Final Deliverable

Collection of criteria to quantify the quality and cost competitiveness for solar cooling systems

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IEA Solar Heating and Cooling Program

The Solar Heating and Cooling Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency. Its mission is *"to enhance collective knowledge and application of solar heating and cooling through international collaboration to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050.*

The member countries of the Programme collaborate on projects (referred to as "Tasks") in the field of research, development, demonstration (RD&D), and test methods for solar thermal energy and solar buildings.

A total of 53 such projects have been initiated to-date, 39 of which have been completed. Research topics include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44)
- Solar Cooling (Tasks 25, 38, 48, 53)
- Solar Heat for Industrial or Agricultural Processes (Tasks 29, 33, 49)
- Solar District Heating (Tasks 7, 45)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52)
- Solar Thermal & PV (Tasks 16, 35)
- Daylighting/Lighting (Tasks 21, 31, 50)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42)

In addition to the project work, there are special activities:

- SHC International Conference on Solar Heating and Cooling for Buildings and Industry
- Solar Heat Worldwide – annual statistics publication
- Memorandum of Understanding with solar thermal trade organizations
- Workshops and conferences

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1. Executive Summary

Subtask B concentrates on developing tools and deliverables permitting to show the level of quality of the solar cooling and heating systems. In order to achieve this goal, procedures (possibly 1 or more if needed) have to be developed **extending the quality characteristics from a component level (Subtask A) to a system level**.

Starting from 1) on-going work in the IEA Annex 34 and Task 44, the French MéGaPICS and the EMERGENCE projects and former work performed in IEA Task38, 2) suitable analysis procedures classified in standards and 3) work performed at research level, **an extension of the procedures will be developed from single stationary tests to a system performance prediction over the whole year** (based on standardized and generally accepted conditions).

In B7, a proposal for an appropriate evaluation procedure for the technical and economic performance assessment of large systems is set up and tested with real cases. It delivers the basis for a comparable assessment of the installed plants independently of installation site and the specific boundary conditions. Beside, a reflection will be carried out on minimum economical ratios to estimate the competitiveness of solar cooling against concurrent technologies.

This activity will give an input and will be carried out in close collaboration with activities **B1** (System/Subsystem characterization & field performance assessment) and **C2** (Methodology for performance assessment, rating and benchmarking).

Specific Objectives

This activity is to be carried out to survey the available procedures that could be adapted to solar cooling systems quality assessment.

1. A collection and review of existing key figures to quantify quality and cost will be performed but also the specific tools to calculate them will be reviewed.
2. Define the crucial key figures for large scale plants (in cooperation with B1) and find a representation for all of the key figures.
3. Review how benchmarks can be calculated (in cooperation with C2) and define minimum ratios for them.
4. Data acquisition for investment (SHC + reference system) and operating (electricity, etc.) costs has to be done in order to find specific minimum economic ratios.
5. The procedure has to be tested and validated with real installations. Therefore participating companies and institutions will provide monitoring data. **Key for the success of this activity is that research institutions are willing to assess the test methods in their laboratories/test sites.**

2. Methods and key figures for quality and cost effectiveness

Key figures for quality and cost effectiveness are compiled. Different subtasks (Quality assurance (B1), incentives (C1), benchmarking and rating (C2), etc.) will request different key figures. Therefore the different possibilities are presented and listed first.

Even the same figure can be calculated in different ways, taking different system boundaries into account or using different energy quantities, like primary energy (PE) or useful energy. It is essential to define boundaries and used quantities clearly.

Main distinction has to be made whether the solar cooling system itself (in- or excluding backup solution), space heating, domestic hot water or the complete system, including different energy quantities (electricity, natural gas, etc.) are taken into account.

2.1. General Nomenclature

Nomenclature is defined accordingly and after clearance with IEA SHC Task 44 / HPP Annex 38 [Malenkovic 2012, B1.1] and enlarged by specifically used subscripts by this SHC Task 48.

COP	Coefficient of Performance (-)	SPF	Seasonal Perform. Factor (-)
SCOP	Seasonal COP (-)	Q	Energy flow (kWh)
EER	Energy Efficiency Rate (-)	$\dot{Q}$	Thermal Power (W)
SEER	Seasonal EER (-)	CAP	Capacity (W)
PER	Primary Energy Ratio (-)	P	Power (W)

Subscripts, capital

ACM	Ab/Adsorption chiller	FE	Final Energy
NRE	Non-renewable	HOM	Heating operation mode
DHW	Domestic hot water	HP	Heat pump
SH	Space heating	HR	Heat rejection
C	Cooling	UE	Useful energy
BU	Backup unit	SC	Solar collector
COM	Cooling operating mode	HS	Heat source
LT	Low temperature	HX	Heat exchanger
MT	Medium temperature	PE	Primary energy
HT	High temperature	SHP	Solar heat pump
CU	Control Unit	SHP+	Solar heat pump plus energy distribution system
VCC	Vapor compression chiller	LHV	Lower heating value
CT	Cooling Tower	FC	Fan Coils
DEC	Desiccant and evaporative cooling	SHC	Solar Heating and Cooling
Ref	Reference (system) (VCC)		

Subscripts, small

el	electrical	sys	System
coll	collector	th	thermal

2.2. Meaning / Usage of different performance figures

In different standards for solar and heat pump system performance figures and calculation methods are available but use different definitions. Within SHC Task 44/ HPP Annex 38 a number of standards were analyzed and a coherent nomenclature and definition of performance figures was developed [Malenkovic 2012, B1.1].

Performance figures are defined for heating and domestic hot water preparation separately or combined and for cooling mode only. A performance figure including all three modes is not covered yet. Proposals for different overall figures will be given later on.

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

2.3. System representation

The following system representations may vary in layout and nomenclature of energy fluxes. The energy fluxes can be numbered or have certain names following a logical nomenclature structure.

2.3.1. IEA SHC Task 38

In order to enable a structured collection of monitoring data and to define a common evaluation methodology of energy performance of SHC plants, a unified monitoring procedure has been developed in IEA SHC Task 38 [Napolitano et al. 2010].

A maximum solar heating and cooling system has been developed on the base of commonly valid layouts for SHC systems. The representation includes largely diverse systems (Figure 1). Heat is delivered from flat plate collectors or from a backup heat source, which can be driven by renewable energies or waste heat. Surplus energy out of heat supply is stored in the hot storage. This heat can be used for domestic hot water (DHW), cooling (C) or space heating (SH). If used for cooling heat is delivered to the ab-/adsorption chiller (ACM). Further component is the cooling tower (CT). On the chilled water side the cold storage, backup cold source (e.g. vapor compression chiller (VCC)) and the delivery system (e.g. fan coils (FC)) are located. Further a desiccant and evaporative cooling unit (DEC) is included.

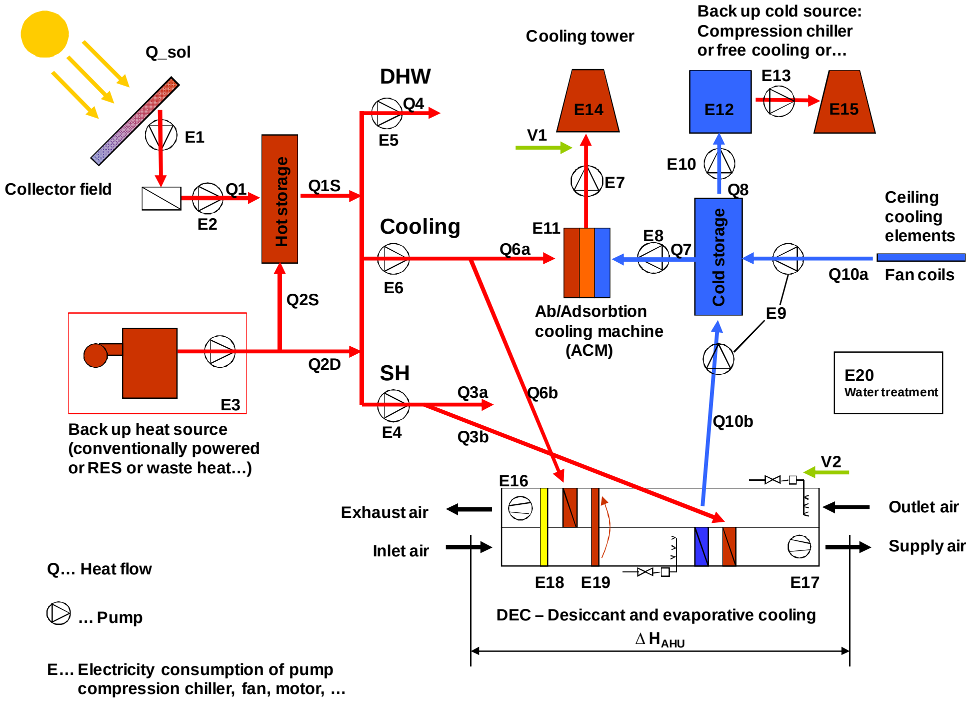


Figure 1: Reference solar heating and cooling system including the single energy fluxes (SHC Max System) [Napolitano et al. 2010]

The selected conventional system (Figure 2) is taken as reference for comparisons with the SHC Max System (Figure 1). A condensing natural gas boiler provides energy for SH and DHW. A storage tank with typical heat losses, based on the measured DHW-consumption, is assumed to be heated by the natural gas boiler. Finally, the cooling load is supposed to be matched by a VCC.

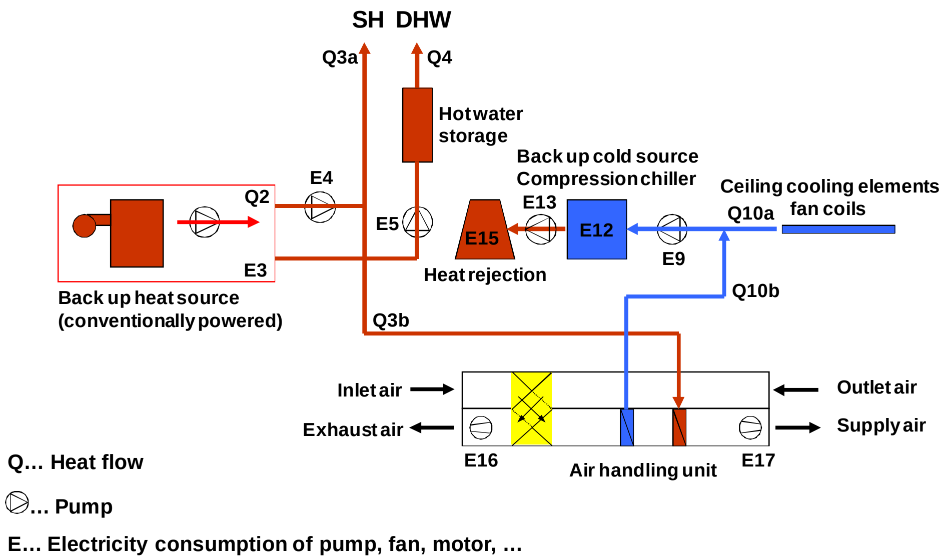


Figure 2: Diagram of the selected conventional reference systems including energy flows [Napolitano et al. 2010]

2.3.2. Variations of Task 38 used in MeGaPICS

A variation of the representations invented in Task 38 was created in the French project "Méthode pour Garantir les Performances des Installations de Climatisation / Chauffage Solaire" [MeGaPICS]. The idea of numbering the energy fluxes was kept, but the arrangement was restructured to differ between sources, sinks, distribution systems and heat rejection (Figure 3).

Two common systems are defined. They take into account the vast majority of potential system configurations, by no means exhaustive. However, the existing system configurations are capable to provide good performance levels. Depending on the system configuration, some components or hydraulic links may not be required and do not need to be taken into account [Boudéhenn et al. 2012].

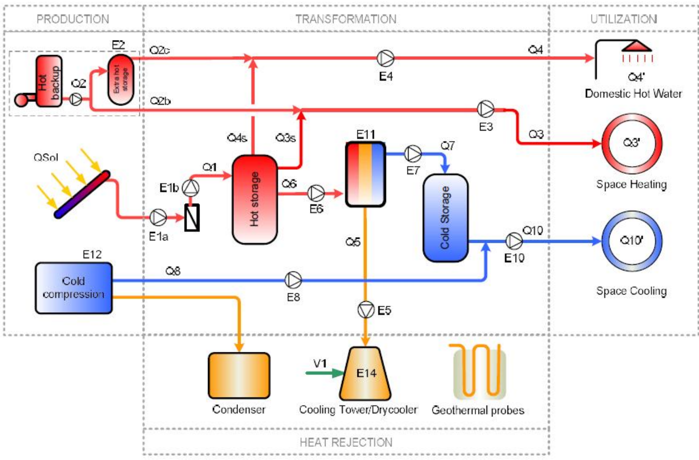


Figure 3: System representation of a "collective" solar air-conditioning/heating/domestic hot water system used in MeGaPICS [Boudéhenn et al. 2013]

2.3.3. Variations of Task 38 used in Task 48 / Subtask C

System boundaries (Figure 4) are slightly adapted form that used in MeGaPICS or Activity C4 "Measurement and Verification of Solar Heating and Cooling Systems" [Boudéhenn et al. 2013].

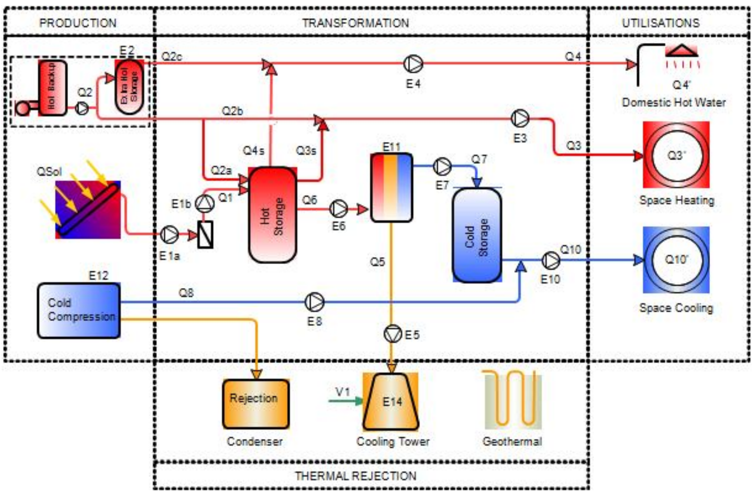


Figure 4: System representation used in Sub-Task C, Activity C2 [Boudéhenn et al. 2013]

2.3.4. IEA SHC Task 44 / Source-Sink Approach

More details of the Source-Sink Approach may be found in Reports of Subtask B, Activity B1 or T44/A38 B1.1.

The presented system evaluation method is based on all components possibly installed in the system. In particular, it is centered on a source-sink approach, in which virtually any component can act either as a sink or a source of thermal and/or electric energy for any of the components. The clear benefit is the degree of freedom left to the description of the connections. To manage the definition of such connections easily, an Excel table has been elaborated, where the first column shows all possible elements of the system, treated as sources, and the first row reports the same elements regarded as sinks.

Every element is fully identified by a two-letter code. The acronym includes the first two letters of the name (Sun = Su) or first initials of a composite name (Solar Collectors = SC). Hence every component is marked with an intuitive abbreviation, which identifies also all heat and electricity fluxes within the system. Energy flux is named as “source”.”sink” (i.e. Su.SC means Sun.Solar Collector). The system is described by marking a cross between the specific sources and sinks.

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

Figure 5: Reduced source-sink table with nomenclature of the heat and electricity fluxes

The source-sink table (Figure 5) fully describes the system from the point of view of the existing fluxes among components (nothing is disclosed about quantities yet). However, it is not as intuitive as needed, from the visual point of view. Therefore, an additional representation is used to assist the first one. The energy flow chart is automatically generated (again in the excel worksheet), starting from the source-sink table: all system elements in the table are shown on a diagram (Figure 6), with a steady color representation.

