

# Adapted Monitoring Procedure for the thermal side of New Generation Solar Heating & Cooling Systems

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# 1 Executive Summary

Activity 1 of Subtask C is dedicated to prepare the testing and the monitoring methodology to measure the performances of the selected demo projects for NG H&C-Systems.

A valorization of past and ongoing results from IEA SHC Task 38, 44 and 48 was done on how to properly monitor these systems, in order to achieve reliable indicators and significant information on the performance as well as primary energy savings and reduction of greenhouse gases, plus finally also on economic criteria.

In Task 48 Subtask C4 the most important measurement points and the way to collect the measurement data for demo projects in the solar cooling framework have been defined or updated from previous works and are very precisely described in the Final report “Measurement and Verification Procedures” (Deliverable M-C4.3 Task IEA SHC 48) [1] ., Even if the quantity of considered energy flows in Task 53 is significantly enlarged, the practical procedure is valid for a central part of the plants considered in Task 53, and the most important specific references will be given in the following chapters. New issues due to the superseded norm EN 1434-1 (heat meters) are considered.

Specific measurement issues for the photovoltaic systems are discussed in Deliverable D–C1.1 “Monitoring Procedure for Field Test & Demo Systems with Compression Heat Pumps Driven by Photovoltaic Solar Energy” by Universidad Miguel Hernández de Elche (P. V. Quiles and F. A. Valero), where this type of technology is evaluated by means of an example for a HVAC system in the range of 3 kW.

For the calculation of Key Performance indicators from the monitored data, the approach used in the more recent Subtask B7 of Task 48 was chosen. The tool developed in this framework “Collection of criteria to quantify the quality and cost competitiveness for solar cooling systems” (D. Neyer et al.), which enables technical and economic performance assessment for large solar cooling systems, has been adapted and extended for the use in this Subtask.

## Nomenclature

Subscripts			
C	Cooling	NRE	Non-renewable
DC	District Cooling	el	Electrical
SH	Space heating	equ	Equivalent
DH	District Heating	sys	Overall system (C & DHW & SH)
DHW	Domestic hot water		
Nomenclature			
PER <sub>NRE</sub>	Primary Energy Ratio (-)	ACM	Absorption chiller,
fsav <sub>NRE</sub>	Fractional savings (-)	AHP	Absorption heat pump
SPF <sub>equ</sub>	Seasonal Performance Factor (-)	VCC	Vapour compression chiller
SEER	Seasonal Energy Efficient Ratio	CT	Cooling tower
ε	Primary Energy Factor (kWh/kWh <sub>PE</sub> )	HS	Hot storage
		CS	Cold storage
		BS	Battery storage
		EC	Energy Carrier

## 2 Data collection (Monitoring procedure) for solar thermal heating and cooling systems

### 2.1 Previous works

In the activities of previous working groups which dealt with solar thermal cooling systems (IEA Tasks 38 and 48) as well as IEA Task 44 “Solar and Heat Pump Systems” different but similar approaches for the visualization and the appropriate evaluation of solar (thermal) systems, as shown in Figure 1 and Figure 2 were used:

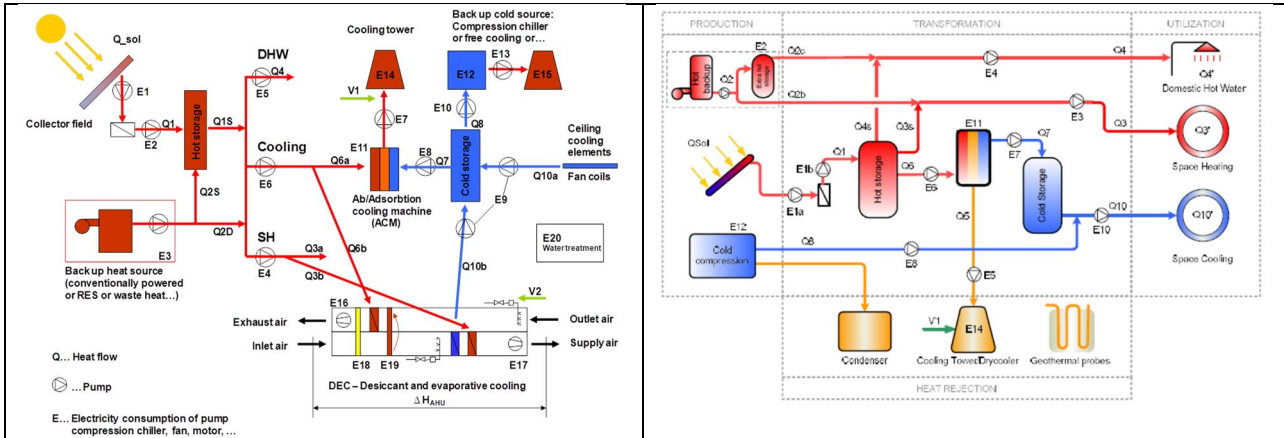


Figure 1: left: Reference solar heating and cooling system including the single energy fluxes (SHC Max System) and a conventional HC system [Task IEA SCHC 38, Napolitano et al. 2010]; right: System representation of a “collective” solar air-conditioning/heating/ domestic hotwater system used in MeGaPICS and IEA Task 48 C4 [Boudéhen et al. 2013]

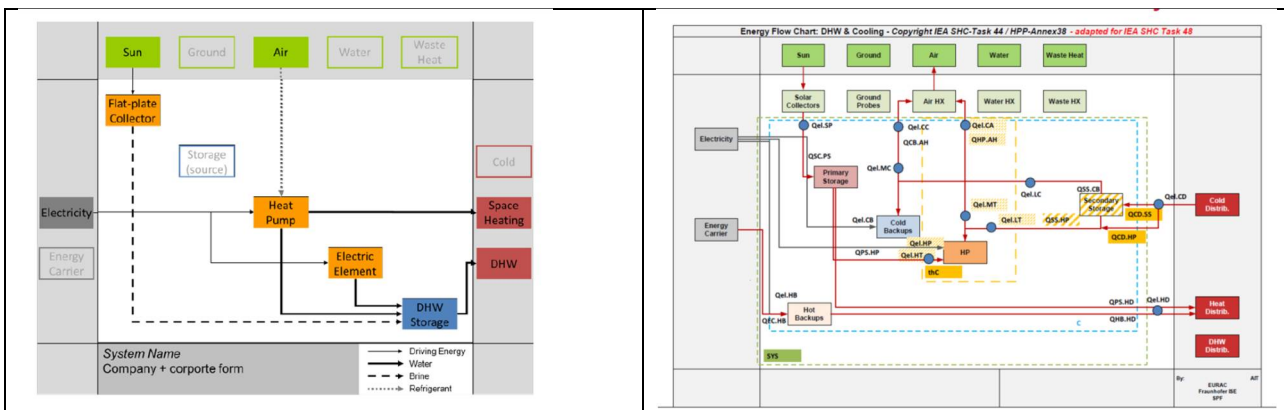


Figure 2 left: example of visualisation of a Solar Heat Pump System [Task IEA 44- HPP-Annex 38, Malencovic et al. 2012]; right: Energy Flow Chart for a complex solar + HP system [Task IEA 48 B7, Neyer et al et al. 2015]

In the present Subtask, the last concept (Task 48 B7) with a sink/source-approach is used and further developed for calculation (by means of an appropriate calculation tool) of Key Performance Figures. On the other hand, for the data acquisition and monitoring (except for the PV-plant) the final document of Task 48 C4 will be the starting point, where all requirements for data collection of solar cooling systems are precisely investigated and described.

