Current Work on Performance Evaluation of Solar Thermal and Heat Pump Hybrid Systems within IEA SHC Task 44 / HPP Annex 38 and IEE QAiST Projects

Ivan Malenković
Austrian Institute of Technology, Energy Department
Giefinggasse 2, 1210 Vienna, Austria
Tel.: +43 50 550 - 6350, Fax: +43 50 550 - 6679
ivan.malenkovic@ait.ac.at / www.ait.ac.at

Introduction

A large number of integrated heat pump and solar thermal systems (SHP), mostly for heating and hot water preparation for residential applications, have recently been brought to the market in many European countries (1). Although standardised testing and rating procedures, as well as different quality labels are available for both single technologies, the combined systems are lacking both. Besides, the components optimised for an integrated operation i.e. the solar collector and the heat pump unit often do not meet the quality standards needed in the respective labelling scheme. This is mainly due to the fact, that the current standards are not designed to cover many of the operation conditions, specific designs etc. which are found in combined systems. This fact can have a negative impact on the further development and marketing of solar and heat pump systems in the mid and long term. It is therefore very important for a sustainable development of this technology to include relevant operating conditions and specific features of the components into current standards and to consider developing new procedures for their performance evaluation.

Many different system configurations and specific design features are already available on the SHP market. To be able to cover most of these in future performance evaluation methods, a systematic approach is needed. Currently, two international projects are working on this topic – SHC Task 44 / HPP Annex 38 (2) within the International Energy Agency and the IEE QAiST Project (3).

Definition of performance figures

The first step towards defining a uniform and harmonised nomenclature for different performance figures was to analyse currently available standards for testing and rating of heat pumps, solar thermal collectors and their respective systems.

Review of the standards

Table 1 gives an overview of analysed standards and a short description of the performance figures defined within.

Regarding the performance figures for heat pumps, the following can be concluded:

Table 1: Overview of analysed standards for testing and rating of heat pump and solar thermal components and systems

Heat Pump Standards		
Standard	**PF**	**Definition**
EN 14511	COP	The COP is defined as the ratio of the heating output of the heat pump unit to the effective energy input to the unit for a steady state operating condition. Energy inputs and outputs are corrected by the pumping energy needed to overcome the pressure lossses on the heat exchangers inside the unit.
	EER	Same definition like the COP, used for cooling applications (useful energy is cooling).
EN 15879-1	COP / EER	Uses same definitions as EN 14511, applied on direct expansion heat pumps.
AHRI 320/325/330	COP	A ratio of the heating capacity, excluding supplementary resistance heat, to the power input for steady state operating conditions.
	EER	Same definition like the COP, used for cooling applications (useful energy is cooling).
ISO 13256-1	COP	Ratio of the net heating capacity to the effective power input of the equipment at steady state operating conditions. The power inputs and outputs are corrected in the same way as in EN 14511
	EER	Same definition like the COP, used for cooling applications (useful energy is cooling).
prEN 14825	SCOP	Ratio of the overal heating energy delivered over a one year time period to the total energy input to the system. It is a calculatory value obtained under certain assumptions regarding the heating load, climate, controls etc. The basis for the calculation are **unit** tests, e.g. according to EN 14511.
	SEER	Same as SCOP, but for cooling applications.
ASHRAE 116	HSPF	Ratio of the total heat delivered over the heating season (not exceeding 12 months) to the total energy input over the heating season. It is a calculatory value obtained under certain assumptions regarding the heating load, climate, controls etc. The basis for the calculation are **unit** tests.
	SEER	Ratio of the total heat removed during the normal period of usage for cooling (not exceeding 12 months) to the total energy input during the same period. Obtained same as the HSPF.
VDI 4650-2	SPF (β)	The ratio of the useful heat released in the course of one year over the electrical energy used to drive the compressor and the auxiliary drives. It is a calculatory figure based on the test results from EN14511. It does not take into account electricity consumption for e.g. ground water pump, heat pump off-mode etc.
EN 15316-4-2	SPF	The ratio of the overal energy output to the overal energy input (final energy) of the heat pump system for heating and DHW.