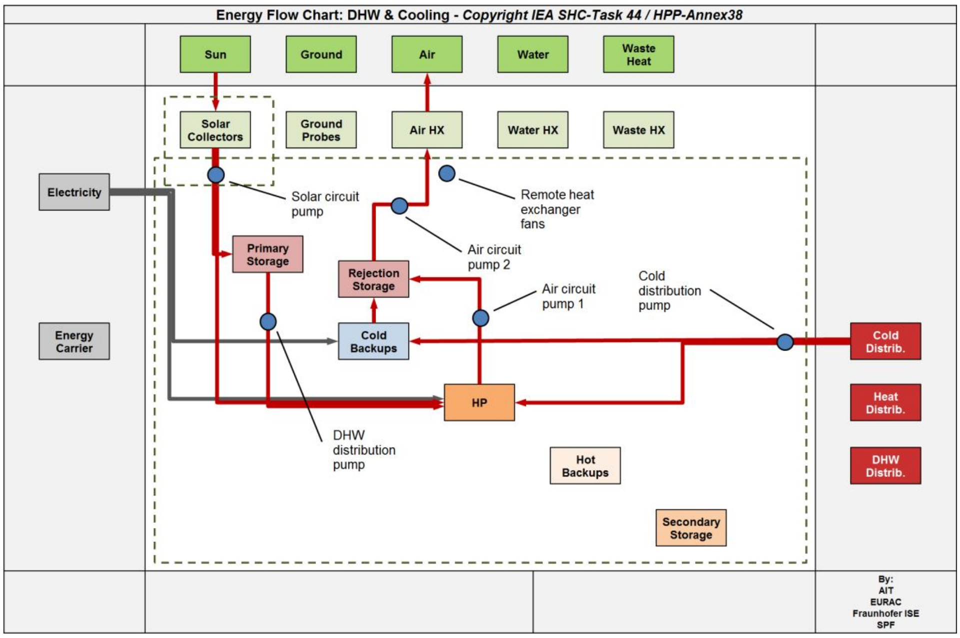


Figure 6: Energy Flow Chart: Complex solar + HP system. Method with permission of IEA-SHC Task 44 -HPP Annex 38, 2011

All necessary boundaries of the system and subsystems can be represented on the diagram and input/output fluxes can be detected. They base on the performance figure calculation and the meters, needed for the acquisition of the required data.

Finally the source-sink approach has been chosen to be used in SHC Task 48 / B7. In the following sections detailed performance figures and their boundaries will be defined.

3. Technical key figures

Beside those figures presented here, a number of other "secondary" performance indicators might be of interest in solar heating and cooling systems, depending on the target group: renewable energy ratio, solar fraction, fractional energy saving, global warming potential, etc.

A complete overview including nomenclature of energy flows and pumps is shown in Figure 7. The reversible heat pump (HP) can be used for heating and cooling mode and is electrically or thermally driven. Therefore in Task 48 the abbreviation ACM stands for HP as well.

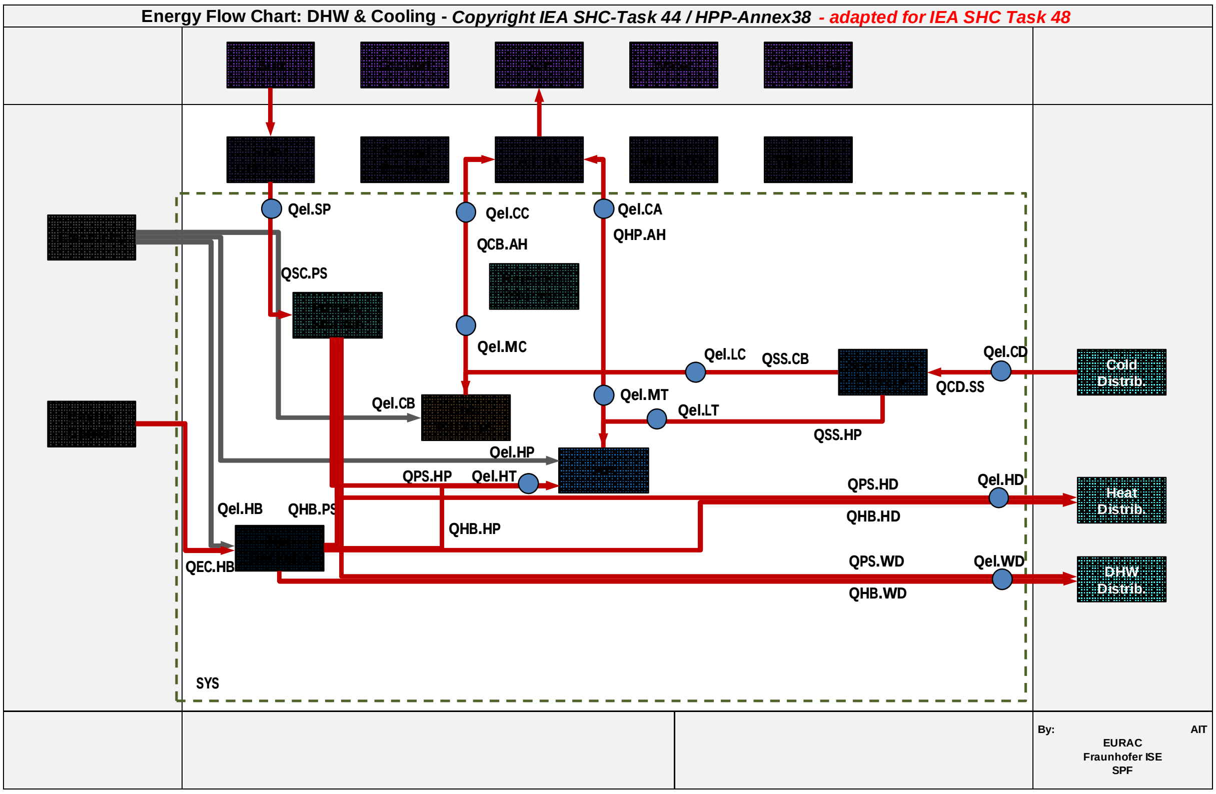


Figure 7: Energy Flow Chart for a complex solar + HP(ACM) system, without showing some possibilities of direct energy usage (QSC.HD, QSC.WD, QCD.CB, QCD.HP)

3.1. Nomenclature for chosen representation

Figure 7 includes possible energy flows, which are necessary to calculate the technical key figures. A detailed description of all energy flows can be found in Table 1, where all possibilities of direct usage are defined (QSC.HD, QSC.WD, QSC.HP, QHB.HD, etc.).

Not each pump or electricity consumer needs its own electricity meter. Depending on the different boundaries some appliances can be measured with one device. The number of meters can be derived of the definition of the key figures (see chapter 3).

Table 1: Nomenclature of all energy flows in the total system

Energy Carrier to Hot Backups	EC.HB
Total Purchased Energy to System	EC.System
Sun to Solar Collectors	Su.SC
Total Renewable Energy to System	RES.System
Solar Collectors to Primary Storage	SC.PS
Solar Collectors to HP	SC.HP
Solar Collectors to Heat Distribution	SC.HD
Solar Collectors to DHW Distribution	SC.WD
Solar Collector heat losses	SC.LO
Solar Collector to Cooling incl. attributable losses	SC.C
Solar Collector to Space Heating incl. attributable losses	SC.SH
Solar Collector to DHW incl. attributable losses	SC.DHW
Air Heat Exchanger to Air	AH.Ar
Total RE harvested to System	REH.System
Primary Storage to HP	PS.HP
Primary Storage to Heat Distribution	PS.HD
Primary Storage to DHW Distribution	PS.WD
Total Primary Storage to System	PS.System
Primary storage heat losses	PS.LO
Cold Backups to Air Heat Exchanger	CB.AH
Total Cold Backups to System	CB.System
HP to Air Heat Exchanger	HP.AH
Total HP to System	HP.System
Hot Backups to Primary Storage	HB.PS
Hot Backups to HP	HB.HP
Hot Backups to Heat Distribution	HB.HD
Hot Backups to DHW Distribution	HB.WD
Hot Backup losses	HB.LO
Hot Backup to Cooling incl. attributable losses	HB.C
Hot Backup to Space Heating incl. attributable losses	HB.SH
Hot Backup to DHW incl. attributable losses	HB.DHW
Total Hot Backups to System	HB.System
Secondary Storage to Cold Backups	SS.CB
Secondary Storage to HP	SS.HP
Total Secondary Storage to System	SS.System
Secondary Storage losses	SS.LO
Cold Distribution to Cold Backups	CD.CB
Cold Distribution to HP	CD.HP
Cold Distribution to Secondary Storage	CD.SS
Total Cold Distribution to System	CD.System
Electricity to Cold Backups	El.CB
Electricity to HP	El.HP
Electricity to Hot Backups	El.HB
Total Electricity to System	El.System
Electricity to Solar Pumps (prim + sec)	El.SP

Electricity to hot temperature Pump (generator ACM)	El.HT
Electricity to medium temperature pump (cold water ACM)	El.MT
Electricity to low temperature pump (chilled water ACM)	El.LT
Electricity to medium temperature pump VCC (cold water vapor compression chiller)	El.MC
Electricity to low temperature pump VCC (chilled water VCC)	El.LC
Electricity to heat rejection ACM mode (cooling tower fan ACM)	El.CA
Electricity to heat rejection VCC mode (cooling tower fan VCC)	El.CC
Total Electricity to Auxiliaries	El.Aux
Electricity to cold water distribution pump	El.CD
Electricity to domestic hot water distribution pump	El.WD
Electricity to hot water distribution pump	El.HD
Electricity for space heating	El.SH
Electricity for domestic hot water preparation	El.DHW
Electricity for vapor compression chiller	El.VCC
Electricity for ab/adsorption chiller	El.ACM
Electricity for overall cooling	El.C
Electricity for thermal cooling	El.thC
Electricity demand reference system	El.ref
Electricity demand reference domestic hot water preparation	El.ref.DHW
Electricity demand reference space heating	El.ref.SH
Hot distribution (SH) to System	HD.System
Water distribution (DHW) to System	WD.System
Solar Collector to System	SC.System
Heat losses	hloss
Cooling losses	closs

3.2. Summary of energy flows

Following definitions of energy flows *Q* and percentage ratios *%* are used to separate different quantities (heat and electricity) into their intended use for cooling, space heating and domestic hot water and to calculate the key figures accordingly.

- Distributed energy

$$Q_{CD.system} = Q_{CD.SS} + Q_{CD.HP} + Q_{CD.CB} \qquad \text{Eq. (1)}$$
$$Q_{HD.system} = Q_{PS.HD} + Q_{HB.HD} + Q_{SC.HD} \qquad \text{Eq. (2)}$$
$$Q_{WD.system} = Q_{PS.WD} + Q_{HB.WD} + Q_{SC.WD} \qquad \text{Eq. (3)}$$

- Main components and sources

$$Q_{SC.system} = Q_{SC.PS} + Q_{SC.HP} + Q_{SC.HD} + Q_{SC.WD} \qquad \text{Eq. (4)}$$
$$Q_{HB.system} = Q_{HB.PS} + Q_{HB.HP} + Q_{HB.HD} + Q_{HB.WD} \qquad \text{Eq. (5)}$$
$$Q_{PS.system} = Q_{PS.HP} + Q_{PS.WD} + Q_{PS.HD} \qquad \text{Eq. (6)}$$
$$Q_{SS.system} = Q_{SS.HP} + Q_{SS.CB} \qquad \text{Eq. (7)}$$

- Losses at storages

$$Q_{hloss} = Q_{SC.PS} + Q_{HB.PS} - Q_{PS.HP} - Q_{PS.WD} - Q_{PS.SH} \qquad \text{Eq. (8)}$$
$$Q_{closs} = Q_{SS.HP} + Q_{SS.CB} - Q_{CD.SS} \qquad \text{Eq. (9)}$$

- Solar collector

Usage of the solar energy

$$\%_{SC.HP} = \frac{Q_{SC.HP}}{Q_{SC.system}} \qquad \text{Eq. (10)}$$
$$\%_{SC.PS} = \frac{Q_{SC.PS}}{Q_{SC.system}} \qquad \text{Eq. (11)}$$
$$\%_{SC.HD} = \frac{Q_{SC.HD}}{Q_{SC.system}} \qquad \text{Eq. (12)}$$
$$\%_{SC.WD} = \frac{Q_{SC.WD}}{Q_{SC.system}} \qquad \text{Eq. (13)}$$
$$\%_{SC.LO} = \%_{SC.PS} * \%_{PS.LO} \qquad \text{Eq. (14)}$$

- Leading to the overall percentage used for cooling, space heating and domestic hot water and taking attributable losses into account.

$$\%_{SC.C} = \%_{SC.HP} + \%_{SC.PS} * \%_{PS.HP} + \%_{SC.LO} * \frac{Q_{CD.system}}{Q_{HD.system} + Q_{WD.system} + Q_{CD.system}} \qquad \text{Eq. (15)}$$
$$\%_{SC.SH} = \%_{SC.HD} + \%_{SC.PS} * \%_{PS.HD} + \%_{SC.LO} * \frac{Q_{HD.system}}{Q_{HD.system} + Q_{WD.system} + Q_{CD.system}} \qquad \text{Eq. (16)}$$
$$\%_{SC.DHW} = \%_{SC.WD} + \%_{SC.PS} * \%_{PS.WD} + \%_{SC.LO} * \frac{Q_{WD.system}}{Q_{HD.system} + Q_{WD.system} + Q_{CD.system}} \qquad \text{Eq. (17)}$$

- Hot backup

Usage of the energy delivered by the hot backup

$$\%_{HB.HP} = \frac{Q_{HB.HP}}{Q_{HB.system}} \quad \text{Eq. (18)}$$

$$\%_{HB.PS} = \frac{Q_{HB.PS}}{Q_{HB.system}} \quad \text{Eq. (19)}$$

$$\%_{HB.HD} = \frac{Q_{HB.HD}}{Q_{HB.system}} \quad \text{Eq. (20)}$$

$$\%_{HB.WD} = \frac{Q_{HB.WD}}{Q_{HB.system}} \quad \text{Eq. (21)}$$

$$\%_{HB.LO} = \%_{HB.PS} * \%_{PS.LO} \quad \text{Eq. (22)}$$

- Leading to the overall percentage used for cooling, space heating and domestic hot water and taking attributable losses into account

$$\%_{HB.C} = \%_{HB.HP} + \%_{HB.PS} * \%_{PS.HP} + \%_{HB.LO} * \frac{Q_{CD.system}}{Q_{HD.system}+Q_{WD.system}+Q_{CD.system}} \quad \text{Eq. (23)}$$

$$\%_{HB.SH} = \%_{HB.HD} + \%_{HB.PS} * \%_{PS.HD} + \%_{HB.LO} * \frac{Q_{HD.system}}{Q_{HD.system}+Q_{WD.system}+Q_{CD.system}} \quad \text{Eq. (24)}$$

$$\%_{HB.DHW} = \%_{HB.WD} + \%_{HB.WD} * \%_{PS.WD} + \%_{HB.LO} * \frac{Q_{WD.system}}{Q_{HD.system}+Q_{WD.system}+Q_{CD.system}} \quad \text{Eq. (25)}$$

- Primary storage

Energy fluxes at the hot (primary) storage

$$\%_{PS.HP} = \frac{Q_{PS.HP}}{Q_{PS.system}+Q_{hloss}} \quad \text{Eq. (26)}$$

$$\%_{PS.WD} = \frac{Q_{PS.WD}}{Q_{PS.system}+Q_{hloss}} \quad \text{Eq. (27)}$$

$$\%_{PS.HD} = \frac{Q_{PS.HD}}{Q_{PS.system}+Q_{hloss}} \quad \text{Eq. (28)}$$

$$\%_{PS.LO} = \frac{Q_{hloss}}{Q_{PS.system}+Q_{hloss}} \quad \text{Eq. (29)}$$

- Secondary storage

Energy flow to the cold (secondary) storage can be divided by the two sources HP and CB.

$$\%_{SS.HP} = \frac{Q_{SS.HP}}{Q_{SS.system}} \quad \text{Eq. (30)}$$

$$\%_{SS.CB} = \frac{Q_{SS.CB}}{Q_{SS.system}} \quad \text{Eq. (31)}$$

- Losses relate to the output of the cold distribution system.

$$\%_{SS.LO} = \frac{Q_{closs}}{Q_{SS.system}} \quad \text{Eq. (32)}$$

- Cold distribution

The cold distribution can be divided in cold from heat pump (chiller) and cold backup. Cold losses are taken into account and spread between the two cold sources when feeding the cold storage.

$$\%_{CD.HP} = \frac{Q_{CD.HP}}{Q_{CD.system}} + \frac{Q_{SS.system}}{Q_{CD.system}+Q_{Closs}} * \%_{SS.HP} \qquad \textit{Eq. (33)}$$

$$\%_{CD.CB} = \frac{Q_{CD.CB}}{Q_{CD.system}} + \frac{Q_{SS.system}}{Q_{CD.system}+Q_{Closs}} * \%_{SS.CB} \qquad \textit{Eq. (34)}$$

3.3. Conversion factors

Table 2, Table 3 and Table 4 include conversion factors (efficiencies, primary energy, CO_2, etc.), which show the Task 48 Standard (agreed among participants) and country standard values fixed by national institutes (Austria: UIBK, Australia: CSIRO, France: TECSOL, Germany: Fraunhofer ISE, Italy: POLIMI). All values represent averages and/or values measured according to standards. Field performance efficiencies may differ from these values. The absolute values also depend on a number of assumptions and country specific input (e.g. transport, etc.).