## 2.2 Thermal Cooling and Heating – recent work in Task 48 B7

Also, if the first practical step of the validation of a technical system is the positioning of measurement devices, it's important to stabilize before the content of information and analyses to achieve by monitoring. For this reason, the main components, energy fluxes and interesting performance figures, as well as the “clustering” of the heating & cooling system in system boundaries, should be presented first.

As described in Deliverable B7 – Collection of criteria to quantify the quality and cost competitiveness for solar cooling systems – march 2015 (by UIBK, EURAC, CSIRO, ASiC), a lot of work has done in Task 48 to facilitate the valorization and comparison of solar thermal cooling systems in terms of performance, primary energy savings and costs. The starting point for prospective monitoring procedures which include solar electric heating and cooling systems was to survey available valorization models (Task 38, Task 44, SEPEMO).

The operated method will be here shortly described because it is the base for the evaluation tool used in Task 53.

### 2.2.1 General structure of the analysis, starting from IEA SHC Task 48 B7

For more detailed analyses and better distinctiveness, the source-sink-approach from Task 44 was employed and adapted to solar thermal cooling requirements.

**Table 1: Reduced source-sink table with nomenclature of the heat and electricity fluxes (Task 48 D-B7)**

Source	Sink	Air	Solar Collectors	Air Heat Exchanger	Primary Storage	Rejection Storage	Cold Backups	HP	Solar Pump	Secondary Pump	Fans	Distribution Pump	Heat Rej Pump
		Ar	SC	AH	PS	RS	CB	HP	P1	P2	FN	PD	PR
Electricity	EI						EI.CB	EI.HP	EI.P1	EI.P2	EI.FN	EI.PD	EI.PR
Sun	Su		Su.SC										
Solar Collectors	SC				SC.PS			SC.HP					
Air Heat Exchanger	AH	AH.Ar											
Primary Storage	PS							PS.HP					
Rejection Storage	RS			RS.AH									
Cold Backups	CB					CB.RS							
HP	HP					HP.RS							
Cold Distribution	CD						CD.CB	CD.HP					

The Energy Flow Chart is automatically generated in the excel worksheet, starting from the source-sink table: all system elements in the table are shown on a diagram, with a consistent color representation.

This Flow Chart is used in Task 48 (Figure 3), defining five different system boundaries:

- ❖ Overall system (including cooling, domestic hot water and space heating) – *green line*
- ❖ Cooling (overall performance of the cooling system) – *light blue line*
- ❖ Thermal cooling (performance of the ab/adsorption chiller including HotBackUp) – *yellow line*
- ❖ Space heating (including backup)
- ❖ Domestic hot water (including backup)

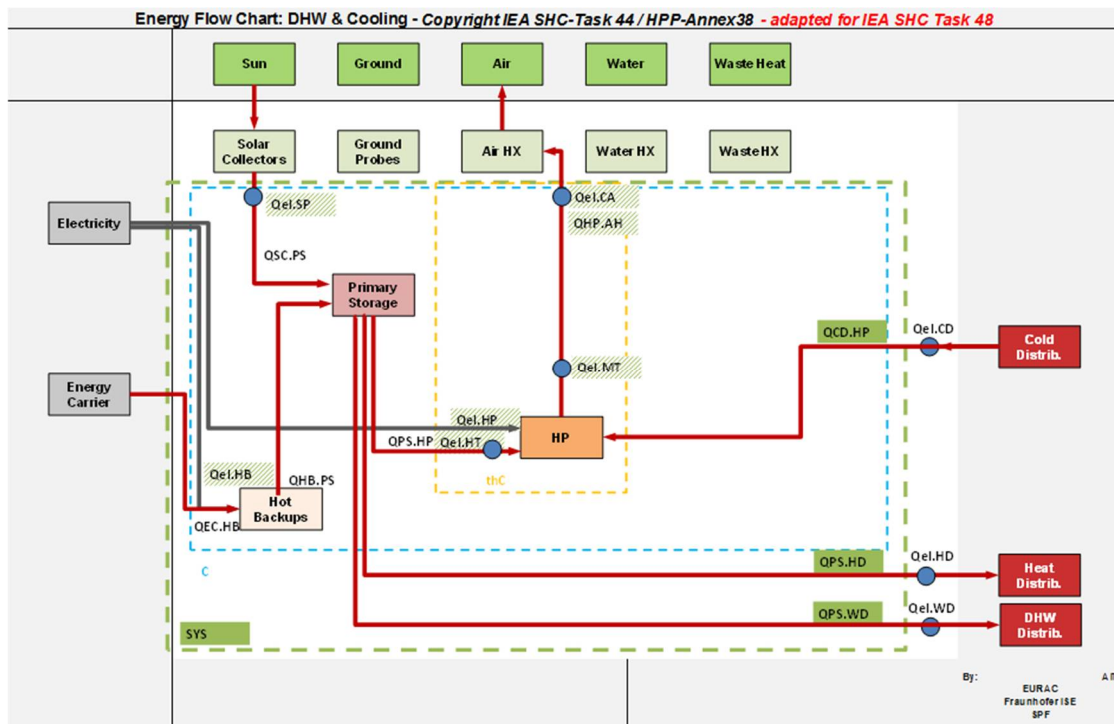


Figure 3: System boundaries and selected energy flows for calculation of e.g. the Seasonal Performance Factor of a SHC-system (Task 48 D-B7)

**Energy flows** are partitioned in

- Distributed energy (Cold distribution, Heat distribution, DHW distribution)
- Main components and sources (Solar collector, Hot BackUp, Primary/Secondary Storage etc.)
- Losses at storages

Percentage usage of **Solar Energy** and of the **Hot Back Up** for Primary storage or directly for Cold production/Heat pump, Heat and DHW distribution are defined.

Further partitions of energy fluxes of **Primary Storage**, **Secondary (Cold-)Storage** and **Cold distribution** have to be calculated.

## 2.2.2 Calculation of Performance Indicators in IEA SHC Task 48 B7

On component level, the main performance figures are defined and intended as follows [6]:

- COP (Coefficient Of Performance) unit effectiveness at nominal rated conditions under steady-state operation, for heating applications only
- EER (Energy Efficiency Ratio) same like COP but for cooling applications
- SCOP (Seasonal Coefficient Of Performance) assessment of the unit performance under defined, time dependent rated conditions over a certain period of time
- SEER (Seasonal Energy Efficiency Ratio) same like SCOP but for cooling applications
- SPF (Seasonal Performance Factor) for the assessment of the (sub-)system performance including all auxiliary components under defined, time dependent rating conditions over a certain period of time (including standby conditions).

For evaluating the energetic and environmental performance of the system, following performance indicators are defined:

- Seasonal Performance Factor (SPF<sub>sys</sub>)
- Primary Energy Ratio (PER)
- Fractional savings (f<sub>sav</sub>)
- Equivalent Seasonal Performance Factor (SPF<sub>equ</sub>)

### 2.2.2.1 Seasonal Performance Factor SPF

The SPF indicates the relation between useful energy and final energy and is defined for thermal and electrical inputs separately (necessary for thermal cooling processes where we have both types of input):

The *thermal SPF* (relevant for thermal COOLING) is defined

$$\frac{\text{useful cold}}{\text{heat from solar collectors for cooling} + \text{heat from hot back up for cooling}}$$

The *electrical SPF* :

$$\frac{\text{useful cold}}{\text{electricity consumption}}$$

The electrical SPF is analyzed separately in Task 48 for the 5 different system boundaries Whole System, Cooling, Thermal Cooling, Heating and Domestic Hot Water.