Solar Thermal Standards		
Standard	**PF**	**Definition**
EN 12975-2	η	The Collector Thermal Efficiency is the ratio of the energy removed by the heat transfer fluid over a specified time period, to the product of a defined collector area (gross, absorber or aperture) and the solar irradiation incident on the collector for the same period, under steady or non-steady state conditions (according to ISO 9488).
ISO 9806	η	Same as EN 12975
ASHRAE 93	ηg	Collector Thermal Efficiency, defined as the actual collected useful energy to the solar energy intercepted by the collector gross area.
EN 12976, EN12977	fsol	Solar Fraction is the energy supplied by the solar part of a system divided by the total system load. The solar part of a system and any associated losses need to be specified, otherwise the solar fraction is not uniquely defined (according to ISO 9488).
	fsav	Fractional Energy Savings is the reduction of purchased energy achieved by the use of a solar heating system, calculated as 1 - [(auxiliary energy used by solar heating system)/(energy used by conventional heating system)] in which both systems are assumed to use the same kind of conventional energy to supply the user with the same heat quantity giving the same thermal comfort over a specified time period (according to ISO 9488).
	Thermal performance	The thermal performance is defined as a set of performance indicators. For solar systems without auxiliary energy sources, these are: The heat delivered by the solar heating system, QL; the solar fraction, fsol; the parasitic energy, Qpar, if any is available. For systems including auxiliary energy sources: The net auxiliary energy demand, Qaux, net; the fractional energy savings, fsav; The parasitic energy, Qpar.
ISO 9459	Thermal performance	Comparable definition to EN 12976 and EN 12977
EN 15316-4-3		Same nomenclature as in EN 12977.

COP – Coefficient of Performance: In all reviewed standards used for the performance of the heat pump unit under steady-state[1] operating conditions. However, the consideration of the liquid circulation pumps' influence on the energy inputs and outputs differ among the standards. It is generally used for heating applications only.
EER – Energy Efficiency Ratio: The same like COP, but used for cooling applications in most of the European standards. In many US standards defined as Btu/hr of cooling energy per W electricity consumption.
SCOP – Seasonal Coefficient of Performance: Used only in one standard to express the calculated heating efficiency of the heat pump unit only for an assumed climate, building load etc.
SEER – Seasonal Energy Efficiency Ratio: Same like SCOP, but for cooling applications.
SPF – Seasonal Performance Factor: In the VDI guideline used to express roughly the same efficiency as the SCOP – not taking into account the whole system but only the heat pump unit with some auxiliary energy. In European standards used as a figure to express the efficiency of the overall system, including all auxiliary energy inputs.

For solar thermal, four main performance indicators can be found:

[1] Defrosting process for air-source heat pump represents a deviation from the common definition of steady-state conditions but will not be discussed here further.

For η – *Collector Thermal Efficiency*, f_{sol} – *Solar Fraction* and f_{sav} – *Fractional Energy Savings*, the same definition was found in all analysed standards, according to Table 1.
Thermal Performance: In the reviewed standards, no system performance figure similar to SPF for the heat pump systems was found. However, from the delivered heat and the parasitic energy, as defined in the reviewed standards, the efficiency of the system could be calculated in the same manner as for the heat pump systems.

Systematic approach of performance figures definition
As described above, a multitude of different definitions and denominations of performance indicators for heat pumps and heat pump systems can be found in the literature. It is therefore often very difficult or even impossible to compare different products or installations – even within one product group (e.g. ground source compressor heat pumps with hydronic heat distribution systems). In many publications the system boundary used for energy balancing is not provided – a COP for example might or might not include the auxiliary energy consumption, it can even stand for the annual or seasonal efficiency of the whole system.

In order to have more transparency when reporting test results, a unified nomenclature for different heat pump applications can be advantageous. Based on the analysis of standards, other related publications and a similar approach proposed for thermally driven heat pumps (4), a systematic approach for the nomenclature of performance figures for SHP systems was proposed, Fig. 1.

