frac{Q_{PVT} + Q_T + E_{PVT}^{AC} + E_{PV}^{AC}}{G_{col} \cdot (A_{PVT}^{gross} + A_{PV}^{gross} + A_T^{gross})}$

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comparison of combinations of PV / T / PVT

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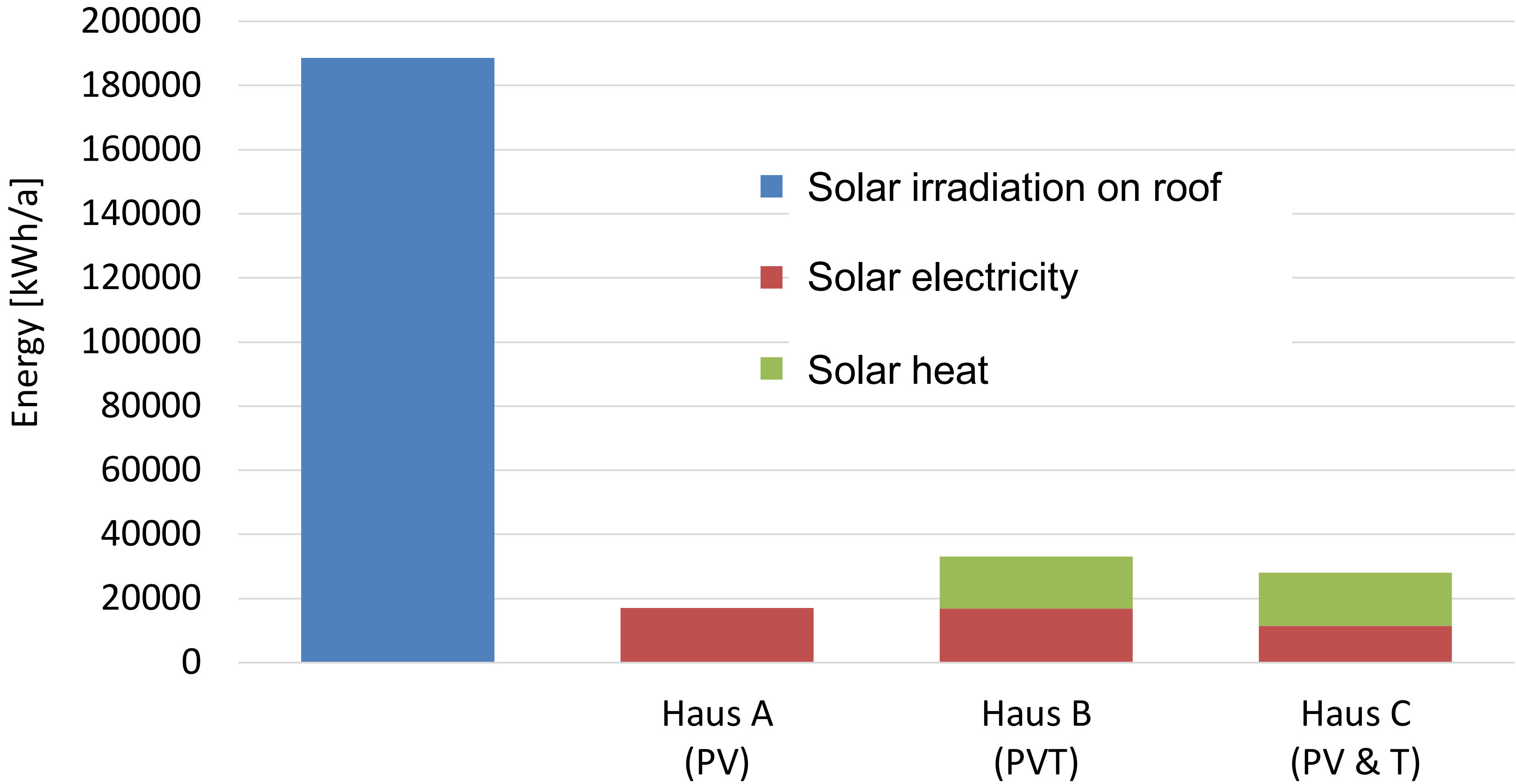
comparison of combinations of PV / T / PVT