### 2.2.2.2 Primary Energy Ratio (PER)

The PER is defined as the ratio of the useful energy output ( $\Sigma Q_{i,out}$ ) to the primary energy input ( $W_{el,i,in}$  and  $Q_{i,in}$  converted into Primary Energy) to the system boundary

$$PER_i = \frac{\Sigma Q_{i,out}}{\Sigma \left( \frac{W_{el,i,in}}{\varepsilon_{el}} + \frac{Q_{i,in}}{\varepsilon_{in}} \right)} \quad (51) \text{ D B7 Task 48}$$

The PER can be

- “overall” (i.e. comprising all types of Primary Energy) or “non-renewable only” (PER<sub>NRE</sub>) – in this framework always the last one is considered



- substituted with emission factors (e.g. expressed in kgCO<sub>2,eq</sub> per kWh energy) or energy price (e.g. expressed in monetary unit per kWh energy)

Agreed conversion factors ( $\varepsilon$ ) for Primary Energy and CO<sub>2</sub>-Emissions and values for efficiency factors for compression chillers, natural gas and pellets boilers ( $\eta$ ) were already stabilized in Task 38 and Task 48, and are updated for Task 53 [8].

### 2.2.2.3 Fractional savings ( $f_{sav}$ )

are calculated to compare the renewable SHC system with a reference (might also be another renewable system).

$$f_{sav.NRE.PER} = 1 - \frac{PER_{NRE.ref}}{PER_{NRE.i}} \quad (16) \text{ D B7 Task 48}$$

The formula is applicable for all subsystems in the stabilized boundaries.

### 2.2.2.4 Equivalent Seasonal Performance Factor ( $SPF_{equ}$ )

This indicator can be used to compare the investigated solar heating and cooling system with a reference vapour compression chiller or a reversible heat pump based on the electrical seasonal performance factors  $SPF_{el,i}$  and  $SPF_{ref}$  respectively.

The  $SPF_{equ}$  can be calculated following the unit conversion

$$\left[ \frac{kWh_{th}}{kWh_{el}} = \frac{\frac{kWh_{th}}{kWh_{prim}}}{\frac{kWh_{el}}{kWh_{prim}}} = \frac{PER_{NRE,i}}{\varepsilon_{el}} \right] \quad (71) \text{ D B7 Task 48}$$

$$SPF_{equ.sys} = \frac{PER_{NRE.sys}}{\varepsilon_{el}} \quad (76) \text{ D B7 Task 48}$$

Same  $SPF_{equ}$ 's indicates finally an equal primary demand of different systems.

### 3 Enlarged considerations for New Generation Solar Heating and Cooling Systems

The aim in this activity was to adapt the evaluation tool developed for Task 48 for the multitude of system configurations under the new heading of SHC. (A detailed description of the additional components considered in New Generation (NG) systems and of the new technical and economic assessment tool is given in the manual [9]).

So-called New Generation SHC-Systems embrace thermal and electrical Heating and Cooling if solar electricity or solar electricity and solar thermal energy production is included. For this reason, a wider range of components has to be taken into consideration.

Heating Sources may be a (reversible) heating pump or a boiler with fossil or renewable fuel), but also a CHP or an electrical heating element. The Cold Sources can be represented by a thermal or an electrical cooling device. Further electrical heating elements for SH & DHW are included.

Several heating and cooling sources can be chosen within the tool (**Erreur ! Source du renvoi introuvable.**). Any combination of these components is possible (bivalent/hybrid operation). Only exception is that just one solar thermal and one PV panel, as well as two heating- and cooling sources and two cooling towers are combined. For storage systems two sizes per storage class can be implemented. Within the calculation they are just considered separately for the economic cost determination. (A secondary hot water tank (for DHW) is assigned to the distribution part and therefore not listed here.

**Table 2: Components in NG Heating & Cooling Systems**

Solar thermal	SC	Flat plate collector Vacuum tube collector
Photovoltaic	PV	Photovoltaic (PV)
Heating	H1/H2	Natural gas boiler Pellets boiler Heat pump (HP) (reversible / non-reversible) Natural gas absorption heat pump (AHP) (reversible / non-reversible) CHP unit Condensing boiler District heating
Cooling	C1/C2	Air- or water-cooled vapor compression chiller (VCC)Single effect (SE) absorption chiller (ACM) Double effect (DE) ACM Adsorption chiller District cooling
Cooling tower	CT	
Storage	HS CS BS	Hot storage (HS) Cold storage (CS) Battery storage (BS)

The Maximum scheme for Electrical and Thermal Solar Heating and Cooling Systems was supplemented by new components, and it's now a little bit more complex. So also, the list of energy fluxes has been extended.

Figure 4 shows the new maximal scheme for NG SHC Systems. All possible sources, sinks and components and all corresponding energy flows are represented which could be necessary to be monitored, to calculate the technical key figures. Also, water consumption for direct evaporative cooling is included.

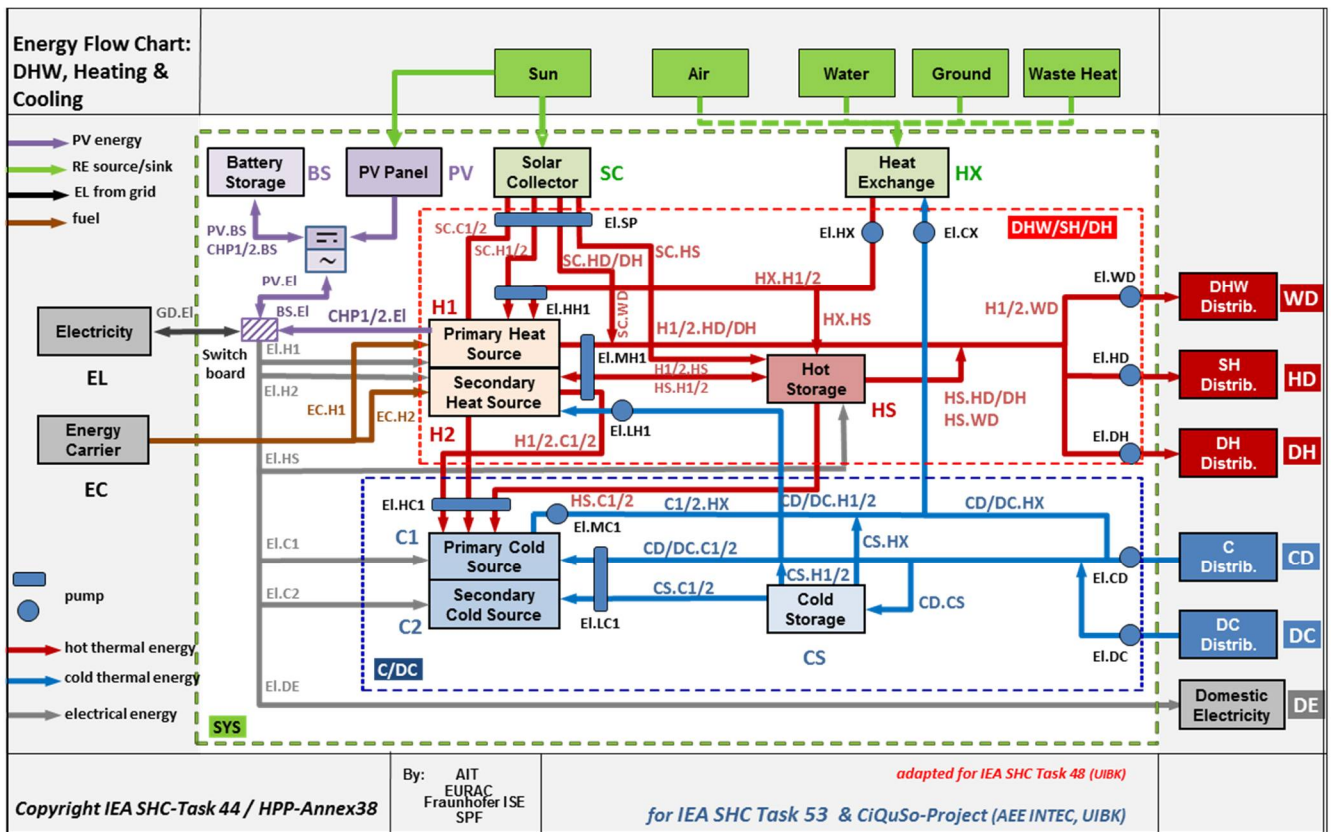


Figure 4: Maximal Scheme of energy flows in NG SHC-systems (including distribution)