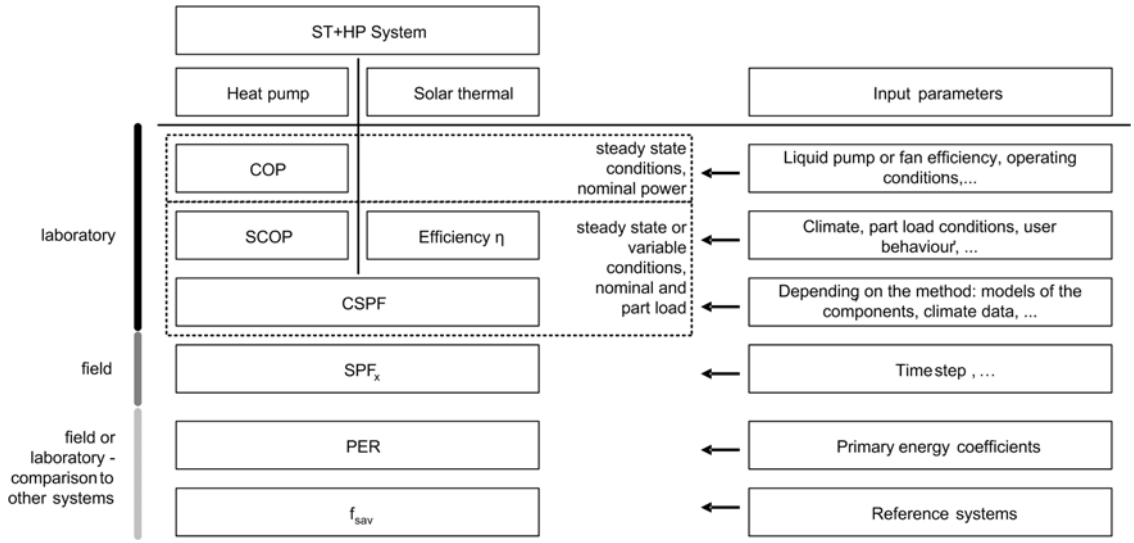

Figure 1: Systematic approach to the nomenclature of main performance figures

The definition of performance figures is based on four main criteria:
- Component (heat pump or solar) or combined system;
- Steady state or transient boundary conditions;
- Real or laboratory conditions;
- Purpose – comparison of performance within the same technology or comparison to other technologies.

As the definitions of the performance figures of single technologies are already available to a large extent, the current work within the projects concentrates on the definition of the system performance figures, SPF in the first place.

Boundary conditions and SPF

For the definition of different performance figures, which can be applied to different system configurations, it is helpful to define a "generic system". Ideally, this system should include all possible configurations and energy flows of the known system designs. Particular configurations can then ideally be obtained by removing the non-existing components and energy flows. A proposal for a generic system for solar and heat pump combination is given in Figure 2, presented in an extended "square view" format proposed by Frank et al. (5).