For more detailed analysis monthly values for all conversions factors would be necessary. In this Task 48 and the specific Tool the monthly values are neglected. It is assumed that the monthly values of the conversion factors are the same as the annual values.

The factors are used to convert monitored and / or simulated data into the defined key figures and are implemented in the Excel Tool (chapter 5). Two extra columns (x1, x2) can be defined in the Tool for project specific conversions factors.

Standard boilers are used as reference or hot backup. Normal system configurations with thermal cooling do not allow deep return temperatures for the use of condensing boilers. Never the less if one wants to include a condensing boiler x1 or x2 can be used.

Table 2: Efficiency and primary energy factors for specific energy carrier (EC)

	efficiency of the boiler (LHV) - η_{HB} (-)				primary energy factor – ε_{EC} (kWh_{FE}/kWh_{prim})			
country	natural gas	reference	pellets	reference	natural gas	reference	pellets	reference
Austria	0.875	H 5056	0.814	H 5056	0.854	OIB 6	5	ENEV09
Australia	0.66	RIS	0.85	Ass.	0.9	Ass.	5	Ass.
France	0.91	RT2012	0.78	RT2012	1	RT2012	1.7	BBC
Germany	up to 0.96	NRW	0.85-0.95	Ass.	0.9	ENEV09	5	ENEV09
Italy	0.9	Ass.	0.85	Ass.	0.86	prEN15315	5	
T48 Standard	0.90		0.85		0.9		5	

The conversion factors for electricity represent conventional power generation, transmission losses are not included. The conversion factors are especially sensible on the fuel mix and might even vary in one country (e.g. Australia). An Average value is used in the excel tool then. If specific values should be used, define own values in the columns (x1, x2).

Table 3: Conversion factors for electricity

country	primary energy - ε_{el} (kWh_{FE}/kWh_{prim})	reference	CO_2 factor (kg/kWh)	reference
Austria	0.465	OIB 6	0.417	OIB 6
Australia	0.4	Ass.	0.2268-1.3356	ANGA
France	0.388	RT2012	0.18 (heating) & 0.04 (cooling)	ADEME & EDF (2005)
Germany	0.416 (0.55)	ENEV2014 (planed for ENEV2016)	0.562 (0.559)	UBA (2012) (ass. 2013)
Italy	0.46	AEEGSI	0.562	ISPRA 2012
T48 Standard	0.4		0.55	

Table 4: CO_2 factors for different energy carrier

country	natural gas (kg/kWh)	reference	pellets	reference
Austria	0.236	OIB 6	0.027	KEA
Australia	0.198-0.233	ANGA	0	ANGA
France	0.209	ADEME	0.04	ADEME
Germany	0.247	KEA	0.027	KEA
Italy	0.213	POLIMI	0.026	Progetto RACES
T48 Standard	0.26		0.045	

3.4. Reference - VCC

The reference (ref) system was designed and calculated by Cofely Kaeltetechnik GmbH in Austria [Cofely 2014]. Depending on the capacity (5-1'000 kW) the state of the art technology was chosen. Cofely selected the corresponding technologies for compressor, heat exchangers, pumps, control strategies, configuration (one circuit: VCC and load in series, two circuit: VCC and load parallel), storage volume, etc. for water- and air-cooled VCCs.

Important boundary conditions for the calculation of EER / ESEER are the temperature and loads according to the EUROVENT certification scheme (Table 5). On the evaporator side the conditions for air-conditioning are chosen as reference (7/12 °C).

Table 5: Boundary conditions for the calculation of EERs according to Eurovent

	Inlet temp. condenser (°C)		Load (%)	Weighting factors
	water cooled	air cooled		
EER_A	30	35	100	A = 0.03
EER_B	26	30	75	B = 0.33
EER_C	22	25	50	C = 0.41
EER_D	18	20	25	D = 0.23

The ESEER (European Seasonal Energy Efficiency ratio) for vapor compression chiller (Eq. (35) is calculated with the weighted EERs of the different loads (according to Eurovent). The factors A, B, C and D characterize the percentage of hours operated under the specific boundary conditions.

$$ESEER = A \cdot EER_A + B \cdot EER_B + C \cdot EER_C + D \cdot EER_D \qquad \textit{Eq. (35)}$$

Information of the chosen technology and the results can be found in Table 6 and Figure 8. In the Excel tool just 75 % of the calculated ESEER is taken into account, because the boundary conditions of EUROVENT and real installed cases may differ. The ESEER is interpolated linearly between the calculated capacities.

Table 6: SPF_{ref} (complete system) for vapor compression chillers and different sizes

	Configuration (1/2 circuits) & type of compressor		EER at 100% load (-)		ESEER (-)	
Capacity (kW)	water cooled	air cooled	water c.	air c.	water c.	air c.
5	-	1c, scroll.	-	2.75	-	3.95
10	-	1c, scroll.	-	2.85	-	4.44
20	1c, scroll	1c, scroll.	3.73	2.99	3.05	4.08
50	1c, scroll	1c, scroll.	3.60	2.73	4.06	4.20
100	1c, scroll	1c, scroll.	3.75	2.78	4.25	4.19
250	2c, scroll / 2c, turbo	2c, scroll / 2c, turbo	3.65 / 4.44	2.71/ 3.28	4.19 / 5.84	3.95 / 4.71
500	2c, turbo	2c, screw / 2c, turbo	4.53	3.07/ 3.32	5.81	3.78 / 5.09
1000	2c, turbo	2c, screw / 2c, turbo	4.43	3.22/ 3.37	5.99	3.94 / 5.06

Figure 8 left shows the reference values for ESEER of water and air cooled VCC. Up to a capacity of 100 kW the ESEERs increases. With growing capacity the ESEER of air cooled VCC remains around 4 (for screw comp.). With the change to turbo compressors at 250 kW the ESEER has an abruptly increase from 4 up to ca. 6. With further increase in capacity the ESEER of water cooled VCC remains at 6.

Cofely also provided the costs for all configurations. Specific costs per kW capacity for water and air cooled VCCs are compared in Figure 8 right. Investment costs decrease rapidly with increasing capacity up to 250 kW. Between 250 and 1’000 kW just a slight cost decrease can be seen.

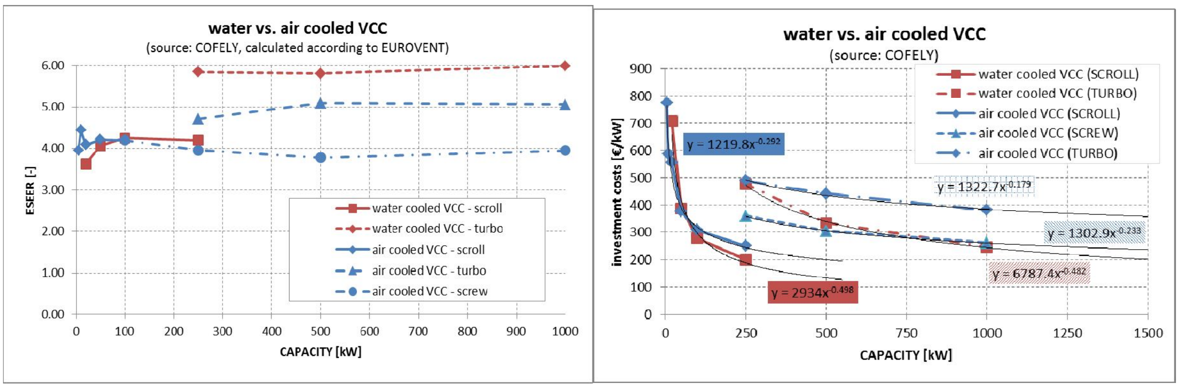


Figure 8: Reference values for ESEERs (left) and specific costs per kW capacity (right) for water- and air- cooled VCCs

3.5. Seasonal Performance Factor - SPF

The **Seasonal Performance Factor** can generally be defined as the ratio of useful energy output to energy input with respect to a given system boundary *i* (Eq. (36):

$$SPF_i = \frac{\sum Q_{i,out}}{\sum E_{i,in}}$$
Eq. (36)

Especially in hybrid systems different types of end energies are used for system operation: Beside the electrical energy, gas, oil, biomass or heat from a district heating network or waste heat from an industrial process might be used. Due to different energy types and their specific exergy, economic values and environmental impacts have to be evaluated separately. For a system with thermal (or chemical) and electric energy inputs, the electrical and thermal SPF has to be provided independently from each energy input (Eq. (37), (Eq. (38):

$$SPF_{i,th} = \frac{\sum Q_{i,out}}{\sum Q_{i,in}}$$
Eq. (37)

$$SPF_{i,el} = \frac{\sum Q_{i,out}}{\sum W_{el,i,in}}$$
Eq. (38)

Different boundaries can be defined and used depending on the goal of the key figure. Five possibilities are listed in the Task 44 / Annex 38 report. Defining the SPF at system level and breaking it down to single components.

In Task 48 five different boundaries are defined and discussed below. Main goal is to analyze and evaluate following subsystems and its efficiency separately.

Overall system (including cooling, domestic hot water and space heating)	- sys
Cooling (overall performance of the cooling system)	- C
Thermal cooling (performance of the ab-/adsorption chiller)	- thC
Space heating (including backup)	- SH
Domestic hot water (including backup)	- DHW

3.5.1. Overall System Performance (el)

The equation of the overall electrical system performance base on the ratio sum of energy flow from total cold distribution to system ($Q_{CD.sys}$), from hot distribution to system ($Q_{HD.sys}$) and from water distribution to system ($Q_{WD.sys}$) to the sum of total electrical energy flow of the system ($Q_{el,sys}$) (Eq. (39)).

$$SPF_{el,sys} = \frac{Q_{CD.sys}+Q_{HD.sys}+Q_{WD.sys}}{\sum Q_{el,sys}} \qquad \textit{Eq. (39)}$$

Using all electricity consumptions, except the electricity demand for the distributions pumps (CD, HD, WD), the sum of the total electrical energy flow is given in (Eq. (40).

$$\sum Q_{el,sys} = Q_{el.SP} + Q_{el.HT} + Q_{el.MT} + Q_{el.LT} + Q_{el.HP} + Q_{el.MC} + Q_{el.LC} + Q_{el.CB} + Q_{el.CA} + Q_{el.CC} + Q_{el.LT} \qquad \textit{Eq. (40)}$$

The result of the overall efficiency $SPF_{el,sys}$ depends on the system configuration and its fraction of cooling, heating and domestic hot water. The system boundary and the most important energy flows (no direct usage of SC, EC) are shown in Figure 9.

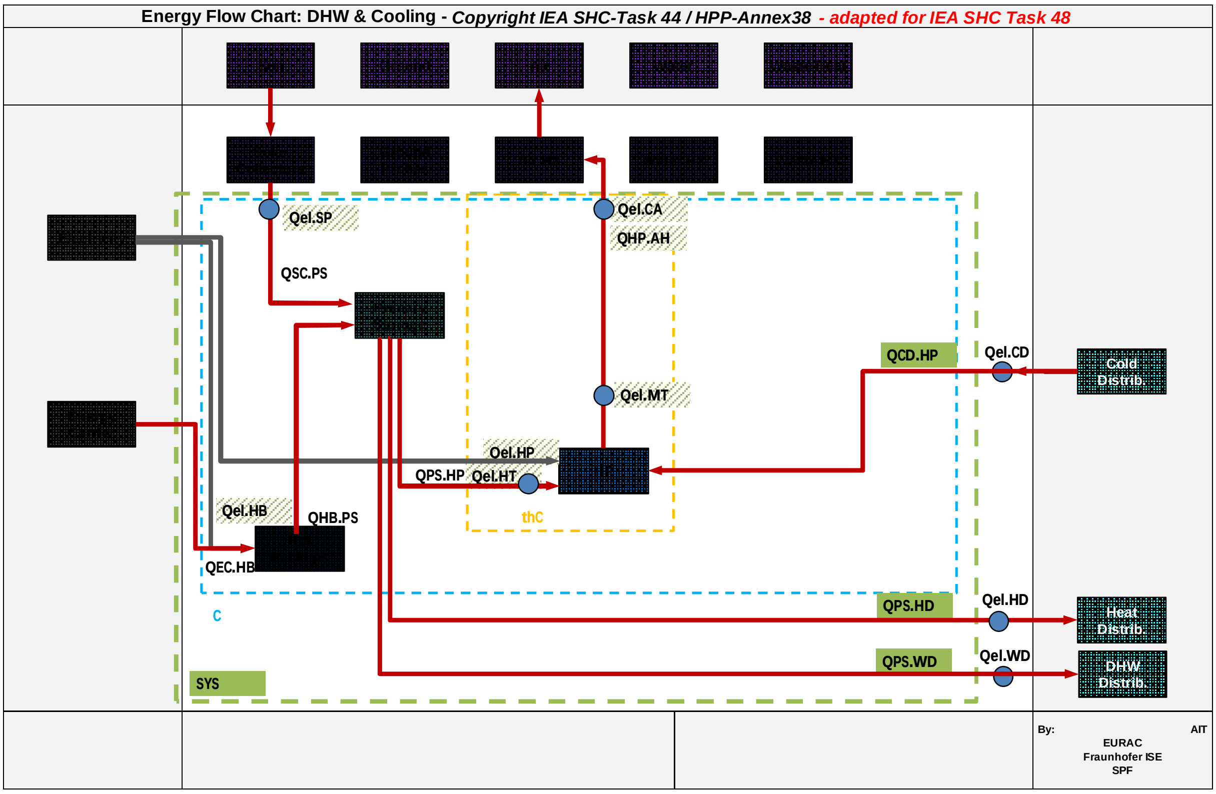


Figure 9: system boundary and possible energy flows for the $SPF_{el,sys}$

3.5.2. Cold production by thermal cooling (ACM including hot backup) (el)

The numerator includes the energy flow “cold distribution to secondary storage” times the percentage of “heat pump to the secondary cooling storage” plus the energy flow “cold distribution to heat pump”. The denominator equals the sum of electricity used for thermal cooling (Eq. (42)). Eq. (43) describes the electrical energy flow of the ACM. The ratio of Eq. (41) characterizes the electrical SPF for thermal cooling.

$$SPF_{el,thC} = \frac{Q_{CD.SS} \cdot \%_{C,SS.HP} + Q_{CD.HP}}{\sum Q_{el,th.C}} \qquad \text{Eq. (41)}$$

With

$$\sum Q_{el,thC} = Q_{el.SP} \cdot \%_{SC.C} + Q_{el.ACM} + Q_{el.HB} \cdot \%_{HB.C} \qquad \text{Eq. (42)}$$

$$\sum Q_{el,ACM} = Q_{el.HT} + Q_{el.MT} + Q_{el.LT} + Q_{el.HP} + Q_{el.CA} \qquad \text{Eq. (43)}$$

The electrical energy for ACM ($Q_{el.ACM}$) includes all three external circuits and the consumption of the chiller ($Q_{el.HP}$) itself. The overall electricity of thermal cooling includes the $Q_{el.ACM}$ and also the solar and hot backup electricity consumptions. The percentages of hot backup ($\%_{HB.C}$) and solar collector ($\%_{SC.C}$) represent the fractions that are used for the thermal cooling production only. This approach neglects differences in performance due to different temperature requirements, control strategies, etc. if one of the devices is used for other distributions only.