Monitoring data to fill in the tool have always to be collected and elaborated in the context of the chosen system boundary (explained more in paragraph 4.1). Renewable sources / sinks (light green) are sun (Su), air, water, ground and waste heat. The last four usually are used with heat exchangers (HX). Solar energy can be converted by a solar thermal collector or a photovoltaic panel (PV). To run the whole plant electricity from the grid and energy carrier for the hot backup is necessary. Red/blue arrows refer to hot/cold thermal energy. Grey arrows mark electrical energy. The consumers are Domestic Hot Water (DHW or Water Distribution WD), Space Heating (SH), District Heating DH, Cooling Distribution (CD) and District Cooling (DC) as well as domestic electricity (DE).

For this multitude of components, also the number of energy flows to measure is correspondingly enlarged. The previous nomenclature as e.g. from Task 48 C4 is not more sufficient. A detailed description of all energy flows (summarized for bivalent options) can be found in Table 3.

Table 3: Nomenclature of all energy flows in the total system

Energy Carrier to Hot Backups	EC.H1/H2	Flow meter * calorific value
<b>Total Purchased Energy to System</b>	<b>EC.System</b>	
Sun to Solar Thermal Collectors	Su.SC	Radiation $E_{sol} * A_{Coll}$
Sun to Photovoltaic Collectors	Su.PV	Radiation $E_{sol} * A_{PV}$
<b>Total Renewable Energy to System</b>	<b>RES.System</b>	
Solar Collectors to Heat Source1/2	SC.H1/H2	% of SC (heat output SC)
Solar Collectors to Cold Source (ACM) 1/2	SC.C1/2	% of SC
Solar Collectors to Hot Storage	SC.HS	% of SC
Solar Collectors to District Heating	SC.DH	% of SC
Solar Collectors to Heat Distribution	SC.HD	% of SC
Solar Collectors to DHW Distribution	SC.WD	% of SC
Heat Exchanger to Primary/Secondary Heat Source (HP)	HX.H1/H2	Thermal energy meter
Heat Exchanger to Hot Storage	HX.HS	Thermal energy meter
<b>Total RE harvested to System</b>	<b>REH.System</b>	
Primary Heat Source to Prim./Second. Cold Source (ACM)	H1.C1/C2	Thermal energy meter
Primary Heat Source to Hot Storage	H1.HS	Thermal energy meter
Primary Heat Source to District Heating	H1.HDH	Thermal energy meter (consumer)
Primary Heat Source to Heat Distribution	H1.HD	Thermal energy meter (consumer)
Primary Heat Source to DHW Distribution	H1.WD	Thermal energy meter (consumer)
<b>Total Primary Heat Source to System</b>	<b>H1.System</b>	
<b>Total Secondary Heat Source to System</b> (as for H1)	<b>H2.System</b>	
Hot Storage to Primary/Secondary Heat Source (AHP)	HS.H1/H2	Thermal energy meter
Hot Storage to Primary/Secondary Cold Source (ACM)	HS.C1/C2	Thermal energy meter
Hot Storage to District Heating	HS.DH	Thermal energy meter (consumer)
Hot Storage to Heat Distribution	HS.HD	Thermal energy meter (consumer)
Hot Storage to DHW Distribution	HS.WD	Thermal energy meter (consumer)
<b>Total Hot Storage to System</b>	<b>HS.System</b>	
Primary Cold Source to Heat Exchanger	C1.HX	Thermal energy meter
Secondary Cold Source to Heat Exchanger	C2.HX	Thermal energy meter
<b>Total Cold Source to System</b>	<b>C.System</b>	
Cold Storage to Primary/Secondary Cold Source	CS.C1/C2	Thermal energy meter
Cold Storage to Primary/Secondary Heat Source (AHP)	CS.H1/H2	Thermal energy meter
Cold Storage to Heat Exchanger	CS.HX	Thermal energy meter
<b>Total Cold Storage to System</b>	<b>CS.System</b>	
District Cooling to Heat Exchanger (Freecooling)	DC.C1/C2	Thermal energy meter (consumer)
District Cooling to Primary/Secondary Cold Source	DC.C1/C2	Thermal energy meter (consumer)
District Cooling to Primary/Secondary Heat Source (AHP)	DC.C1/C2	Thermal energy meter (consumer)
District Cooling to Cold Storage	DC.CS	Thermal energy meter (consumer)
<b>Total District Cooling to System</b>	<b>DC.System</b>	
Cold Distribution to Heat Exchanger (Freecooling)	CD.HX	Thermal energy meter
Cold Distribution to Primary/Secondary Cold Source	CD.C1/C2	Thermal energy meter (consumer)
Cold Distribution to Prim./Second. Heat Source (AHP)	CD.H1/H2	Thermal energy meter (consumer)
Cold Distribution to Cold Storage	CD.CS	Thermal energy meter (consumer)
<b>Total Cold Distribution to System</b>	<b>CD.System</b>	
Photovoltaic to Primary/Secondary Heat Source	PV.H1/H2	% of PV (electricity meter output PV)
Photovoltaic to Hot Storage	PV.HS	% of PV
Photovoltaic to Primary/Secondary Cold Source	PV.C1/C2	% of PV
Photovoltaic to Battery Storage	PV.BS	% of PV
Photovoltaic to Pumps (El.Aux and El.Distr)	PV.Pumps	% of PV

Photovoltaic to Domestic Electricity	PV.DE	% of PV
<b>Total Photovoltaic to System</b>	<b>PV.sys</b>	
Battery Storage to Switch Board Electricity	BS.El	Electricity meter
Grid to Switch Board Electricity	GD.El	Electricity meter (El.Supplier)
<b>Total Electricity to Switch Board</b>	<b>El.In.System</b>	
Switch Board Electricity to Grid	El.GD	Electricity meter (El.Supplier)
<b>Total Switch Board to Grid</b>	<b>El.GD.System</b>	
Switch Board Electricity to Primary/ Secondary Heat Source	El.H1/H2	Electricity meter
Switch Board Electricity to Heat Storage (el. Heating Element)	El.HS	Electricity meter
Switch Board Electricity to Primary/Secondary Cold Source	El.C1/C2	Electricity meter
<b>Total Switch Board to System</b>	<b>El.Comp.Syst.</b>	
Switch Board Electricity to Solar Pump	El.SP	Electricity meter
Switch Board Electricity to H1/H2 Hot Temp. Pump	El.HH1/2	Electricity meter
Switch Board Electricity to H1/H2 Medium Temp. Pump	El.MH1/2	Electricity meter
Switch Board Electricity to H1/H2 Low Temp. Pump	El.LH1/2	Electricity meter
Switch Board Electricity to C1/C2 Hot Temp. Pump	El.HC1/2	Electricity meter
Switch Board Electricity to C1/C2 Medium Temp. Pump	El.MC1/2	Electricity meter
Switch Board Electricity to C1/C2 Low Temp. Pump	El.LC1/2	Electricity meter
Switch Board Electricity to Heat Exchange for Cooling (incl. MT)	El.CX	Electricity meter
Switch Board Electricity to Heat Exchange for Heating	El.HX	Electricity meter
<b>Total Switch Board to Auxiliaries</b>	<b>El.Aux.System</b>	
Switch Board Electricity to Cold Distr. Pump	El.CD	Electricity meter
Switch Board Electricity to DHW Distr. Pump	El.WD	Electricity meter
Switch Board Electricity to Heat Distr. Pump	El.HD	Electricity meter
Switch Board Electricity to District Cooling	El.DC	Electricity meter
Switch Board Electricity to District Heating	El.DH	Electricity meter
<b>Total Switch Board to Distribution Pumps</b>	<b>El.Distr.System</b>	
Switch Board Electricity to Domestic Electricity	El.DE	Electricity meter
<b>Total Switch Board to Domestic Electricity</b>	<b>El.DE.System</b>	