- **Weighted average operating temperature («Quality of heat»)**

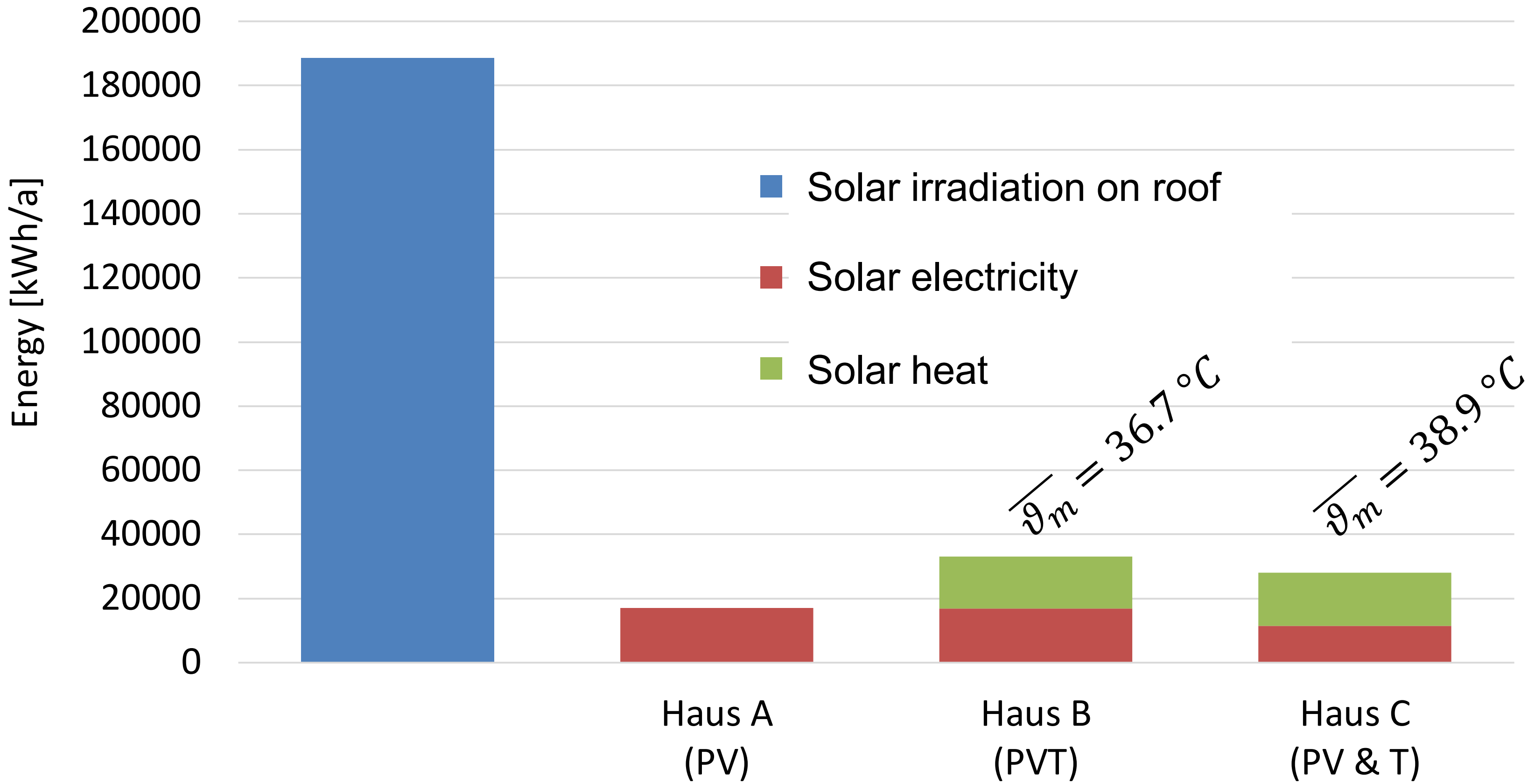
$$\overline{\vartheta_m} = \frac{\int d\,t\, \vartheta_m \cdot \dot{Q}_{PVT/T}}{\int d\,t\, \dot{Q}_{PVT/T}}$$