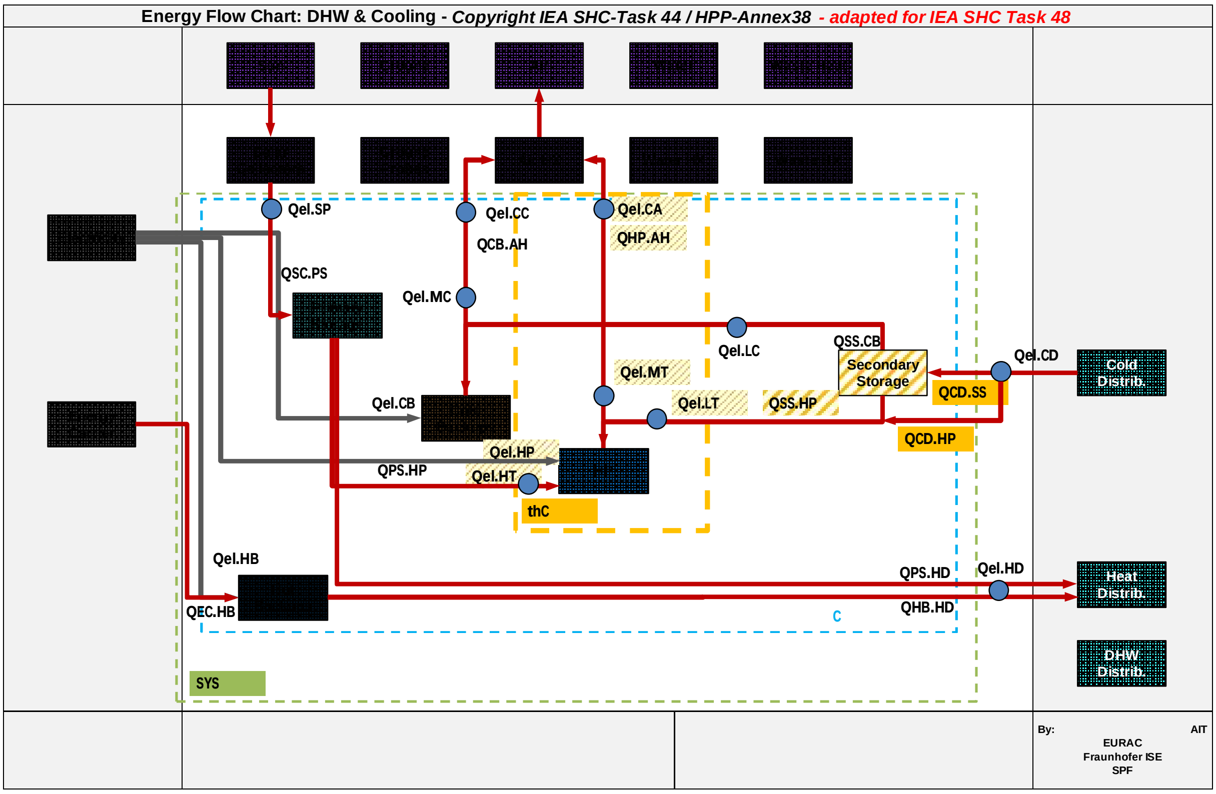


Figure 10: System boundary and possible energy flows for the $SPF_{el.thC}$

This $SPF_{el.thC}$ represents the performance of the thermal cooling (ACM + hot backup) and its cold water production including all main electricity consumptions (Figure 10).

3.5.3. Overall cold production by ACM and backups (hot or cold) (el)

The $SPF_{el,C}$ (Eq. (44)) equals the ratio of energy flows of cold distribution to secondary storage ($Q_{CD.SS}$), 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 for the supply of the overall chilled water ($Q_{el,C}$) in the denominator (Eq. (45)). The percentage definitions of chapter 0 are used.

$$SPF_{el,C} = \frac{Q_{CD.SS} + Q_{CD.HP} + Q_{CD.CB}}{\sum Q_{el,C}} \qquad \text{Eq. (44)}$$

with

$$\sum Q_{el,C} = Q_{el.SP} \cdot \%_{SC.C} + Q_{el.ACM} + Q_{el.VCC} + Q_{el.HB} \cdot \%_{HB.C} = Q_{el.thC} + Q_{el.VCC} \qquad \text{Eq. (45)}$$

$$\sum Q_{el.ACM} = Q_{el.HT} + Q_{el.MT} + Q_{el.LT} + Q_{el.HP} + Q_{el.CA} \qquad \text{Eq. (46)}$$

$$\sum Q_{el.VCC} = Q_{el.MC} + Q_{el.LC} + Q_{el.CB} + Q_{el.CC} \qquad \text{Eq. (47)}$$

This $SPF_{el,C}$ represents the performance of the cold water production including all electricity consumptions and heat rejection devices (Figure 11).

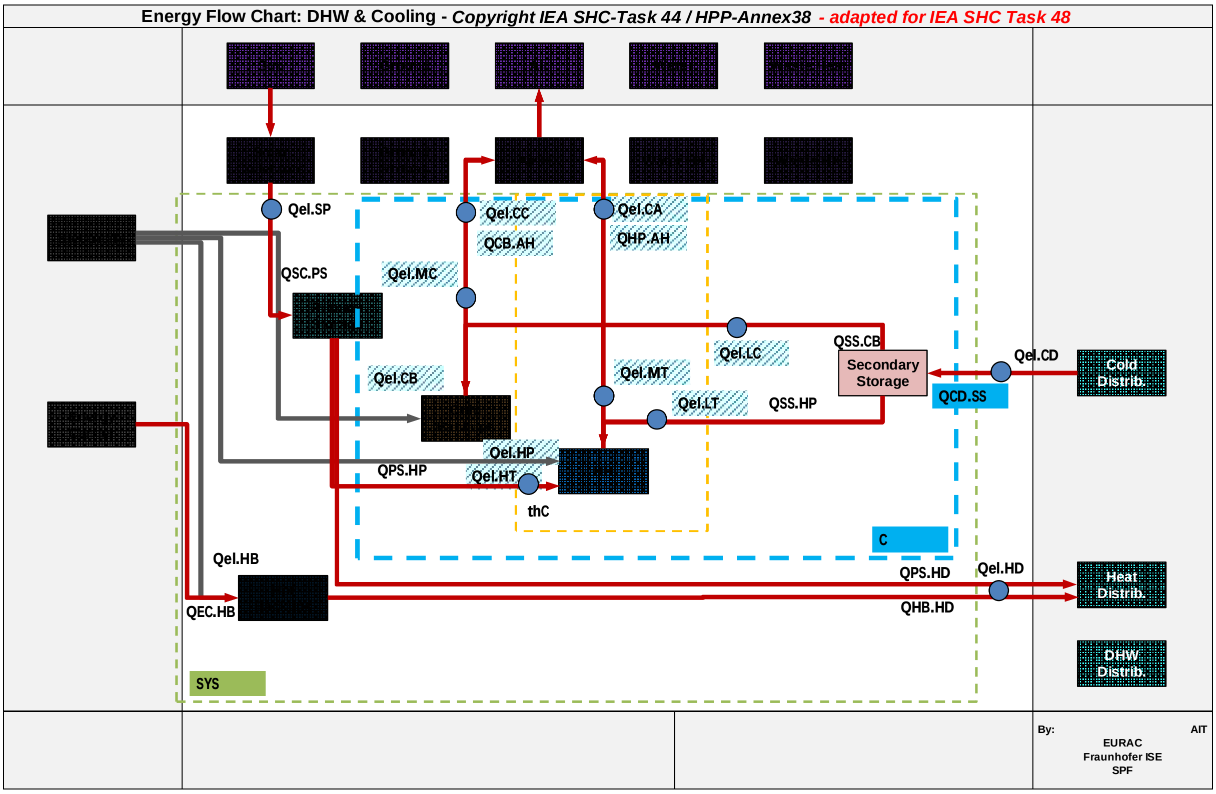


Figure 11: System boundary and possible energy flows for the $SPF_{el,C}$

3.5.4. Space heating and domestic hot water (el)

The nominator of $SPF_{el.SH}$ (Eq. (48) includes the energy flows “primary storage to heat distribution” ($Q_{PS.HD}$), “solar collectors to heat distribution” ($Q_{SC.HD}$) and “hot backups to heat distribution” ($Q_{HB.HD}$). The denominator (Eq. (50)) is the sum of all electrical energy flows used for space heating ($Q_{el.SH}$).

$$SPF_{el.SH}=\frac{Q_{PS.HD}+Q_{SC.HD}+Q_{HB.HD}}{\sum Q_{el.SH}} \qquad \text{Eq. (48)}$$

The nominator of $SPF_{el.DHW}$ (Eq. (49)) includes the energy flows “primary storage to DHW distribution” ($Q_{PS.WD}$), “solar collectors to DHW distribution” ($Q_{SC.WD}$) and “hot backups to DHW distribution” ($Q_{HB.WD}$). The denominator is the sum of all electrical energy flows used for domestic hot water preparation ($Q_{el.DHW}$) (Eq. (51)).

$$SPF_{el.DHW}=\frac{Q_{PS.WD}+Q_{SC.WD}+Q_{HB.WD}}{\sum Q_{el.DHW}} \qquad \text{Eq. (49)}$$

with

$$\sum Q_{el.SH} = Q_{el.SP} \cdot \%_{SC.SH} + Q_{el.HB} \cdot \%_{HB.SH} \qquad \text{Eq. (50)}$$

$$\sum Q_{el.DHW} = Q_{el.SP} \cdot \%_{SC.DHW} + Q_{el.HB} \cdot \%_{HB.DHW} \qquad \text{Eq. (51)}$$

This $SPF_{el,SH}$ and $SPF_{el.DHW}$ represents the performance of space heating and domestic hot water production including all electricity consumptions, except the distribution pumps as they are outside the system boundary.

3.5.5. Thermal SPF (th)

Two figures are calculated here; the first one follows the known definition ($SPF_{th.C}$) and represents the chiller performance (Eq. (52)). The second one is on system level ($SPF_{th.sys}$) and includes the hot water storage losses. The $SPF_{th.sys}$ (Eq. (53)) can be interpreted as $SPF_{th.C}$ multiplied by the storage efficiency. If a solar thermal system is used for cooling only (with high solar fractions) high standby times can occur and the system performance is low.

$$SPF_{th.C}=\frac{Q_{SS.HP}+Q_{CD.HP}}{Q_{SC.HP}+Q_{PS.HP}+Q_{HB.HP}} \qquad \text{Eq. (52)}$$

$$SPF_{th.sys}=\frac{Q_{SS.HP}+Q_{CD.HP}}{Q_{SC.system}*\%_{SC.C}+Q_{HB.system}*\%_{HB.C}} \qquad \text{Eq. (53)}$$

3.6. Primary Energy Ratio - PER

In most cases the SPF provides a good figure to estimate the quality of the subsystem. Difficulties may occur when rating the overall system performance, because of different quality ratings for cooling, space heating or domestic hot water. Under given operating conditions, the **Primary Energy Ratio (PER)** gives more in-depth information under the economic or environmental point of view. It is defined as the ratio of the useful energy output to the primary energy input to the system boundary (Eq. (54)). To be able to calculate the PER, certain primary energy conversion factors for every type of energy input have to be provided (see chapter 3.3).

$$PER_i = \frac{\sum Q_{i,out}}{\sum\left(\frac{Q_{el,i,in}}{\varepsilon_{el}} + \frac{Q_{i,in}}{\varepsilon_{in}}\right)} \qquad \textit{Eq. (54)}$$

Depending on the aim of the calculation, the primary energy can be defined as “overall” (e.g. for the analysis of the economic aspects) or “non-renewable only” (e.g. to estimate net emissions). The primary energy factors ε_i depend on the location of the system, time of the year and on local policies. However, some generalized values are given in the national Annexes of the EN 15316 or in EN 15603:2008. If substituted with emission factors (e.g. expressed in $kgCO_{2,equ}$ per kWh energy) or energy price (e.g. expressed in monetary unit per kWh energy), the equivalent CO_2 emissions or the energy costs of the system over the considered period of time can be obtained.

For comparison with conventional technologies a simple reference system can be defined based on known useful heat consumption (measured or simulation results) for DHW, SH and cooling. This procedure was developed by Thomas Letz [Letz, 2002] done within IEA SHC Task 26 and Task 32 for solar heating systems. It was further extended for solar heating and cooling systems and described in detail in the IEA SHC Task 38 report “Monitoring Procedure for Solar Cooling Systems - A joint technical report of subtask A and B (D-A3a / D-B3b)” [Napolitano, 2011].

3.6.1. Reference System

The primary energy ratio PER_{ref_NRE} for the reference system taking only “**N**on **R**enewable **E**nergy” into account and is defined in Eq. (55). A further differentiation is made between cooling ($PER_{NRE.ref.C}$, Eq. (56)), domestic hot water ($PER_{NRE.ref.DHW}$, Eq. (58)) and space heating ($PER_{NRE.ref.SH}$, Eq. (59)).

$$PER_{NRE.ref.sys} = \frac{Q_{HD.sys} + Q_{WD.sys} + Q_{CD.sys}}{\frac{Q_{HD.sys} + Q_{WD.sys} + Q_{loss.ref}}{\varepsilon_{EC.ref} * \eta_{HB.ref}} + \frac{Q_{CD.sys}}{SPF_{ref} * \varepsilon_{el}} + \frac{Q_{el.ref}}{\varepsilon_{el}}} \qquad \textit{Eq. (55)}$$

$$PER_{NRE.ref.C} = SPF_{ref} * \varepsilon_{el} \qquad \textit{Eq. (56)}$$

$$PER_{NRE.ref.thC} = SPF_{CB.th} * \varepsilon_{el} \qquad \textit{Eq. (57)}$$

$$PER_{NRE.ref.DHW} = \frac{Q_{WD.sys}}{\frac{Q_{WD.sys} + Q_{loss.ref}}{\varepsilon_{EC.ref} * \eta_{HB.ref}} + \frac{Q_{el.ref.DHW}}{\varepsilon_{el}}} \qquad \textit{Eq. (58)}$$

$$PER_{NRE.ref.SH} = \frac{Q_{HD.sys}}{\frac{Q_{HD.sys}}{\varepsilon_{EC.ref}*\eta_{HB.ref}}+\frac{Q_{el.ref.SH}}{\varepsilon_{el}}} \qquad \textit{Eq. (59)}$$

Heat losses of a reference domestic hot water tank are calculated in Eq. (60).

$$Q_{loss_{ref}} = 0.00016 * \sqrt{0.75 * V_D} * (T_T - T_a) * 8760 \qquad \textit{Eq. (60)}$$

V_D … average daily hot water consumption [liter / day]
T_T … set point temperature of the hot water tank (default 52.5 °C)
T_a … ambient temperature around the hot water tank (default 15 °C)
For an annual calculation 8'760 hours are valid. For seasonal or monthly calculations the number of hours must be adapted accordingly.