The useful energy flows on the whole system level are now:

**Cold distribution (CD) of total system:**

$$Q_{CD.system} = Q_{CD.C1} + Q_{CD.C2} + Q_{CD.CS} + Q_{CD.H1} + Q_{CD.H2} + Q_{CD.HX} \quad \text{Eq. 1.1}$$

**Heat distribution (HD) of total system :**

$$Q_{HD.system} = Q_{SC.HD} + Q_{HS.HD} + Q_{H1.HD} + Q_{H2.HD} \quad \text{Eq. 1.2}$$

**Domestic hot water distribution (WD) of total system :**

$$Q_{WD.system} = Q_{SC.WD} + Q_{HS.WD} + Q_{H1.WD} + Q_{H2.WD} \quad \text{Eq. 1.3}$$

**District cooling (DC) of total system :**

$$Q_{DC.system} = Q_{DC.C1} + Q_{DC.C2} + Q_{DC.CS} \quad \text{Eq. 1.4}$$

**District heating (DH) of total system :**

$$Q_{DH.system} = Q_{SC.DH} + Q_{H1.DH} + Q_{H2.DH} + Q_{HS.DH} \quad \text{Eq. 1.5}$$

**Total distributed energy :**

$$Q_{system} = Q_{CD.system} + Q_{HD.system} + Q_{WD.system} + Q_{DC.system} + Q_{DH.system} \quad \text{Eq. 1.6}$$

**Detailed formulas are given in the description of the Tool [9].**

With this approach it's not more necessary to define a "reference system" separately, because all energy production options are considered. The reference i.e. the system which the NG system is to compare, means in this context or a Solar Fraction of 0. If the system to analyze is an electrical or hybrid cooling system, the "reference" could be also a thermal driven Cooling system. The reference is always included in the scheme.

Electrical consumption here is not distinct between PV-produced or delivered from the grid. This will be defined by the electrical Solar Fraction, i.e. the photovoltaic contribution to Heating/Cooling or DHW production, as it is usually calculated for the solar thermal contribution.

## 4 Data Acquisition and Evaluation of data with Key Performance Figures

The main aim of the monitoring procedure is the verification of the functionality and performance of the Solar Heating & Cooling plant. As just mentioned in this regard, “it is desirable to have a more specific and targeted guide for solar cooling in order to simplify procedures, improve confidence in results and to assist M&V implementation with more detailed guidance”. [1] Now in Task 53 these guidelines were to be checked for their validity for “New Generation Systems”, and to be updated/enlarged where necessary. -

The following chapter gives an overview, which data of energy flows have to be measured and mapped for the respective system boundaries, in order to calculate technical and economic Key Figures by means of the calculation tool.

### 4.1 System boundaries of New Generation systems

In the maximal scheme in Figure 4, main system boundaries are marked with dashed lines:

- System: sys (green)
- Cooling: C / Cooling Distribution: CD or District Cooling: DC (blue)
- Domestic Hot Water: DHW and Space Heating: SH or District Heating: DH (red)

(Data related to DHW production certainly can be measured and analyzed separately, but the components and energy flows are quit the same as for Space Heating.)

The above-mentioned KPI's SPF, PER and  $f_{save}$  will be calculated for the particular applications by means of the tool, and formulas and details are given in the tool description [8]. Furthermore, the solar thermal fraction (SF or % $SC$ ), solar electrical usage (% $PV$ ) and the self-consumption of solar electricity would be interesting.

$$\%SC = \frac{Q_{SC}}{Q_{SC} + Q_{Hot\ Backup}} \quad \text{Eq. 2}$$

The “Electrical Solar Fraction” or “usage of solar electricity” in general is described by

$$\%PV = \frac{PV.EL}{PV.EL + GD.EL} \quad \text{Eq. 3}$$

and will be apportioned equally between the consuming components.

It is not necessary (only if desired to know it) to specify if electrical energy is used as auxiliary energy for pumps etc., or for direct transformation in thermal energy. Direct Heating by PV e.g. may be represented by EL.H1/H2 and H1/2.HD (without thermal losses).

#### 4.1.1 Cooling energy

The components and energy flows related to a Cooling system (e.g. with air as re-cooling source) are highlighted in Figure 5. (Hot storage and Hot backup in summer operation can be partially used also for DHW-production).

Cooling energy can be produced by a thermal way (ACM), assisted by electrical cold or hot back up, or directly with an electrical heat pump. The choice between monovalent or bivalent/hybrid systems with 2 cooling devices is possible. The reference system is included in the same scheme and can be chosen depending on the real case to investigate.

In Table 4 the maximum possible energy flows involved in a NG Solar Cooling system are presented. It can be used as a check-list for planning the disposition of measuring equipment for the real existing energy content



in the cooling system. The collocation of thermal energy meters should allow the correct attribution of losses (near to the consumer and to source output/storage output).