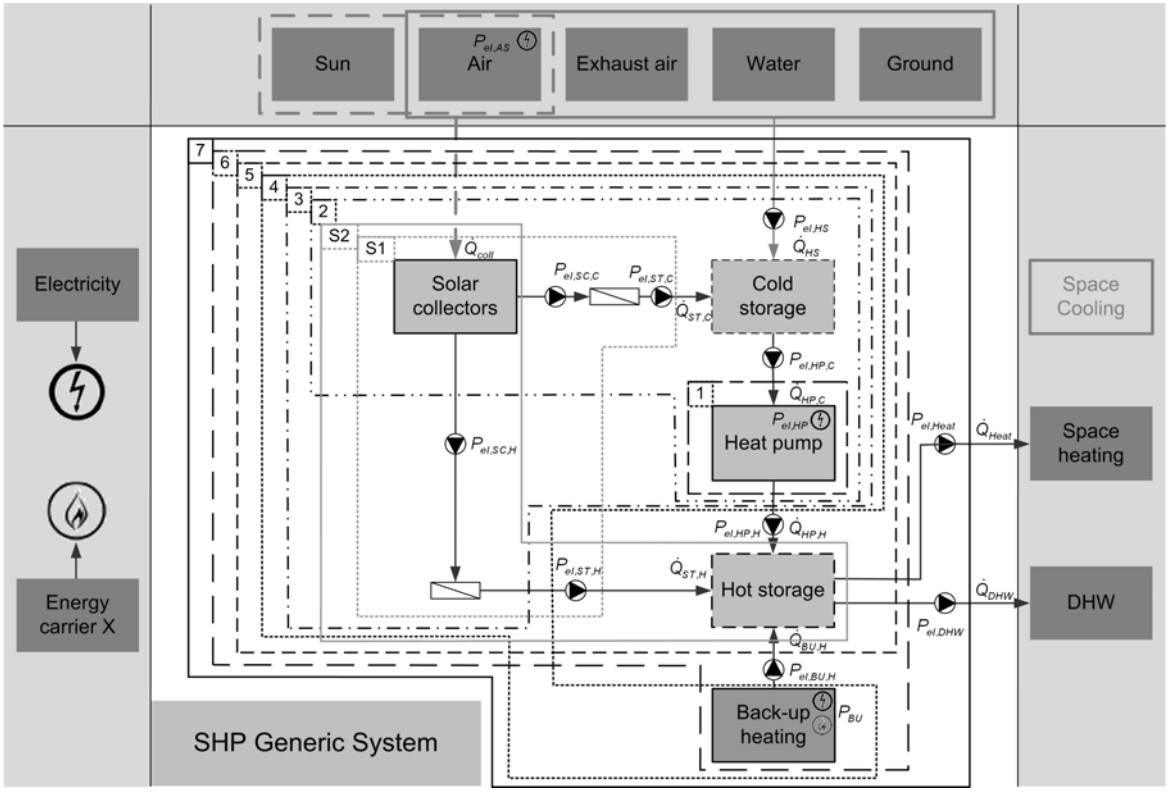

Figure 2: SHP generic system presented as a "square view" diagram with system boundaries for defined performance figures

When choosing system boundaries for SPFs, the following goals were pursued:

- Possibility of a quick analysis of the system – easy identification of optimisation potential by comparing different SPF levels;
- Applicability to different system configurations;
- Harmonisation of definitions and comparability of performance figures with other heat pump and solar thermal applications;
- Usability for various purposes: scientific analysis, testing and validation, labelling etc.

For each system boundary, at least one performance figure is defined:

System boundary 1 - $SPF_{H,HP}$: This system boundary includes the heat pump unit with the main energy input to the compressor, as well as a number of energy inputs for supporting

systems like controls, crankcase heaters etc. This boundary is similar to the one currently used for the definition of the COP and SCOP in a number of standards, excluding liquid pump corrections.
System boundary 2 – $SPF_{H,HP+HS}$: Here, the heat pump with all its heat sources is taken into account. With this figure, the efficiency of the whole heat pump unit including the source can be evaluated.
System boundary 3 and 4 – $SPF_{H,bSt-BU}$ and $SPF_{H,bSt}$: These two figures take into account the heat delivered to the hot storage – without and with the heat input from the back-up unit, respectively.
System boundary 5 and 6 – $SPF_{H,SHP-BU}$ and $SPF_{H,SHP}$: Analogue to the previous two figures, the system boundaries stretch however to the hot storage and include the electricity consumption of the liquid pumps for the storage charging.
System boundary 7 – SPF_H: This figure gives the overall efficiency of the whole system, including the consumptions of the heat distribution system.
System boundaries S1 and S2 – $SPF_{H,ST,tot}$ and $SPF_{H,ST,H}$: With system boundary S1, the efficiency of the whole solar thermal system, excluding storage losses, can be calculated. Besides, solar contribution to the system can be evaluated in form of e.g. solar yield. System boundary S2 corresponds to the system defined in various standards given in Table 1. The efficiency or thermal performance on the high temperature side of the solar system can be evaluated.