The reference calculation includes several reference values for a standardized comparison (Eq. (61), Eq. (62) and Eq. (63). Most of them are defined in chapter 3.3 "Conversion factors". Additionally the parasitic electricity consumption for a reference system (e.g. boiler, pumps, etc.) in (kWh_{el}) has to be defined.

$$Q_{el.ref} = 0.02 * (Q_{HD.sys} + Q_{WD.sys} + Q_{loss_{ref}}) \qquad \textit{Eq. (61)}$$

$$Q_{el.ref.DHW} = 0.02 * (Q_{WD.sys} + Q_{loss_{ref}}) \qquad \textit{Eq. (62)}$$

$$Q_{el.ref.SH} = 0.02 * (Q_{HD.sys}) \qquad \textit{Eq. (63)}$$

The reference values for PER cooling and thermal cooling are calculated in the same way. The cooling value uses the SPF_{ref}, which is calculated with the reference cooling peak load, the chosen chiller type and the reference ESEER to SPF. The reference of PER thermal cooling in comparison is calculated with the $SPF_{CB.th}$, which use the absorption chiller capacity, the vapor compression chiller type and also the reference ESEER to SPF. So the cooling value displays the reference system. The thermal cooling value shows the theoretical value for a vapor compression chiller with the same capacity as the absorption chiller. The values are interpolated within Table 6 according to following equations.

$$SPF_{ref} = ESEER_{ref.to.SPF} * (SPF_{up.i} + \frac{SPF_{lo.i}-SPF_{up.i}}{(P_{lo.i}-P_{up.i})*(P_{CD}-P_{up.i})}) \qquad \textit{Eq. (64)}$$

$$SPF_{CB.th} = ESEER_{ref.to.SPF} * (SPF_{up.i} + \frac{SPF_{lo.i}-SPF_{up.i}}{(P_{lo.i}-P_{up.i})*(P_{ACM}-P_{up.i})}) \qquad \textit{Eq. (65)}$$

$ESEER_{ref.to.SPF}$ is the reference value to convert the ESEER to SPF with a standard value of 0.75. SPF_{lo}, SPF_{up}, P_{lo}, P_{up} are the lower and upper SPF and accordingly capacities (P) values, which are looked up at the Table 6 by their individual capacity (P_{CD} and P_{ACM}).

The reference system of T48 contains a natural gas boiler and an air cooled vapor compression chiller. A small hot water tank for domestic hot water is included. The cold water storage volume is calculated according to standards of Cofely. No hot water storage is considered. The specific reference system can be chosen including biomass boilers, water storages, etc.

3.6.2. Overall System Performance

The determination of $PER_{NRE,sys}$ is comparable with the one of $SPF_{el.sys}$ and can be seen in Eq. (66).

$$PER_{NRE,sys} = \frac{Q_{CD.sys}+Q_{HD.sys}+Q_{WD.sys}}{\frac{\sum Q_{el.sys}}{\varepsilon_{el}}+\frac{Q_{EC.HB}}{\varepsilon_{EC}}} \quad \text{Eq. (66)}$$

Using the same definition like in $SPF_{el.sys}$ (Eq. (39), ε_{EC} is depending on the type of energy source (energy carrier) for the hot backup ($Q_{EC.HB}$).

3.6.3. Thermal cooling only

The $PER_{NRE,thC}$ (Eq. (67) is comparable with the $SPF_{el.thC}$ (Eq. (41), which takes the thermal cold production into account.

$$PER_{NRE,thC} = \frac{Q_{SS.HP}+Q_{CD.HP}}{\frac{\sum Q_{el.thC}}{\varepsilon_{el}}+\frac{Q_{EC.HB}*\%_{HB.C}}{\varepsilon_{EC}}} \quad \text{Eq. (67)}$$

The energy flow and percentage terms correlate to the one in $SPF_{el,thC}$.

3.6.4. Overall Cold production by ACM and backups (hot or cold)

The $PER_{NRE,C}$ (Eq. (68) is comparable with the $SPF_{el.C}$ (Eq. (44).

$$PER_{NRE,C} = \frac{Q_{CD.SS}+Q_{CD.HP}+Q_{CD.CB}}{\frac{\sum Q_{el.C}}{\varepsilon_{el}}+\frac{Q_{EC.HB}*\%_{HB.C}}{\varepsilon_{EC}}} \quad \text{Eq. (68)}$$

The energy flow ($Q_{el.C}$) and percentage ($\%_{HB.C}$) terms correlate to the one in $SPF_{el.C}$.

3.6.5. Space heating and domestic hot water

The $PER_{NRE.SH}$ (Eq. (69)) and $PER_{NRE.DHW}$ (Eq. (70)) are comparable with the $SPF_{el.SH}$ (Eq. (48)) and $SPF_{el.DHW}$ (Eq. (49)).

$$PER_{NRE.SH} = \frac{Q_{HD.sys}}{\frac{\sum Q_{el.SH}}{\varepsilon_{el}}+\frac{Q_{EC.HB}*\%_{HB.SH}}{\varepsilon_{EC}}} \quad \text{Eq. (69)}$$

$$PER_{NRE.DHW} = \frac{Q_{WD.sys}}{\frac{\sum Q_{el.DHW}}{\varepsilon_{el}}+\frac{Q_{EC.HB}*\%_{HB.DHW}}{\varepsilon_{EC}}} \quad \text{Eq. (70)}$$

The energy flow ($Q_{el.SH}$) and percentage ($\%_{HB.SH}$) terms correlate to the one in $SPF_{el.SH}$.

3.7. Fractional savings - f_{sav}

In order to compare the renewable SHC system with a reference system the **fractional savings (f_{sav})** can be used. Thereby the reference system can also be another renewable system. The non-renewable primary energy savings ($f_{sav\text{-}NRE.PER}$) in comparison to a reference system can be calculated as follows (Eq. (71)):

$$f_{sav.NRE.PER} = 1 - \frac{PER_{NRE.ref}}{PER_{NRE.i}} \qquad \textit{Eq. (71)}$$

General saving can be calculated when substituting PER with any other magnitude of interest (CO_2, costs, etc.) for the reference system and the investigated system:

$$f_{sav.NRE.PER.sys} = 1 - \frac{PER_{NRE.ref.sys}}{PER_{NRE.sys}} \qquad \textit{Eq. (72)}$$

$$f_{sav.NRE.PER.C} = 1 - \frac{PER_{NRE.ref.C}}{PER_{NRE.C}} \qquad \textit{Eq. (73)}$$

$$f_{sav.NRE.PER.thC} = 1 - \frac{PER_{NRE.ref.thC}}{PER_{NRE.thC}} \qquad \textit{Eq. (74)}$$

$$f_{sav.NRE.PER.SH} = 1 - \frac{PER_{NRE.ref.SH}}{PER_{NRE.SH}} \qquad \textit{Eq. (75)}$$

$$f_{sav.NRE.PER.DHW} = 1 - \frac{PER_{NRE.ref.DHW}}{PER_{NRE.DHW}} \qquad \textit{Eq. (76)}$$

Since f_{sav} is not intuitive to understand and not common in the standard nomenclature it is useful to convert the obtained results and figures into a known quantity, like the seasonal performance factor (SPF).

3.8. Equivalent Seasonal Performance Factor - SPF_{equ}

The **equivalent Seasonal Performance Factor (SPF_{equ})** can be used to compare the investigated solar heating and cooling system with a reference vapor 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 (Eq. (77). Same SPF_{equ}'s indicates finally an equal primary demand of different systems.

$$\left[\frac{kWh_{th}}{kWh_{el}} = \frac{\frac{kWh_{th}}{kWh_{prim}}}{\frac{kWh_{el}}{kWh_{prim}}} = \frac{PER_{NRE,i}}{\varepsilon_{el}}\right] \qquad \textit{Eq. (77)}$$

For the defined boundaries the SPF_{equ} are calculated as follows.

$$SPF_{equ.thC} = \frac{PER_{NRE,thC}}{\varepsilon_{el}} \qquad \textit{Eq. (78)}$$

$$SPF_{equ.C} = \frac{PER_{NRE,C}}{\varepsilon_{el}} \qquad \textit{Eq. (79)}$$

$$SPF_{equ.SH} = \frac{PER_{NRE,SH}}{\varepsilon_{el}} \qquad \textit{Eq. (80)}$$

$$SPF_{equ.DHW} = \frac{PER_{NRE,DHW}}{\varepsilon_{el}} \qquad \textit{Eq. (81)}$$

$$SPF_{equ.sys} = \frac{PER_{NRE,sys}}{\varepsilon_{el}} \qquad \textit{Eq. (82)}$$

3.9. Incremental Solar System Performance Metrics

In some circumstances it may be preferable to use metrics that determine only the component that is “the change”, resulting from introducing solar heating and cooling to an otherwise reference business-as-usual base case form of heating and cooling provision. Ideally this would be done in a manner that fully harmonizes all forms of energy (electricity, heat, cold) into a single comparable form.

While SPF and PER are performance metrics based on all the energy flows (solar and fossil derived) incurred in delivering a complete heating and cooling system, the incremental performance metrics below deal only with the energy flows that are different from business as usual.

3.9.1. Incremental Solar Cooling Capacity (CAP_{thC})

At a superficial level, the name-plate cooling capacity of an absorption chiller could be used to define the thermal cooling capacity of a solar cooling system. However, this approach (if incorporated into an incentive scheme) could result in the practice of over-sizing the absorption chiller, relative to the solar collector field, to achieve higher subsidies based on a high apparent capacity, but very low solar fraction. This practice could result in excessive use of gas backup and undesirable on/off cycling of the absorption chiller.

Instead a maximum capacity approach is taken. The CAP is the average reduction in peak electricity demand (kVA or kW) resulting from the solar heating and cooling system. The period of interest cannot be defined generally. When peak avoidance should be rated the period of interest has to be chosen accordingly.

It should be noted however that different parts of the grid are subject to different peak demand constraints. For example, the centralized electricity generation plant is producing electricity into the whole of the grid and is generally seeing a peak demand constraint in the early afternoon. In contrast, a residential dominated electricity distribution substation would typically see peak demand in the late afternoon as people come home from work and turn on the air-conditioner to cool down a house that has heated up over the day. Furthermore the duration of the peak period may vary significantly based on the nature of the dominant load being serviced by the electricity grid (industrial vs commercial vs residential) and the climate.

Consequently there is not one size that fits all rules for the duration and timing of the peak demand period over which the capacity of the solar cooling system should be evaluated. It is also assumed that peak solar production and utilization is in summer cooling mode rather than winter heating mode, and hot water production is ignored.

Another complication is the impact of thermal storage. If the duration of the monitored peak period is taken as a quite short period (say one hour) then the possible coincidence (or not) of the peak demand measurement period occurring at the same time as drawing down of thermal energy from the thermal store, could lead to an artificially inflated or deflated measurement of peak capacity.

Eq. (83) uses this approach to describe capacity in terms of an incremental avoided peak demand in electrical equivalent units. Where electricity is not the form of energy under consideration (e.g. thermal heat energy or thermal cooling energy) then energy is converted into electrical equivalents using primary energy conversion factors or the reference vapor compression EER factor respectively.

$$CAP_{solar} = \frac{\left(\frac{Q_{CD.sys}+Q_{closs}-Q_{CB.sys}}{EER_{ref}(f(kW))} - \frac{Q_{HB.sys}*\%_{HB.C}*\epsilon_{el}}{\epsilon_{EC}*\eta_{HB}} - \Delta E_{aux.thC}\right)}{t} \qquad \textit{Eq. (83)}$$

Description of terms of Eq. (83):

- CAP_{solar} is the incremental peak electrical savings rate (capacity) from solar cooling in electrical equivalent units (kW_{el}).
- $Q_{CD.sys}, Q_{CB.sys}, Q_{HB.sys}$ are energy flows (kWh) as defined in Figure 7, summed over the period of interest.
- Q_{closs} characterize the refrigeration losses, being the measured difference between the refrigeration produced by the chiller and air conditioning provided to the building, when solar cooling is not operating. In the absence of a suitable measurement, this is assumed to be zero. Currently only defined as the storage losses: $Q_{Closs} = Q_{SS.CB} + Q_{SS.HP} - Q_{CD.SS}$
- EER_{ref} is the design energy efficiency ratio of the reference vapor compression chiller (see Table 6 or chapter 3.4)
- ε_{el}; η_{HB}; ε_{EC} are the conversion factors defined in chapter 3.3
- $\%_{HB.C}$ is the fraction from the hot backups for cooling
- $\Delta E_{aux.thC}$ is the difference in the electrical consumption of auxiliary equipment (cooling tower fans, pumps etc.) between the solar thermal system and a reference system (Eq. (84)). The default electricity consumption of the auxiliary equipment in the reference system ($q_{el.ref}$) is 0 kWh_{el}/kWh_{cold} for small and 0.03 kWh_{el}/kWh_{cold} for large systems.

$$\Delta E_{aux.thC} = Q_{el.ACM} - Q_{el.thC.ref} \qquad \text{Eq. (84)}$$

$$Q_{el.thC.ref} = q_{el.ref} * (Q_{SS.HP} + Q_{CD.HP}) + (Q_{el.SP} * \%_{SC.C}) \qquad \text{Eq. (85)}$$

- t is the duration of the period of interest (e.g. 3 hours, etc.)

Full capacity (design) EER is used in equation above, because the equation aims to represent peak performance at design conditions rather than average performance over a season.

Where the capacity is preferentially expressed as a metric that is relative to the size of the air-conditioning load, then Eq. (86) can be normalized to the floor area of the air conditioned space

$$\widehat{CAP}_{solar} = \frac{CAP_{solar}}{A} \qquad \text{Eq. (86)}$$

$\widehat{CAP}_{solar}$ is the peak electrical savings rate per unit floor area (kW_{el}/m^2).

A is the net lettable floor area of the building (m^2).

3.9.2. Incremental Energy Saved (ΔE_{e-equ})

Primary energy savings are summed over the entire year and include all of winter heating, summer cooling and domestic hot water. All components are converted into equivalent electrical energy savings by using an appropriate primary energy ratio to convert heat to electricity, and utilizing appropriate reference efficiencies for the business as usual alternative heating or cooling appliance. The default business-as-usual reference efficiencies base on a gas boiler being used for space heating and domestic hot water, and a vapor compression chiller for space cooling.

The Incremental Energy Saved in electrical equivalents units equals to

(1) + Heating and domestic hot water solar input

(2) +Thermal cooling (solar + hot backup) input

(3) – hot backup input

(4) - parasitic electricity consumption

The resulting equation for ΔE_{e-equ} is Eq. (87):

$$\Delta E_{e-equ} = \frac{(Q_{WD.sys}+Q_{HD.sys}+Q_{hloss})*\varepsilon_{el}}{\varepsilon_{EC}*\eta_{HB}} + \frac{Q_{HP.sys}+Q_{closs}}{SPF_{CB.th}} - \frac{(Q_{HB.sys})*\varepsilon_{el}}{\varepsilon_{EC}*\eta_{HB}} - (\Delta E_{aux.sys} + Q_{el.VCC}) \quad \textit{Eq. (87)}$$

The subsystem figures are calculated as following.

$$\Delta E_{e\_equ\_C} = \Delta E_{e\_equ\_thC} + \frac{(Q_{hloss}*\%_{SC.C})*\varepsilon_{el}}{\varepsilon_{EC}*\eta_{HB}} - Q_{el.VCC} \quad \textit{Eq. (88)}$$

$$\Delta E_{e\_equ\_thC} = \frac{(Q_{HP.sys}+Q_{closs})}{SPF_{CB.th}} - \frac{(Q_{HB.sys}*\%_{HB.C})*\varepsilon_{el}}{\varepsilon_{EC}*\eta_{HB}} - \Delta E_{aux.thC} \quad \textit{Eq. (89)}$$

$$\Delta E_{e\_equ\_DHW} = \frac{(Q_{WD.sys}+Q_{hloss}*\%_{SC.DHW})*\varepsilon_{el}}{\varepsilon_{EC}*\eta_{HB}} - \frac{(Q_{HB.sys}*\%_{HB.DHW})*\varepsilon_{el}}{\varepsilon_{EC}*\eta_{HB}} - \Delta E_{aux.DHW} \quad \textit{Eq. (90)}$$

$$\Delta E_{e\_equ\_SH} = \frac{(Q_{HD.sys}+Q_{hloss}*\%_{SC.SH})*\varepsilon_{el}}{\varepsilon_{EC}*\eta_{HB}} - \frac{(Q_{HB.sys}*\%_{HB.SH})*\varepsilon_{el}}{\varepsilon_{EC}*\eta_{HB}} - \Delta E_{aux.SH} \quad \textit{Eq. (91)}$$

Thermal cooling is just the thermally provided part of cooling (due to the absorption chiller). Therefore the Energy saved due to cooling includes the Energy saved due to thermal cooling. The system energy saving contains the savings from cooling, domestic hot water and space heating. The auxiliary energy consumption excludes the electrical energy consumption of the vapor compression chiller.