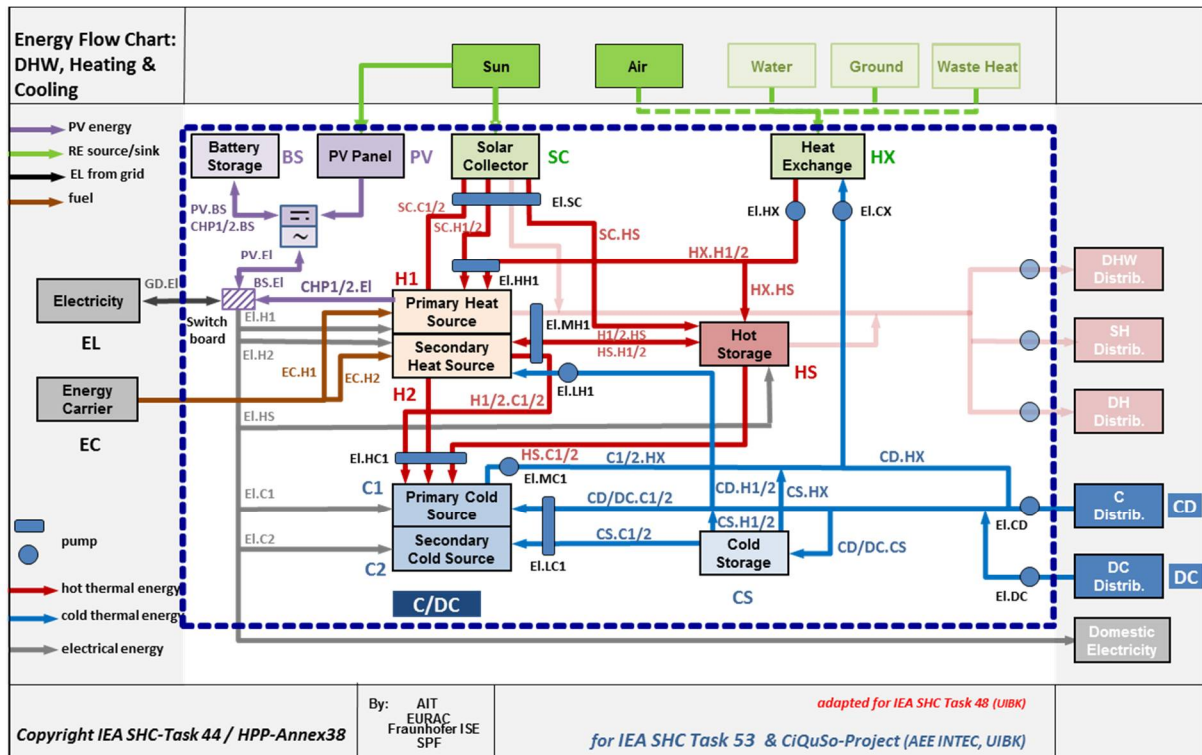


Figure 5: Energy flows for Cooling operation with air-recooling

Table 4: Possible Energy flows to monitor for Cooling system

Energy Carrier to Hot Backups	EC.H1/H2	Flow meter * calorific value
<b>Total Purchased Energy to System</b>	<b>EC.System</b>	
Sun to Solar Thermal Collectors	Su.SC	Radiation $E_{sol} * A_{coll}$
Sun to Photovoltaic Collectors	Su.PV	Radiation $E_{sol} * A_{PV}$
<b>Total Renewable Energy to System</b>	<b>RES.System</b>	
Solar Collectors to Heat Source1/2	SC.H1/H2	% of SC (heat output SC)
Solar Collectors to Cold Source (ACM) 1/2	SC.C1/2	% of SC
Solar Collectors to Hot Storage	SC.HS	% of SC
Heat Exchanger to Primary/Secondary Heat Source (HP)	HX.H1/H2	Thermal energy meter
Heat Exchanger to Hot Storage	HX.HS	Thermal energy meter
<b>Total RE harvested to System</b>	<b>REH.System</b>	
Primary Heat Source to Primary/Secondary Cold Source (ACM)	H1.C1/C2	Thermal energy meter
Primary Heat Source to Hot Storage	H1.HS	Thermal energy meter
<b>Total Primary Heat Source to System</b>	<b>H1.System</b>	
<b>Total Secondary Heat Source to System (as H1)</b>	<b>H2.System</b>	
Hot Storage to Primary/Secondary Heat Source (AHP)	HS.H1/H2	Thermal energy meter
Hot Storage to Primary/Secondary Cold Source (ACM)	HS.C1/C2	Thermal energy meter
<b>Total Hot Storage to System</b>	<b>HS.System</b>	
Primary Cold Source to Heat Exchanger	C1.HX	Thermal energy meter
Secondary Cold Source to Heat Exchanger	C2.HX	Thermal energy meter
<b>Total Cold Source to System</b>	<b>C.System</b>	
Cold Storage to Primary/Secondary Cold Source	CS.C1/C2	Thermal energy meter
Cold Storage to Primary/Secondary Heat Source (AHP)	CS.H1/H2	Thermal energy meter
Cold Storage to Heat Exchanger	CS.HX	Thermal energy meter
<b>Total Cold Storage to System</b>	<b>CS.System</b>	



District Cooling to Heat Exchanger (Freecooling)	DC.C1/C2	Thermal energy meter (consumer)
District Cooling to Primary/Secondary Cold Source	DC.C1/C2	Thermal energy meter (consumer)
District Cooling to Primary/Secondary Heat Source (AHP)	DC.C1/C2	Thermal energy meter (consumer)
District Cooling to Cold Storage	DC.CS	Thermal energy meter (consumer)
<b>Total District Cooling to System</b>	<b>DC.System</b>	
Cold Distribution to Heat Exchanger (Freecooling)	CD.HX	Thermal energy meter (consumer)
Cold Distribution to Primary/Secondary Cold Source	CD.C1/C2	Thermal energy meter (consumer)
Cold Distribution to Primary//Secondary Heat Source (AHP)	CD.H1/H2	Thermal energy meter (consumer)
Cold Distribution to Cold Storage	CD.CS	Thermal energy meter (consumer)
<b>Total Cold Distribution to System</b>	<b>CD.System</b>	
Photovoltaic to Primary/Secondary Heat Source	PV.H1/H2	% of PV (electricity meter output PV)
Photovoltaic to Hot Storage	PV.HS	% of PV
Photovoltaic to Primary/Secondary Cold Source	PV.C1/C2	% of PV
Photovoltaic to Battery Storage	PV.BS	% of PV
Photovoltaic to Pumps (El.Aux and El.Distr)	PV.Pumps	% of PV
<b>Total Photovoltaic to System</b>	<b>PV.sys</b>	
Battery Storage to Switch Board Electricity	BS.El	Electricity meter
Grid to Switch Board Electricity	GD.El	Electricity meter (El.Supplier)
<b>Total Electricity to Switch Board</b>	<b>El.In.System</b>	
Switch Board Electricity to Grid	El.GD	Electricity meter (El.Supplier)
<b>Total Switch Board to Grid</b>	<b>El.GD.System</b>	
Switch Board Electricity to Primary/ Secondary Heat Source	El.H1/H2	Electricity meter
Switch Board Electricity to Heat Storage (el. Heating Element)	El.HS	Electricity meter
Switch Board Electricity to Primary/Secondary Cold Source	El.C1/C2	Electricity meter
<b>Total Switch Board to System</b>	<b>El.Comp.System</b>	
Switch Board Electricity to Solar Pump	El.SP	Electricity meter
Switch Board Electricity to H1/H2 Hot Temp. Pump	El.HH1/2	Electricity meter
Switch Board Electricity to H1/H2 Medium Temp. Pump	El.MH1/2	Electricity meter
Switch Board Electricity to H1/H2 Low Temp. Pump	El.LH1/2	Electricity meter
Switch Board Electricity to C1/C2 Hot Temp. Pump	El.HC1/2	Electricity meter
Switch Board Electricity to C1/C2 Medium Temp. Pump	El.MC1/2	Electricity meter
Switch Board Electricity to C1/C2 Low Temp. Pump	El.LC1/2	Electricity meter
Switch Board Electricity to Heat Exchange for Cooling (incl. MT)	El.CX	Electricity meter
Switch Board Electricity to Heat Exchange for Heating	El.HX	Electricity meter
<b>Total Switch Board to Auxiliaries</b>	<b>El.Aux.System</b>	
Switch Board Electricity to Cold Distr. Pump	El.CD	Electricity meter
Switch Board Electricity to District Cooling Pump	El.DC	Electricity meter
<b>Total Switch Board to Distribution Pumps</b>	<b>El.Distr.System</b>	

The **Key Performance Indicators** are:

The  $SPF_{el,C}$  is the ratio of energy (heat-) flows of cold distribution to cold storage ( $Q_{CD,CS}$ ), cold distribution to heat pump ( $Q_{CD,HP}$ ) and cold distribution to cold backups ( $Q_{CD,CB}$ ) in the nominator and the sum of all electrical energy flows on the cold side ( $Q_{el,C}$ ) in the denominator (T48 B7).

$$SPF_{el,C} = \frac{Q_{CD,CS} + Q_{CD,HP} + Q_{CD,CB}}{\sum Q_{el,C}} \quad (44 \text{ T48 B7})$$

Actually, the electrical Seasonal Performance ratio in NG Systems (for all levels) will not be very meaningful as single value, because the electricity-source (solar or grid) for its definition is indifferent. Therefore, Primary Energy considerations (PER,  $SPF_{equ}$ ) will be more significant for environmental and economic evaluation. Further the electrical SPF can give misleading results when a hot backup is used, because the equation does not distinguish between useful cooling derived from solar and thermal backup sources. For this reason, if a hot backup is being used, then either the PER provides a better comparison with a reference system [9].