As mentioned above, one of the goals when developing system boundaries was the comparability of SHP systems with other heat pump and solar thermal applications. Table 2 gives an overview of comparable performance figures for heat pumps from three ongoing international projects, which aim at setting standardised procedures for the calculation of system performance. As all projects are still ongoing, further development and harmonisation can be expected.

Table 2: Corresponding SPFs for different heat pump applications, as defined in relevant projects

IEE SEPEMO (6)	IEE QAiST / IEA SHC T44,HPP A38	IEA HPP Annex 34 (4)
SPF_{H1}	$SPF_{H,HP}$	SPF Level 2a
SPF_{H2}	$SPF_{H,bSt-BU}$	SPF Level 2b
SPF_{H3}	$SPF_{H,bSt}$	-
SPF_{H4}	SPF_{H}	SPF Level 1

Conclusions and outlook

Following an analysis of the relevant standards and previous work done on systematic development of performance figures for different applications of heat pumps, a proposal for performance figures for SHP systems was elaborated. This proposal will be further discussed within the groups. An important input to the applicability of this approach should come from the implementation of the figures to the systems monitored by the projects' participants.

Further work will concentrate on:

- Validation of the definitions through implementation on available field trial data;
- Extension of performance figures to cooling applications;

- Discussion on the primary energy ratio, possible definition of primary energy factors;
- Definition on the reference systems for different applications / regions for the calculation of f_{sav};
- Definition of procedures for the calculation of the RES utilisation;
- Procedure for the calculation of system performance in different operation modes, e.g. DHW preparation and heating;
- Definition of further performance figures, which might help in analysis and transparent reporting on the performance of SHP systems, e.g. solar yield, high and low temperature solar fractions, back-up energy fraction etc.;
- Definition of performance of multienergetic systems in terms energy consumption.

Nomenclature

CSPF	calculatory SPF	coll	collector	HP	heat pump
Q, P	power in W	DHW	domestic hot water	HS	heat source
Subscripts		el	electrical	S	source
bSt	bevor storage	FC	free cooling	SC	solar circuit
BU	back-up unit	H	high temperature	ST	solar thermal
C	low temperature	coll	collector	St	storage

Acknowledgements

The work presented in the paper was conducted within the QAiST Project (Contract No. IEE/08/593/SI2.529236) funded by the European Commission through the Intelligent Energy Europe Programme and within the national contribution to the IEA SHC Task 44 / HPP Annex 38 "Solar and Heat Pump" Project, funded by the Austrian Ministry of Transportation, Innovation and Technology and managed by the Austrian Research Promotion Agency.

The author would further like to thank all partners from both projects, who made a valuable contribution to work presented.

References

(1) Sparber, W., Vajen, K., Fedrizzi, R., D'Antoni, M., 2011, Overview on solar thermal plus heat pump systems and review of monitoring results. Proc. of the ISES Solar World Congress 2011, Kassel, Germany
(2) Hadorn, J.C., 2011, Solar and heat pump systems – Status of IEA SHC Task 44 & HPP Annex 38. Proc. of the ISES Solar World Congress 2011, Kassel, Germany
(3) ESTIF, 2011, www.qaist.org
(4) Malenković, I., Melograno, P., Kühn, A., Schossig, P., 2011, Current work within HPP Annex 34 on performance evaluation and testing methods of thermally driven heat pumps for heating and cooling. Proc. of the 10th IEA Heat Pump Conference 2011, Tokyo, Japan
(5) Frank, E., Haller, M., Herkel, S., Ruschenberg, J., 2010, Systematic classification of combined solar thermal and heat pump systems. Proc. of the International Conference on Solar Heating, Cooling and Buildings 2010, Graz, Austria
(6) Zottl, A., Nordman, R., Miara, M., Huber, H., 2011, System boundaries for SPF-calculation. Proc. of the 10th IEA Heat Pump Conference 2011, Tokyo, Japan