Where

- ΔE_{e-equ} is the annual incremental electrical equivalent savings of the SHC system (kWh_{el}).
- Q_C, $Q_{SS.CB}$, Q_{DHW}, Q_{SH}, $Q_{HB.PS}$, $Q_{HB.WD}$, $Q_{CD.SS}$ are energy flows (kWh) as defined in chapter 0, summed over the full year.
- SPF_{ref} is the seasonal performance factor of the reference vapor compression chiller (see Table 6)
- $\Delta E_{aux.sys}$ is the difference in the electrical consumption of auxiliary equipment for heating, domestic hot water and cooling (cooling tower fans, pumps, etc.) between the solar thermal system and a reference system (Eq. (92). The default electricity

consumption of the cooling auxiliary equipment in the reference system ($q_{el.ref}$) is 0 kWh_{el}/kWh_{cold} for small and 0.03 kWh_{el}/kWh_{cold} for large systems.

$$\Delta E_{aux.sys} = \Delta E_{aux.thC} + \Delta E_{aux.DHW} + \Delta E_{aux.SH} \qquad \text{Eq. (92)}$$

$$\Delta E_{aux.C} = Q_{el.C} - q_{el.ref} * (Q_{SS.HP} + Q_{CD.HP}) + (Q_{el.SP} * \%_{SC.C}) \qquad \text{Eq. (93)}$$

$$\Delta E_{aux.thC} = Q_{el.ACM} - q_{el.ref} * (Q_{SS.HP} + Q_{CD.HP}) + (Q_{el.SP} * \%_{SC.C}) \qquad \text{Eq. (94)}$$

$\Delta E_{aux.DHW}$ and $\Delta E_{aux.SH}$ are defined as the electrical consumption of domestic hot water or space heating reduced with the fraction of the electrical consumption of the total space heating or domestic hot water consumption. If the result is smaller than the electrical consumption of solar pumps, only the electrical consumption of the solar pumps is taken into account. The conversion factor for electricity consumption of the space heating and domestic hot water in the reference system ($HB_{el.ref}$) is 0.02 kWh_{el}/kWh_{th}.

$$\Delta E_{aux.DHW} = Q_{el.DHW} - HB_{el.ref} * Q_{WD.sys} \qquad \text{Eq. (95)}$$

$$\Delta E_{aux.SH} = Q_{el.SH} - HB_{el.ref} * Q_{HD.sys} \qquad \text{Eq. (96)}$$

3.9.3. Incremental Seasonal Performance ΔSPF_{sys}

A range of energy efficiency metrics are commonly used in the vapor compression air-conditioning industry, including coefficient of performance (COP), seasonal coefficient of performance (SCOP), energy efficiency ratio (EER) and seasonal energy efficiency ratio (SEER).

It would be useful to compare the performance of the incremental change, resulting from a solar air-conditioning system with that of conventional vapor compression air-conditioners, directly. Given the transient nature of solar air-conditioning, this can only be done on a seasonal basis. Furthermore, as conventional air-conditioners use electricity as the driving energy source, the energy sources in a solar air-conditioning system must be converted into electrical equivalents.

The resulting Eq. (97)/Eq. (98) for the conversion into electrical equivalents is

$$SPF_{sys} = \left(\frac{heating\ and\ cooling\ provided\ by\ a\ non\ conventional\ source\ (solar)}{Primary\ energy\ supplied\ by\ the\ conventional\ source\ (in\ Electricity\ equivalent\ units)}\right) \quad \text{Eq. (97)}$$

$$\Delta SPF_{sys} = \frac{Q_{WD.sys}+Q_{HD.sys}+Q_{hloss}-Q_{HB.sys}*(1-\%_{HB.C})+Q_{HP.sys}+Q_{closs}}{\frac{Q_{HB.sys}*\%_{HB.C}*\varepsilon_{el}}{\varepsilon_{EC}*\eta_{HB}}+E_{aux.sys}} \quad \text{Eq. (98)}$$

$$\Delta SPF_{C} = \Delta SPF_{thC} \quad \text{Eq. (99)}$$

$$\Delta SPF_{thC} = \frac{Q_{HP.sys}+Q_{closs}}{\frac{Q_{HB.sys}*\%_{HB.C}*\varepsilon_{el}}{\varepsilon_{EC}*\eta_{HB}}+E_{aux.thC}} \quad \text{Eq. (100)}$$

$$\Delta SPF_{DHW} = \frac{Q_{WD.sys}+Q_{hloss}*\%_{SC.DHW}-Q_{HB.sys}*(1-\%_{HB.C}-\%_{HB.SH})}{E_{aux.DHW}} \quad \text{Eq. (101)}$$

$$\Delta SPF_{SH} = \frac{Q_{HD.sys}+Q_{hloss}*\%_{SC.SH}-Q_{HB.sys}*(1-\%_{HB.C}-\%_{HB.DHW})}{E_{aux.SH}} \quad \text{Eq. (102)}$$

Where

- ΔSPF_{sys}, ΔSPF_{C}, ΔSPF_{thC}, ΔSPF_{DHW}, ΔSPF_{SH} are the incremental seasonal performance factors of the solar heating and cooling system. Useful energy is the energy displaced as the solar by non-conventional sources. Consumed energy is only used to drive the solar equipment and the chiller. It does not include any backup energy from the business-as-usual equipment of gas heating (-).
- $E_{aux.sys}$, $E_{aux.C}$, $E_{aux.thC}$, $E_{aux.DHW}$, $E_{aux.SH}$ are the annual electrical energy consumption of the auxiliary components (pumps and fans, excluding chilled water pump) in the solar heating and cooling system (kWh) (chapter 3.9.2).
- Q_{C}, $Q_{RS.CB}$, Q_{DHW}, Q_{SH}, $Q_{HB.PS}$, $Q_{HB.WD}$ are energy flows (kWh) summed over the entire year (Definitions in chapter 3.2).
- $\%_{HB.C}$, $\%_{HB.DHW}$, $\%_{HB.SH}$ are the fraction from the hot backups to cooling, domestic hot water and space heating

4. Costs key figures

Under the consideration of specific investment, replacement, operation and consumption based costs (m², %, country, etc.; details see chapter 3.3) two main economic figures can be calculated by using the annuity method.

(1) the total annualized costs (€/a) and levelized costs for heating, cooling and domestic hot water production (€/$kWh_{usefull\ energy}$)

(2) the avoidance cost for primary energy and CO_2 emissions

Where

N	number of year of period of analysis (a)	NL	number of years of credit (a)
i	inflation rate (%)	d	market discount rate (%)
m	credit interest rate (%)	fl	equity ratio (%)
ieg	inflation rate for energy prices (%)	p	public funding's rate (%)
iel	inflation rate for energy prices electricity (%)		

In the Excel Tool the nomenclature of specific values is the same, upgraded with the additional subscript "spec".

4.1. Economic base

All parameters influencing the economic figures are defined and fixed here. Some of the parameters influencing the economical calculation are challenging and details could be discussed extensively. The aim of these calculations and definitions is to generate reasonable cutoff values. The results present best known averages and may differ from specific values. If one would like to define its own values, this can be done in the Excel Tool (specific values for x1, x2).

These facts have to be considered, when using the results or changing some values.

- In the T48 Standard the market discount rate equals the inflation rate. This leads to the assumption that there is no financial interest behind the investigation of the solar heating and cooling system. If a project should lead to a yield return use the specific values to specify the rate.
- No VAT is included in the costs.
- Energy prices for business clients are chosen for electricity and gas. This makes the consumption based costs per kWh cheaper, but additional fees for max. power supply occur.
- Water costs only include fresh water costs. Dumping fees are excluded.
- Most important sources are mentioned in the tables. Prices are rounded to reasonable values. Too many decimals dissemble accuracy that cannot be reached.
- Lifetime is set to 25 years in order to replace each component at least ones.

Shortcut in the tables: Ass. Assumption

4.1.1. Economics

Table 7: Economic values used in the calculations

			T48 Standard	Austria	reference	Australia	reference	France	reference	Germany	reference	Italy	reference
period under consideration	a	N	25	25	Ass.							20	Ass.
credit period	a	NL	10	10	Ass.							10	Ass.
inflation rate	%	i	2	2.2	Statistic Austria							2.3	rivaluta.it
market discount rate	%	d	2	2.2	Ass.							2.3	Ass.
credit interest rate	%	m	3	3	WIFO							3	Ass.
inflation rate for energy prices electricity	%	iee	3	3	ON M7140			Same as AUSTRIA		Same as AUSTRIA		8.1	AEEGSI
inflation rate for energy prices	%	ieg	3	3	ON M7140							8.3	ISTAT
fraction of initial investment without financing	%	fL	0	0	Ass.							0	Ass.
public funding's rate	%	p	0	0	Ass.							0	Ass.

4.1.2. Consumption based costs

Huge differences occur when looking at domestic, commercial or industrial use of different energy quantities. Domestic prices are higher, but are mainly based on energy consumption. Commercial and industrial prices have low energy based costs, but can include capacity prices. Different limits are used and prices can hardly be fixed.

The used values should give an adequate overview and some approximations. If one likes to change them, x1 and x2 can be used to implement correct project specific values.

Table 8: Consumption based costs (electricity, gas, pellets and water)

Electricity		T48 Standard	Austria	reference	Australia	reference	France	reference	Germany	reference	Italy	reference
electricity consumption	€/kWh	0,1	0,09	e control VKW	0.18		0.14	DGEMP ADEME			0.22	AEEGSI 2012
electricity peak power	€/kW.a	80	80				-				-	
Energy Carrier												
gas consumption	€/kWh	0.05	0.045	e control Vkw	0.056		0.075	DGEMP ADEME	0.023	NRW	0.087	ISTAT
gas annual fix	€/a	70	70						145	Badenova		
Pellets consumption	€/kWh	0,05	0,05	Pro pellet Austria			0.059	DGEMP ADEME	0.055	NRW	0.05	
Pellets annual	€/a	50	40									
Water consumption												
water consumption	€/m^3	2.5	1.2	ovgw	1.15				1.69	Destatis	1.6	Feder-consumatori

4.1.3. Investment, lifetime and maintenance

Specific costs, lifetime [VDI 2067], maintenance, service and inspection [VDI 2067] for all major components are listed below (Table 9). It has to be noted, that significant deviations to specific projects may occur. The curves indicate typical average values and should only provide reference values. User defined values can be implemented in the Excel Tool.

Table 9: Components and its investment costs, lifetime and maintenance, service and inspection costs

Solar collectors		cost per unit € IN_{spec}	Coefficient k	source	years according to VDI 2067	% of invest according to VDI 2067
Flat plate collectors	€/m²	380	0.084	EvaSolK	20	1.5
Evacuated tube collectors	€/m²	760	0.135	EvaSolK	18	1.5
Solar collectors auxiliaries						
FPC	€/m²	815	0.355	ROCOCO	20	2.5
ETC	€/m²	5500	0.696	ROCOCO	20	2.5
Auxiliary heating system						
natural gas	€/kW	600	0.289	SCH	15	3.5
pellets		2231	0.488	Biemayr	15	6.0
Solar cold production						
Absorption chiller (1st)	€/kW	3700	0.45	EvaSolK	18	3.0
Absorption chiller (2st)	€/kW	4300	0.46	EvaSolK	18	3.0
Adsorption chiller	€/kW	1680	0.17	EvaSolK	18	3.0
Heat rejection						
Cooling tower - wet	€	21.2	1649	T48/A3	20	3.5
Cooling tower - hybrid	€	105.4	593.5	T48/A3	20	3.5
Cooling tower - dry	€	46.8	2638	T48/A3	20	3.5
Storage						
Hot tank	€/m³	2500	0.28	SCH	20	2.0
Cold tank	€/m³	2135	0.299	SCH	20	2.0
Back-up cold production						
water cooled VCC	€/kW	2934/6787	0.498/0.482	Cofely	15	3.5
air cooled VCC	€/kW	1219/1302	0.292/0.233	Cofely	15	3.5

The specific investment costs for the main components are calculated under consideration of a power law (Eq. (103).

Eq. (103)

Except the cost for cooling towers, they are calculated linear with the size following Eq.(88).

Eq. (104)

where

in	Specific cost for the component (€/unit)	x	Size of the component (m², m³, kW, etc.)
a	Price for one unit of the component (€)	k	Scaling factor (-)

The specific cost curves for the main components are shown in Figure 12 to Figure 16.

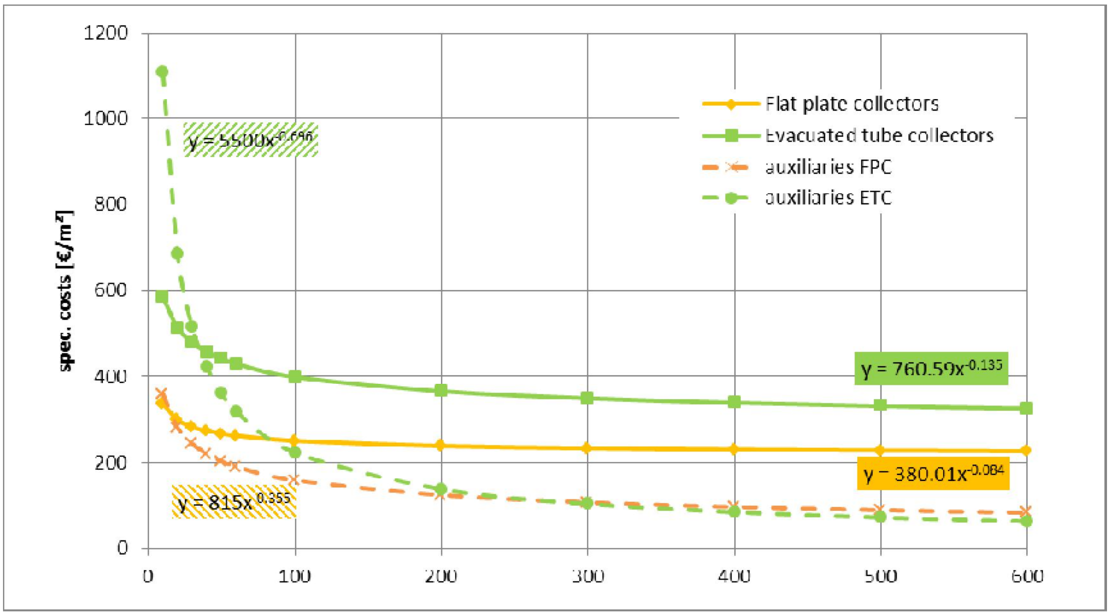


Figure 12: Specific costs for flat plate and evacuated tube collector [SHC 2013] and auxiliaries [EvaSolK 2013]