**Table 5: Possible Energy flows to monitor for Heating systems**

Energy Carrier to Hot Backups	EC.H1/H2	Flow meter * calorific value
<b>Total Purchased Energy to System</b>	<b>EC.System</b>	
Sun to Solar Thermal Collectors	Su.SC	Radiation $E_{sol} * A_{Coll}$
Sun to Photovoltaic Collectors	Su.PV	Radiation $E_{sol} * A_{PV}$
<b>Total Renewable Energy to System</b>	<b>RES.System</b>	
Solar Collectors to Heat Source1/2	SC.H1/H2	% of SC (heat output SC)
Solar Collectors to Hot Storage	SC.HS	% of SC
Solar Collectors to District Heating	SC.DH	% of SC
Solar Collectors to Heat Distribution	SC.HD	% of SC
Heat Exchanger to Primary/Secondary Heat Source (HP)	HX.H1/H2	Thermal energy meter
Heat Exchanger to Hot Storage	HX.HS	Thermal energy meter
<b>Total RE harvested to System</b>	<b>REH.System</b>	
Primary Heat Source to Hot Storage	H1.HS	Thermal energy meter
Primary Heat Source to District Heating	H1.HDH	Thermal energy meter (consumer)
Primary Heat Source to Heat Distribution	H1.HD	Thermal energy meter (consumer)
<b>Total Primary Heat Source to System</b>	<b>H1.System</b>	
<b>Total Secondary Heat Source to System (as H1)</b>	<b>H2.System</b>	
Hot Storage to Primary/Secondary Heat Source (AHP)	HS.H1/H2	Thermal energy meter
Hot Storage to District Heating	HS.DH	Thermal energy meter (consumer)
Hot Storage to Heat Distribution	HS.HD	Thermal energy meter (consumer)
<b>Total Hot Storage to System</b>	<b>HS.System</b>	

Photovoltaic to Primary/Secondary Heat Source	PV.H1/H2	% of PV (electricity meter output PV)
Photovoltaic to Hot Storage	PV.HS	% of PV
Photovoltaic to Battery Storage	PV.BS	% of PV
Photovoltaic to Pumps (El.Aux and El.Distr)	PV.Pumps	% of PV
<b>Total Photovoltaic to System</b>	<b>PV.sys</b>	
Battery Storage to Switch Board Electricity	BS.El	Electricity meter
Grid to Switch Board Electricity	GD.El	Electricity meter (El.Supplier)
<b>Total Electricity to Switch Board</b>	<b>El.In.System</b>	
Switch Board Electricity to Grid	El.GD	Electricity meter (El.Supplier)
<b>Total Switch Board to Grid</b>	<b>El.GD.System</b>	
Switch Board Electricity to Primary/ Secondary Heat Source	El.H1/H2	Electricity meter
Switch Board Electricity to Heat Storage (el. Heating Element)	El.HS	Electricity meter
<b>Total Switch Board to System</b>	<b>El.Comp.System</b>	
Switch Board Electricity to Solar Pump	El.SP	Electricity meter
Switch Board Electricity to H1/H2 Hot Temp. Pump	El.HH1/2	Electricity meter
Switch Board Electricity to H1/H2 Medium Temp. Pump	El.MH1/2	Electricity meter
Switch Board Electricity to H1/H2 Low Temp. Pump	El.LH1/2	Electricity meter
Switch Board Electricity to Heat Exchange for Heating	El.HX	Electricity meter
<b>Total Switch Board to Auxiliaries</b>	<b>El.Aux.System</b>	
Switch Board Electricity to Heat Distr. Pump	El.HD	Electricity meter
Switch Board Electricity to District Heating	El.DH	Electricity meter
<b>Total Switch Board to Distribution Pumps</b>	<b>El.Distr.System</b>	

### Key Performance indicators for Heating:

The useful energy, nominator in the formulas for the SPF and the PER includes the energy flows “hot storage to heat distribution” ( $Q_{HS,HD}$ ), “solar collectors to heat distribution” ( $Q_{SC,HD}$ ), “hot backups to heat distribution” ( $Q_{HB,HD}$ ), heat pump to heating distribution ( $Q_{HP,HD}$ ) and direct electrical heating ( $Q_{EL,HD}$ ). The denominator, e.g. to calculate the PER is the sum of all electrical and thermal energy inputs (after subtracted solar inputs) of devices related to space heating ( $Q_{el,SH} + Q_{th,SH}$ ), converted into Primary Energy.

Fractional savings of non-renewable Primary Energy of the NG Solar Heating System can be calculated referring to a non-solar heating system (same heating energy with %<sub>SC</sub> = 0 and/or %<sub>PV</sub> = 0) but also to a thermal driven heating system.

$$f_{sav.NRE.PER,SH} = 1 - \frac{PER_{NRE.ref,SH}}{PER_{NRE.NG,SH}} \quad \text{Eq. 5}$$

### 4.1.3 Domestic hot water production

Domestic hot water is considered all year, separately but in general contemporaneously with heating or cooling. It can be produced by a thermal way (solar collector) assisted by fossil hot backup, or by PV-electrically driven heat pump, or directly with PV-driven heating elements in the boiler. Distribution consumptions are not included in this level. The “reference system” is characterized by a Solar Fraction (ST and/or PV) = 0.

System boundaries for Domestic hot water production are shown in Figure 7. (Heat Sources and Hot storage in summer operation can be partially used also for Cooling, in winter operation for Heating).