(ϑ_m = mean fluid temperature)

Example Sotchà – Solar yields and characteristic temperatures

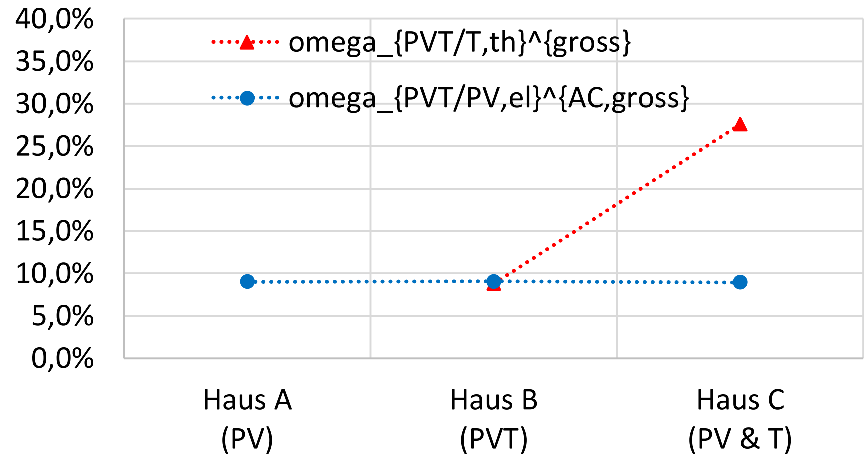


Example Sotchà – Solar yields and characteristic temperatures

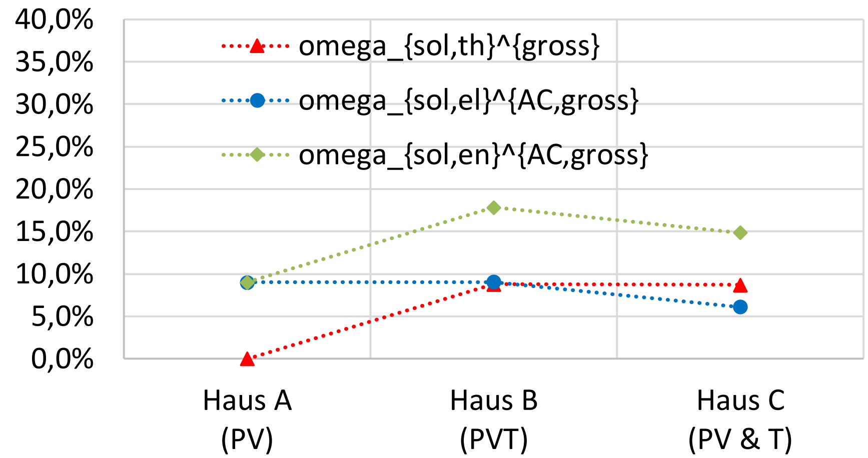