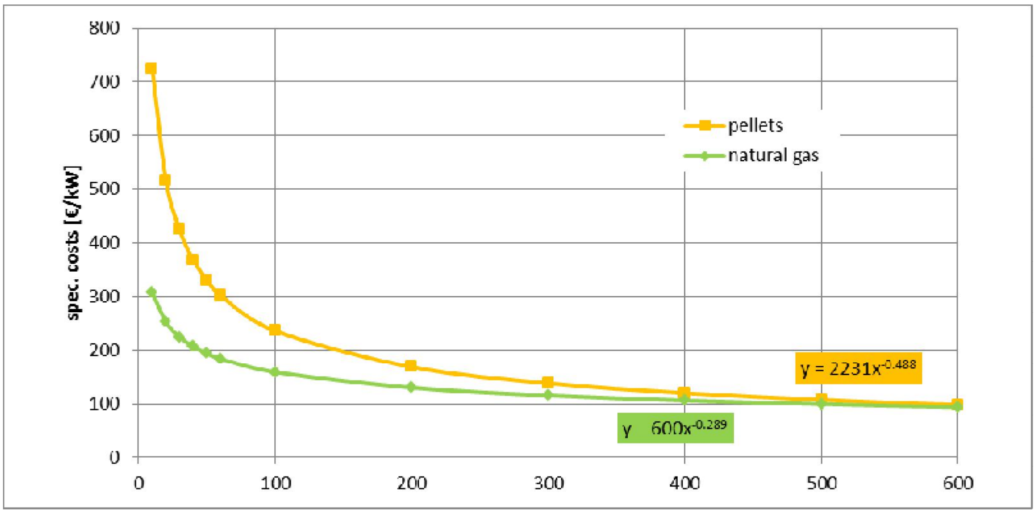


Figure 13: Specific cost for hot backups (natural gas [SHC 2013] and pellets [Biermayr 2013])

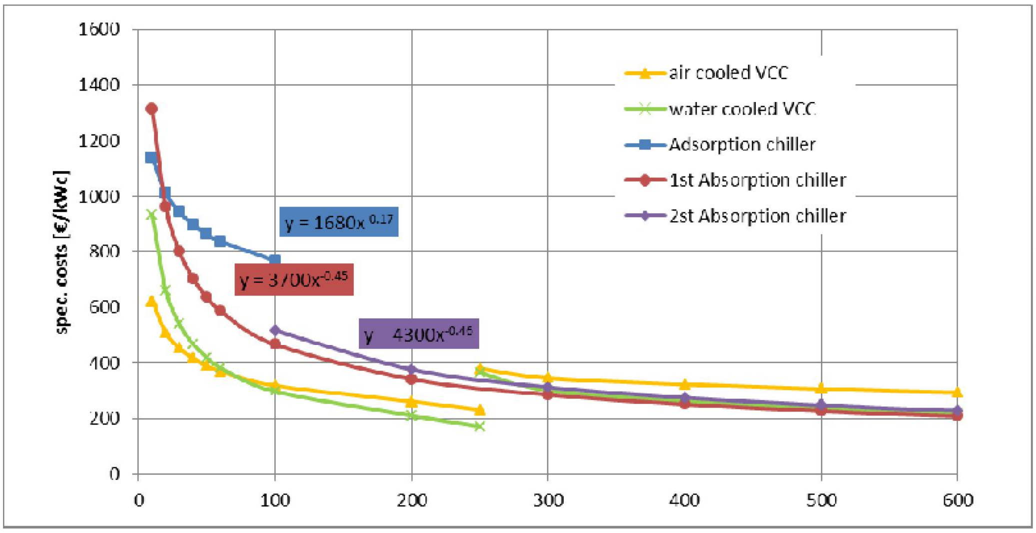


Figure 14: Specific costs for ab-/adsorption machines [EvaSolK 2013] and water- and air cooled vapor compression chillers [see chapter 3.4]

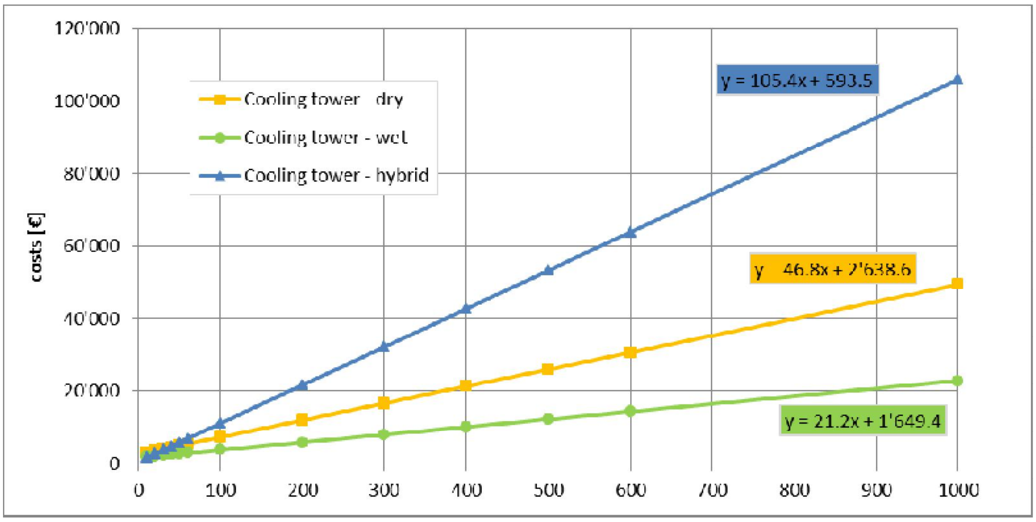


Figure 15: Specific costs for cooling towers (dry and wet) [IEA SHC Task 48, activity A3]

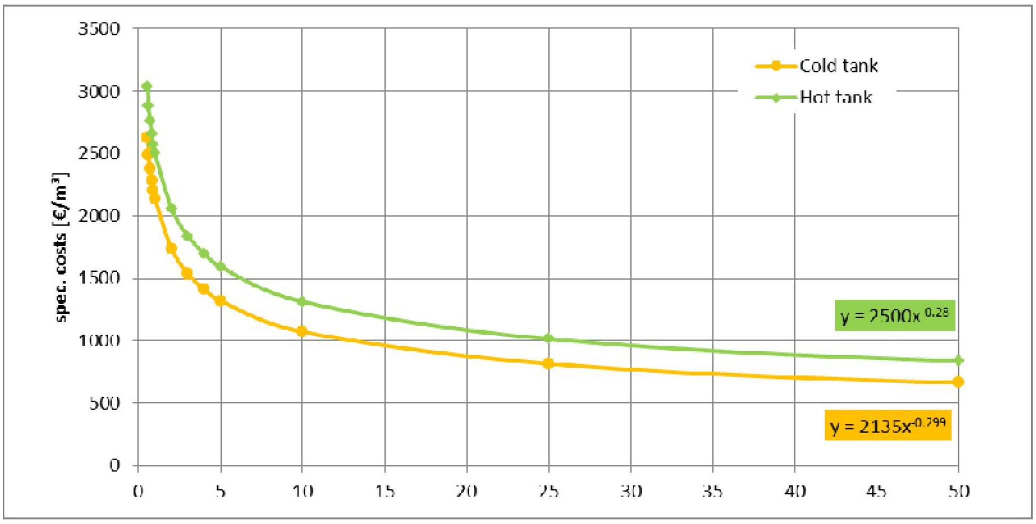


Figure 16: Specific costs for cold and hot water storages [SHC 2013]

Additional costs used in the calculation are shown in Table 10. Cost values may differ for specific projects / countries, depending on the local conditions.

Table 10: Additional costs related to investment of components

			Reference
Control, electricity and monitoring	% of Material	10%	Assumption
Investment-Design/planning			
Design, planning and commissioning	% of total Material	20%	SCH
Other costs over the TOTAL INVESTMENT			
General costs associated to works	% of total Material	30%	SCH
Indirect cost and industrial benefits	% of total Material	5%	Assumption

For the reference system additional costs are listed in Table 11.

Table 11: Additional costs related to investment for the reference system

Cost of REFERENCE Plant			
Auxiliaries	% of boiler	50%	Assumption
	% of chiller	50%	Assumption
Control, electricity and monitoring	% of Material	7%	Assumption
Investment-Design/planning			
Design, planning and commissioning	% of total Material	20%	SCH
Other costs over the TOTAL INVESTMENT			
General costs associated to works	% of total Material	30%	SCH
Indirect cost and industrial benefits	% of total Material	5%	Assumption

4.1.4. Investment costs

The investment cost (Eq. (103) per component is calculated taking the size and the specific costs of the entire component into account.

$$IN = in * size \qquad \text{Eq. (105)}$$

The overall monthly repayments (Eq. (106)) are calculated as fixed-rate mortgages taking the equity ratio f_l, interest rate m, credit period NL, and the period under consideration N into account. I_{tot} represents the sum of all direct (components) and indirect (labour costs, etc.) costs of the plant.

$$IC_{an} = \left(I_{init} + \frac{I_{tot} - I_{init}}{\left[\frac{1}{m}\left(1 - \left(\frac{1}{1+m}\right)^{NL}\right)\right]} * NL \right) * \frac{1}{N} \qquad \text{Eq. (106)}$$

$$I_{init} = I_{tot} * f_l \qquad \text{Eq. (107)}$$

Where

IN	Investment of a specific component (€)	in	specific investment of a component (€/unit)
I_{tot}	Total investment for the SHC or reference system (€)	I_{init}	Initial investment, considering the equity ratio (€)
IC_{an}	annualized cost of the investment (€/a)	NL	Credit period (a)
m	Interest rate (-)	N	period under consideration (a)
f_l	Equity ratio (-)	size	Size of the component (m², m³, etc)

4.1.5. Replacement costs and residual value

Replacement and residual value are calculated separately using the same formula, but different exponents k. The exponent k in Eq. 91 and 92 is the general variable for the exponent replacement costs k_{rc} or exponent residual value k_{rv}. The annualized cost IR_{an} (Eq. 92/93) depends on the annual replacement costs $IR_{an}(k_{rc})$ and on annual residual value $IR_{an}(k_{rv})$. Under consideration of inflation i, market discount rate d and the period under consideration N the respective annualized cost is calculated in Eq. (108) and Eq. (109).

$$\text{if } i \neq d \qquad IR_{an}(k) = \frac{IN}{N} * \left(\frac{\left(\frac{(1+i)^n}{(1+d)^n}\right)^k - 1}{\left(\frac{(1+i)^n}{(1+d)^n}\right) - 1} \right) * \frac{1}{(1+d)} \qquad \text{Eq. (108)}$$

$$\text{if } i = d \qquad IR_{an}(k) = \frac{k * IN}{N * (1+i)} \qquad \text{Eq. (109)}$$

Exponent k_{rc} for replacement costs takes the nearest multiple of significant of $\frac{N}{n}$, the ratio of period under consideration and the lifetime n of the particular component. The exponent k_{rv} represents the residual value of the ratio $\frac{N}{n}$ from the next higher integer.

The annualized sum of interest is summarized in Eq. (110).

$$IR_{an} = IR_{an}(k_{rc}) + IR_{an}(k_{rv})$$ Eq. (110)

Where

$IR_{an}(k)$	annualized replacement cost depending on the exponent k (€/a)	IN	Investment of a specific component (€)
N	period under consideration (a)	i	Inflation (-)
d	Market discount rate (-)	n	Lifetime (a)
k	Exponent (-)	IR_{an}	annualized replacement cost (€/a)
k_{rc}	Exponent for replacement costs with $\frac{N}{n}$ (-)	k_{rv}	Exponent for residual value of $\frac{N}{n}$ (-)

4.1.6. Operation based costs

Operation based costs are calculated according to VDI 2067. This standard defines percentages for maintenance, service and inspection based on investment costs. The calculation of the annualized costs is done by discounting all anticipated costs to the common basis of present value. The annualized costs depend on the values of the inflation rate i, market discount rate d and the period under consideration N [Duffie 2013].

$$PWF(i) = \frac{1}{d-i_x} * \left(1 - \left(\frac{1+i_x}{1+d}\right)^N\right) \qquad \text{if } i_x \neq d$$ Eq. (111)

$$PWF(i) = \frac{1}{(1+i_x)} \qquad \text{if } i_x = d$$ Eq. (112)

For the operation based costs $i_x = i$ the inflation rate. The annualized costs take the sum of all operation based costs MC for each single component into account.

$$MC_{an} = MC * PWF(i)$$ Eq. (113)

Where

PWF(i)	Present worth factor (-)	d	Market discount rate (-)
N	Period under consideration (a)	i_x	Inflation rate (-)
MC	Maintenance costs (€)	MC_{an}	annualized maintenance cost (€/a)

4.1.7. Consumption based costs

Consumption based costs are the sum of energy carrier (EC), electricity (el) and water consumption (WC).

- Energy carrier

Overall energy carrier costs (Eq. (114) include the type, annual costs and the energy demand

$$EC = C_{EC.a} + C_{EC.c} * Q_{EC.HB}$$ Eq. (114)

The calculation of the energy demand of the reference system are based on the energy flows $Q_{CD.System}$, $Q_{HD.System}$ and $Q_{WD.System}$. The energy flows use the defined efficiencies of the vapor compression chiller and the specified boiler. The annualized costs (Eq. (115) for both, the SHC and ref System, are calculated using i_{EC}, the inflation rate for energy carrier.

$$EC_{an} = EC * PWF(i_{EC}) \qquad \textit{Eq. (115)}$$

Where

EC	Energy carrier costs (€/a)	$C_{EC.a}$	Annual costs for energy carrier (€/a)
$C_{EC.c}$	Consumption based costs for energy carrier (€/a*kWh)	$Q_{EC.HB}$	Energy flow energy carrier to hot backup (kWh)
EC_{an}	Annualized energy carrier costs (€/a)	$PWF(i_{EC})$	Present worth factor depending on the inflation rate for EC (-)

- Electricity

Overall electricity costs (Eq. (116) are the sum of peak electricity costs and the total electricity demand (without distribution pumps).

$$EL = c_{el.p} * P_{el} + c_{el.c} * Q_{el.tot} \qquad \textit{Eq. (116)}$$

For the reference system the peak power of the SHC system (input quantity) is converted to the peak power of the reference system taking “worst case” efficiencies of the system into account (Eq. (117). The maximum of cold or space heating and domestic hot water is taken as reference value. A SPF = 2.0 for the VCC and 5% of the boiler power are taken to calculate the peak reference electricity consumption.

$$P_{el.ref} = max\left(\frac{P_{CD}}{2.0}, P_{SH,DHW} * 0.05\right) \qquad \textit{Eq. (117)}$$

The annualized costs for both, the SHC and ref System are calculated in Eq. (118. The present worth factor is calculated using i_{el}, the inflation rate for electricity.

$$EL_{an} = EL * PWF(i_{el}) \qquad \textit{Eq. (118)}$$

Where

EL	Electricity costs (€)	$c_{el.p}$	peak based electricity costs (€/kW)
P_{el}	Peak electricity (kW)	$c_{el.c}$	consumption based electricity costs (€/kWh)
$Q_{el.tot}$	Total electrical energy flow (kWh)	$P_{el.ref}$	Peak electricity of reference system (kW)
P_{CD}	cooling peak load (kW)	$P_{SH,DHW}$	SH and DHW peak load (kW)
EL_{an}	annualized electricity cost (€/a)	$PWF(i_{el})$	Present worth factor depending on the inflation rate for electricity (-)

- Water

Water consumption for heat rejection and air conditioning is defined as input quantity to the Excel Tool for the reference and solar heating and cooling system. To calculate the PWF the inflation rate i is used. The annualized water costs are defined in Eq. (119).

$$WC_{an} = C_{wa.c} * W_{sys} * PWF(i)$$ *Eq. (119)*

Where

WC_{an}	Annualized water costs (€/a)	$C_{wa.a}$	Water costs (€/m³)
W_{sys}	Annual water demand (m³/a)	PWF(i)	Present worth factor depending on the inflation rate (-)

4.1.8. Total annualized costs

The overall annualized cost C_{an} (Eq. (120) equals the sum of annualized investment, replacement, operation based and consumption based costs.

$$C_{an} = IC_{an} + IR_{an} + MC_{an} + EL_{an} + EC_{an} + WC_{an}$$ *Eq. (120)*

Where

C_{an}	Overall annualized costs (€/a)	IC_{an}	annualized cost of the investment (€/a)
IR_{an}	annualized replacement cost (€/a)	MC_{an}	Annualized maintenance cost (€/a)
EL_{an}	Annualized electricity cost (€/a)	EC_{an}	Annualized energy carrier costs (€/a)
WC_{an}	Annualized water costs (€/a)		

4.2. Results of economic calculation

Energy flows of heating, cooling and domestic hot water are summed up. Hence of the difficulty to divide investment costs between single parts, the various energy flows are treated as one. That avoids a discussion about the belonging of components, fractions and parts, because it is impossible to separate the units from each other.