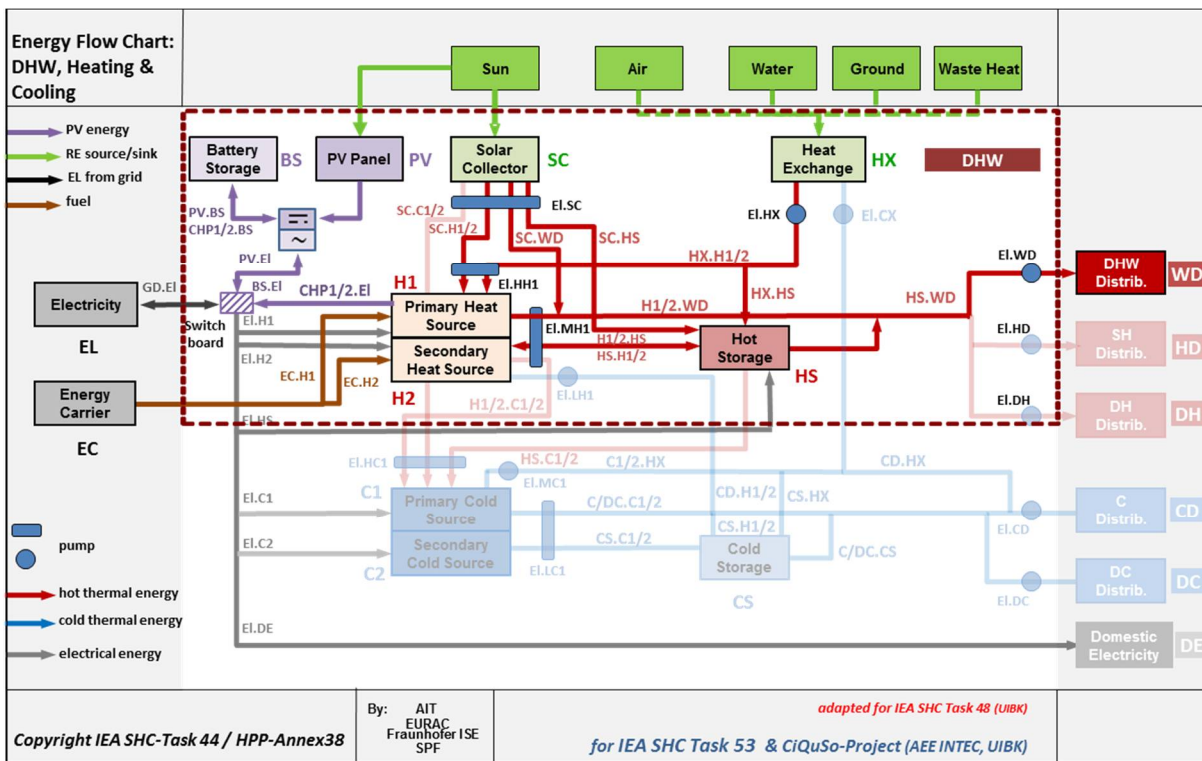


Figure 7: Energy flows and System boundaries for DHW production

In Table 6 the maximum possible energy flows involved in a NG Solar DHW system are presented. It can be used as a check-list for planning the disposition of measuring equipment for the real existing energy content in the DHW system. The collocation of thermal energy meters should allow the correct attribution of losses (near to the consumer and to source output/storage output).

**Table 6: Possible Energy flows to monitor for Domestic Hot Water systems**

Energy Carrier to Hot Backups	EC.H1/H2	Flow meter * calorific value
<b>Total Purchased Energy to System</b>	<b>EC.System</b>	
Sun to Solar Thermal Collectors	Su.SC	Radiation $E_{sol} * A_{coll}$
Sun to Photovoltaic Collectors	Su.PV	Radiation $E_{sol} * A_{PV}$
<b>Total Renewable Energy to System</b>	<b>RES.System</b>	
Solar Collectors to Heat Source1/2	SC.H1/H2	% of SC (heat output SC)
Solar Collectors to Hot Storage	SC.HS	% of SC
Solar Collectors to DHW Distribution	SC.WD	% of SC
Heat Exchanger to Primary/Secondary Heat Source (HP)	HX.H1/H2	Thermal energy meter
Heat Exchanger to Hot Storage	HX.HS	Thermal energy meter
<b>Total RE harvested to System</b>	<b>REH.System</b>	
Primary Heat Source to Hot Storage	H1.HS	Thermal energy meter
Primary Heat Source to DHW Distribution	H1.WD	Thermal energy meter (consumer)
<b>Total Primary Heat Source to System</b>	<b>H1.System</b>	
<b>Total Secondary Heat Source to System ( as H1)</b>	<b>H2.System</b>	
Hot Storage to Primary/Secondary Heat Source (AHP)	HS.H1/H2	Thermal energy meter
Hot Storage to DHW Distribution	HS.WD	Thermal energy meter (consumer)
<b>Total Hot Storage to System</b>	<b>HS.System</b>	
Photovoltaic to Primary/Secondary Heat Source	PV.H1/H2	% of PV (electricity meter output PV)
Photovoltaic to Hot Storage	PV.HS	% of PV
Photovoltaic to Battery Storage	PV.BS	% of PV
Photovoltaic to Pumps (El.Aux and El.Distr)	PV.Pumps	% of PV
<b>Total Photovoltaic to System</b>	<b>PV.sys</b>	
Battery Storage to Switch Board Electricity	BS.El	Electricity meter
Grid to Switch Board Electricity	GD.El	Electricity meter (El.Supplier)
<b>Total Electricity to Switch Board</b>	<b>El.In.System</b>	
Switch Board Electricity to Grid	El.GD	Electricity meter (El.Supplier)
<b>Total Switch Board to Grid</b>	<b>El.GD.System</b>	
Switch Board Electricity to Primary/ Secondary Heat Source	El.H1/H2	Electricity meter
Switch Board Electricity to Heat Storage (el. Heating Element)	El.HS	Electricity meter
<b>Total Switch Board to System</b>	<b>El.Comp.System</b>	
Switch Board Electricity to Solar Pump	El.SP	Electricity meter
Switch Board Electricity to H1/H2 Hot Temp. Pump	El.HH1/2	Electricity meter
Switch Board Electricity to H1/H2 Medium Temp. Pump	El.MH1/2	Electricity meter
Switch Board Electricity to H1/H2 Low Temp. Pump	El.LH1/2	Electricity meter
Switch Board Electricity to Heat Exchange for Heating	El.HX	Electricity meter
<b>Total Switch Board to Auxiliaries</b>	<b>El.Aux.System</b>	
Switch Board Electricity to DHW Distr. Pump	El.WD	Electricity meter
<b>Total Switch Board to Distribution Pumps</b>	<b>El.Distr.System</b>	

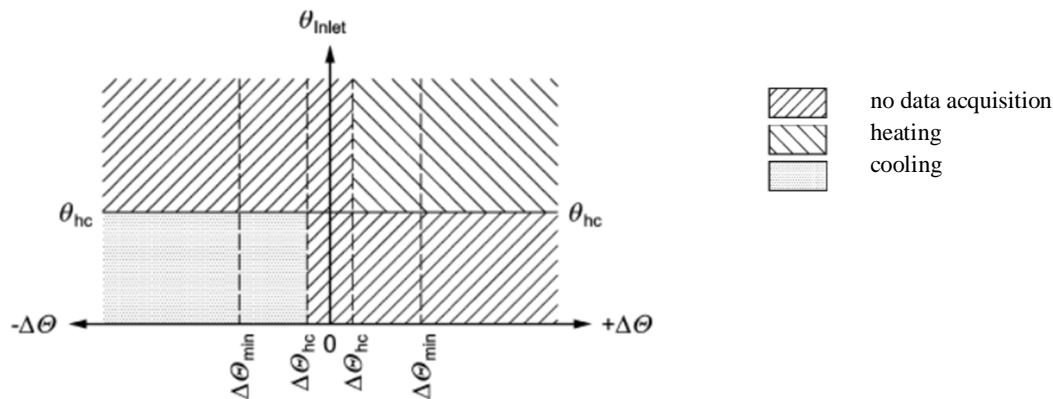
The Key Performance indicators for DHW can be defined in the same mode as for Space Heating.

**Practical examples will be presented in the Report C3. All related formulas are listed in the manual of the tool [9].**

## 5 Measuring and instrumentation

For specific issues of Measurement & Verification (M&V) Methodology and Concept the authors refer to the Task 48-Report C4, especially chapter 5 which can be found in the Annex, where the necessary instrumentation for energy/mass flows or parts of system is reported and explained in detail.

It should be highlighted that the often-cited norm EN 1434-1 “Heat meters - Part 1: General requirements” was updated in 2015. Recommendations related to accuracy of heat meters are still completely valid, the news is the comprehension of combined heat & cold meters.



**Figure 8: EN 1434-1 (2015) – combined heat and cold meters - example for the switching between heating and cooling operation**

The recommendations in chapter 6 for monitoring daily data is also applicable for “new generation” solar cooling and heating systems also if the evaluation figures are extended and further developed; it should be pointed out that the evaluation tool described in the following can also be used for daily data, for being sure that the system works correctly, and to give a first idea on a daily behavior of the system in terms of efficiency.

All recommendations on the required hardware can be transferred to Task 53. Also, if some components (as CHP, heat pump, PV-system) were not considered before in this context, the procedure concerns cooling and heating energy and domestic hot water preparation and however on system level. For efficiency tests of single components, other proceedings are necessary (i.e. for heat pumps a detailed procedure is described in the final report of the SEPEMO-Project (Nordman R. et al)).



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