Example Sotchà – Solar utilization ratios

Component



Complete solar installation



Thank You

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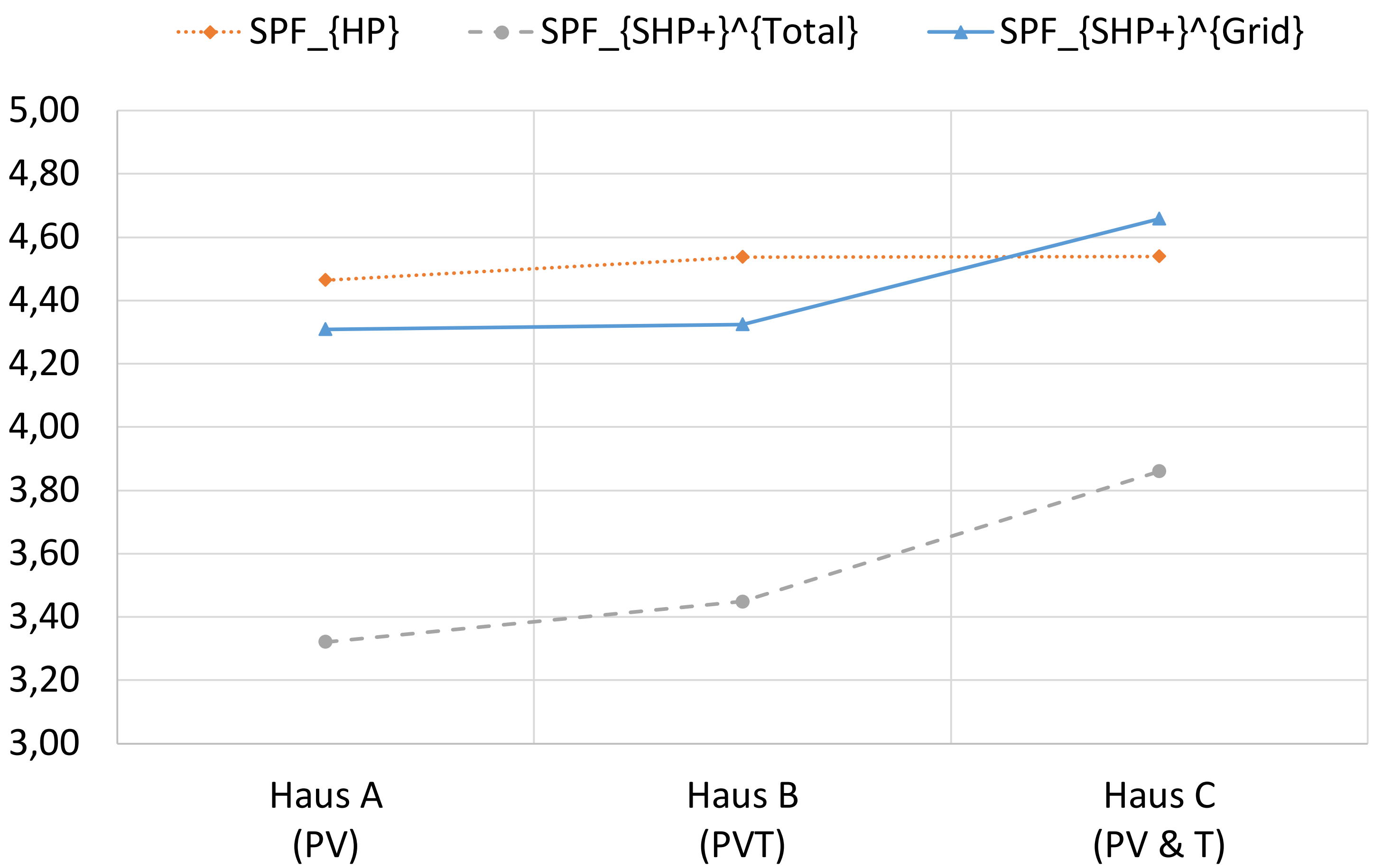
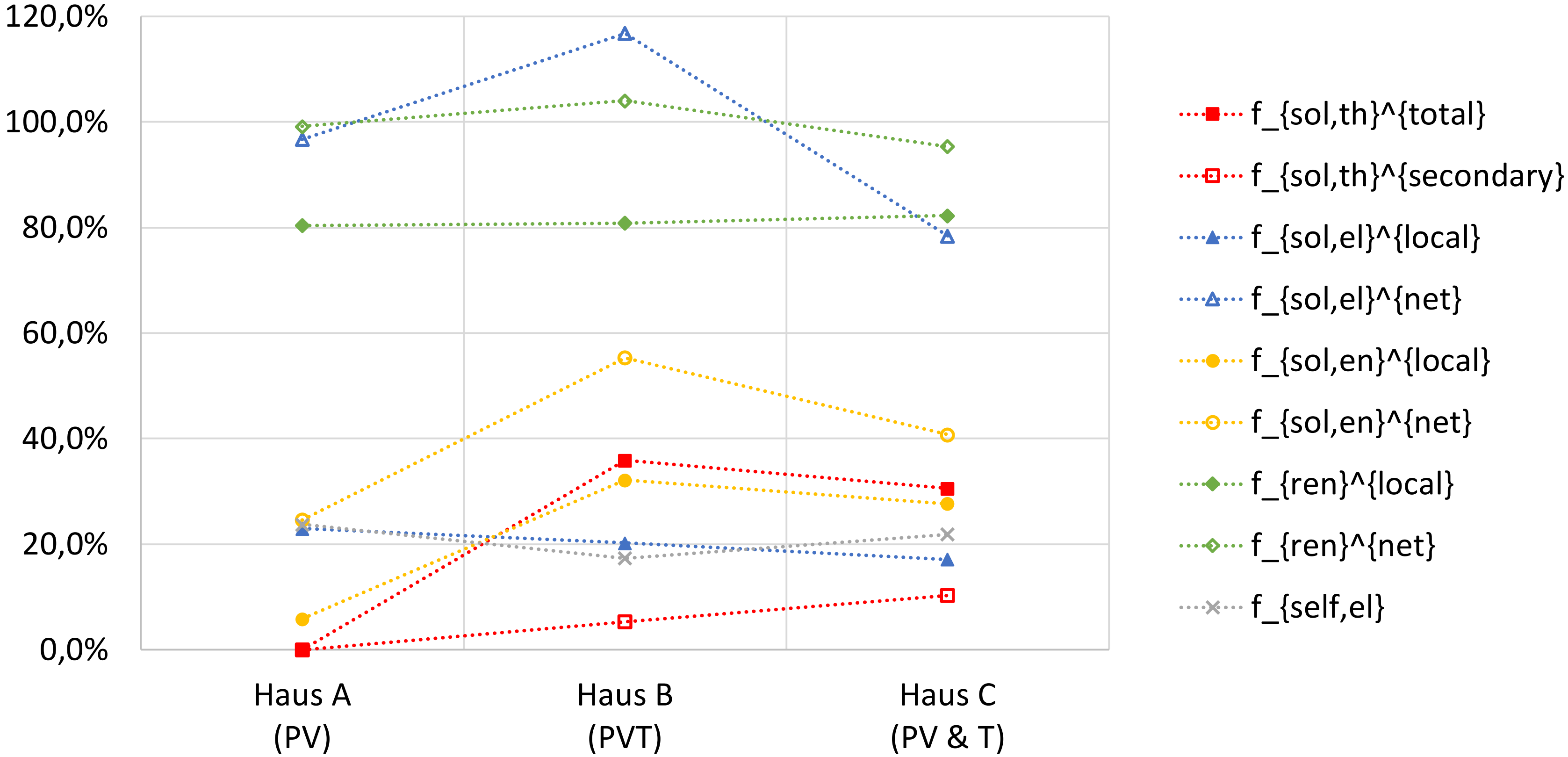
Example Sotchà – Performance Factors of Heat Pump and System



Example Sotchà – Further KPI's on System Level



→ Precise comparison would need system simulations with equal demands, and analysis of long-term evolution of ground temperatures

→ Systems controls not optimized