4.2.1. Levelized costs for cooling, space heating and domestic hot water production

The Levelized costs C_{use} [€/kWh$_{usefull\ energy}$] are calculated using the sum of the annualized costs C_{an} and the delivered energy flows of cooling $Q_{CD.system}$, heating $Q_{HD.system}$ and domestic hot water $Q_{WD.system}$ (Eq. (121).

$$C_{use} = \frac{C_{an}}{Q_{CD.system}+Q_{HD.system}+Q_{WD.system}}$$ *Eq. (121)*

The specific costs are calculated four times in the Excel Tool: C_{use} for the reference and SHC-System each with the T48 standard values and the specific values.

4.2.2. Cost ratio

The cost ratio δ_{Cuse} is determined with the Levelized costs of energy for the SHC system ($C_{use.SHC}$) and the Levelized costs of the reference system ($C_{use.REF}$) (Eq. (122).

$$\delta_{Cuse} = \frac{Energy\ costs\ SHC\ system}{Energy\ costs\ REF\ system} = \frac{C_{use.SHC}}{C_{use.REF}} \qquad \textit{Eq. (122)}$$

4.2.3. Avoidance costs

Using the annualized costs leads to the avoidance costs of primary energy (Eq. (123) and CO_2 (Eq. (124).

For primary energy $C_{PE.saved} = \frac{\Delta C_{an.tot}}{\Delta_{PE}}$ *Eq. (123)*

For CO_2 emissions $C_{CO2.saved} = \frac{\Delta C_{an.tot}}{\Delta_{CO2}}$ *Eq. (124)*

Where

- $\Delta C_{an.tot} = C_{an.SHC} - C_{an.ref}$ is the difference of the annualized costs of the SHC- and reference system.
- $\Delta_{PE} = PE_{ref} - PE_{SHC}$ is the difference of the primary energy demand of the reference system and the SHC-System
- $\Delta_{CO2} = CO2_{ref} - CO2_{SHC}$ is the difference of the CO2 emissions of the reference System and the SHC-System

Remind: This formula is only valid if

(1) the reference system is more expensive than the SHC-system and

(2) the SHC-System emits less CO_2 than the reference system and has less primary energy demand.

Ignoring this two conditions will results in negative avoidance costs, which doesn't match economical or scientific basics!

5. Tool for calculation of key figures

Steps towards your FlowChart, Energy Balance Overviews and IEA SHC Task 48 Key Figures

1	Description of colors	
	drop down menu	Please select an option. Some options are just for information, others influence the result significantly!
	value to be filled in	Please fill in the certain value. ALL values are needed!
	T48 Standard	Input values to the T48 Standard calculation cannot be changed. They were defined and agreed during the work on Task 48.
	specific value	Input values can be adopted at different highlighted positions in this Tool. This allows country or project specific calculation of both technical and economic key figures.
	editing specific values	Cell to edit the specific value.

2	Define all types of sources, capacities and dimensions in the worksheet "INPUTS"
	Each single drop down or dimension to be filled in may has an influence on the results (both technical and economic key figures)
	Take your time and go through with care
	More details about calculations, formulas, methods and utilization of the Tool are available in the B7 deliverable.

3	In the worksheet "Conversion Factors" the necessary factor can be defined.
	T48 Standard values cannot be changed, they represent a reasonable average.
	Country specific values have been chosen with care and should reflect an average. They cannot be changed.
	If you want to define your own values choose x1 or x2 (marked yellow). They can be edited.

4	In the Worksheet "Table" look for the source-sink table for DHW & heating & cooling (Columns "A:AK" Rows "1:30") and mark each connection that exists between all the possible components with an "x"
	There will be only an influence in the flow chart and the Table in "Data" if you add or delete "x" here. This is just for information and can be done optionally.
	If you leave the selection like it is, you have to leave rows blank in "data", otherwise the table will be reduced to your specific system.
	Do not alter the two-letter source and sink abbreviations!
	Make sure you don't have "blank cells" before the last entry in columns "AA:AJ".
	Reasonable options are marked in advance for the "T48 Standard schemes".

5	Press the button "Flow Chart"

!!! All data implemented will be deleted after pressing the button "flow chart"!!!

What happens is, that …

A reduced table show the components that are present only, located underneath the original ones and also the abbreviations, that will be used for the respective energy fluxes, are shown.

a table for entering all monthly and annual energy fluxes between the components in the Worksheet "Data_DHW&Heat" is present.

an updated "EFChart" for your system is available.

6	Go to the "EFChart" and rearrange the flow chart for your needs
	Delete labels that are not needed. If necessary rearrange the connector. The flow chart will be copied automatically in the summary worksheet.

7	Draw additional system boundaries within the "EFChart" as needed
	This has no effect on the calculation. It's a graphical account only.

8	Enter data in the table "Data"
	If you insert monthly data only the yearly sum will be calculated automatically. If you do not have data for the energy carrier to hot backup (EC:HB), it will be calculated automatically using the boiler efficiency. The CAPsolar will be calculated only, if you insert your data in column "P"

9	Go to the Worksheet "eco_base"
	All relevant economic bases are / has to be defined here. Yellow marked cells can be changed only. T48 and country-specific values have been chosen as average standards and cannot be changed.

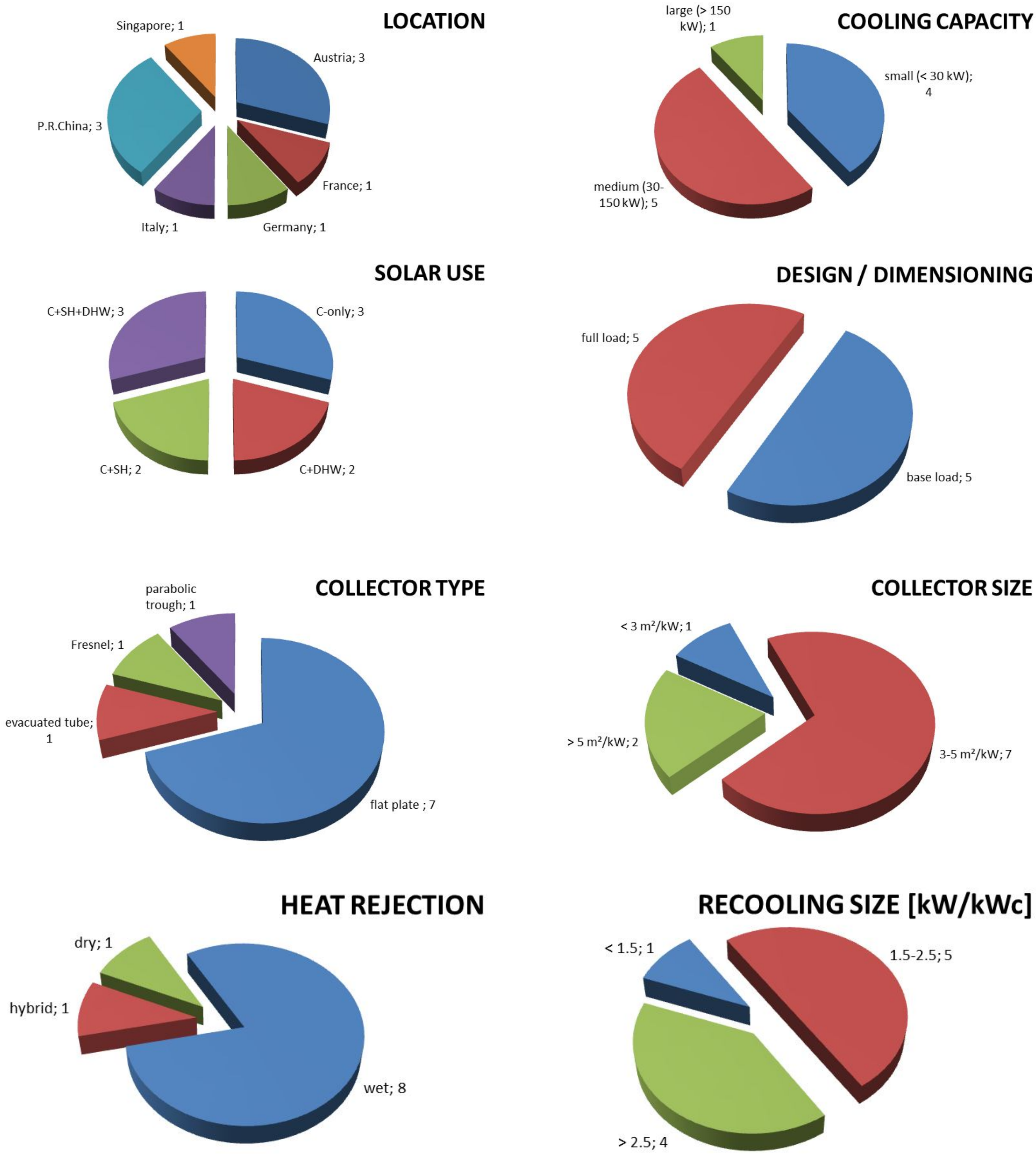
10	In the worksheet "cost_calc" you may find details of the investment, replacement, and maintenance costs
	No inputs are needed here. For your detailed information only.

11	In the worksheet "summary" you may find an overview of your plant and its performance
	You will find a summary of most important inputs, energy balance data and key figures of your SHC-system and reference system.

Actual Version 20th of May 2015 **Task48-B7_keyfigures_V3.8.xlsm**

6. Best practice examples

The designed Excel tool for key figures and costs was tested by implementing 10 realized and operating plants. Each plant is unique as well as its ambient surroundings. These facts allow a broad range of testing. A summary of the most important facts can be found in the overviews of Figure 17.



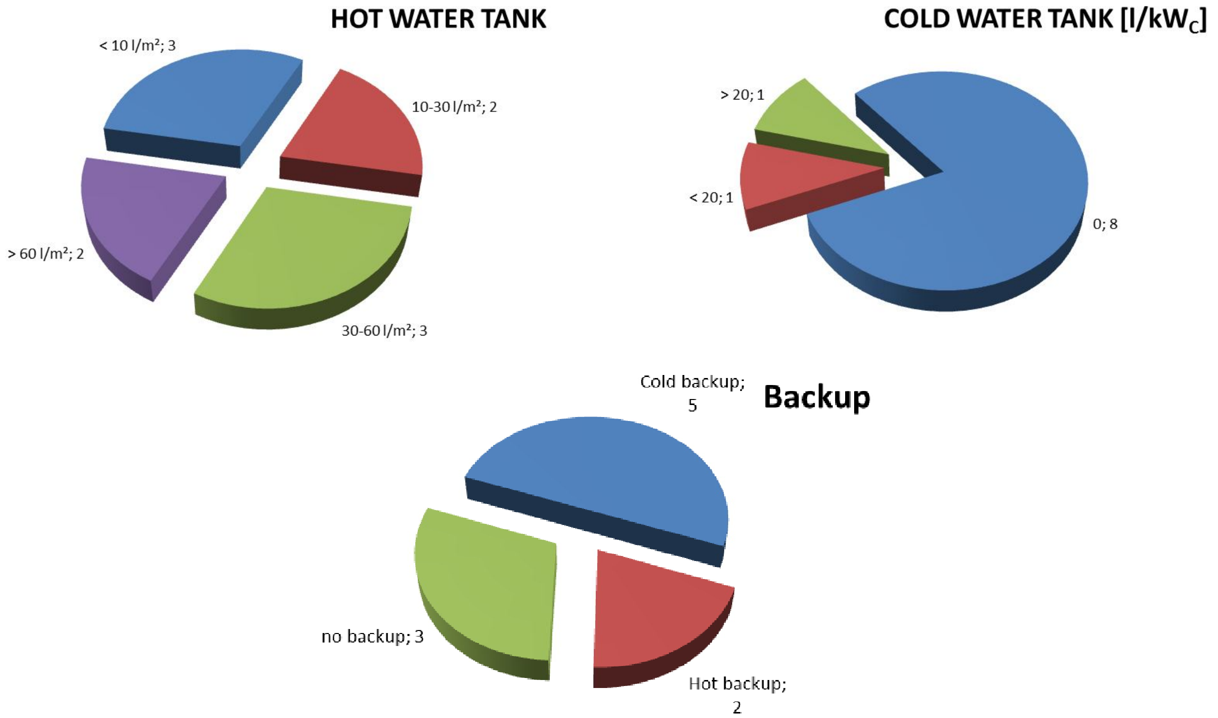


Figure 17: Overview of ten examples analyzed and evaluated with the Task 48 / B7 Tool

Energy flows and energy costs are determined depending on the above mentioned plant combinations. Energy costs represent the cost ratio of the SHC system to the reference system.

Following energy flows (all in kWh/a) are considered in detail:

- Cold distribution to system $Q_{CD.System}$
- Space heating $Q_{HD.System}$
- Domestic hot water $Q_{WD.System}$
- Electricity demand $Q_{el.Total}$
- Energy carrier to hot backup $Q_{EC.HB}$

	Example no.	1	2	4	5	10	3	6	7	9	8
General	Project location	Austria	Germany	France	x1	P.R.China	Italy	Austria	Austria	P.R.China	P.R.China
	Building category	office	office	office	Residential	Other	office	office	office	Commercial	Office
	Cooled/heated area (m²)	1.000	400	11.000	76.000	280	172	2.860	1.000	248	440
	Distribution system	Fan coil	Chilled ceiling	Fan coil	Fan coil	Fan coil	Fan coil	Fan coil	Fan coil	Fan coil	Fan coil
Heating	Collector type	Flat plate collectors	Flat plate collectors	Flat plate collectors	Flat plate collectors	specific SC	Flat plate collectors	Flat plate collectors	Flat plate collectors	Evacuated tube collectors	specific SC
	Collector area (m²)	65	57,4	240	3800	550	60	120	65	168	156
	Hot water storage (m³)	2	2	1,5	60	4	5	8	2	2	1
	Backup type	pellets	pellets	natural gas	natural gas	specific HB	specific HB	no hot backup	natural gas	specific HB	natural gas
	Use of hot backup fo cooling	yes	no	no	no	yes	no	no	no	no	no
	Backup peak load (SH/DHW) (kW)	300	30	70	0	30	14,4	0	45	18	0
	Daily domestic hot water consumption (DHW) (l/day)	0	0	6680	10000	1000	0	0	0	1000	0
Cooling	Chiller type	Absorption chiller SE	Absorption chiller SE	Absorption chiller SE	Absorption chiller SE	Absorption chiller DE	Absorption chiller SE	Absorption chiller SE	Absorption chiller SE	Absorption chiller SE	Absorption chiller SE
	Ab-/ad- chiller capacity (kW)	19	10	35	1500	134	17,6	30	19	35,2	45
	Cold storage (m³)	0	0	0	0	0	1	0,5	0	0	0
	Backup type	no cold backup	no cold backup	no cold backup	no cold backup	no VCC	air cooled VCC (5-600kW)	air cooled VCC (5-600kW)	air cooled VCC (5-600kW)	air cooled VCC (5-600kW)	water cooled VCC (>20kW)
	Backup capacity (kW)	0	10	70	1500	134	13	100	20	33	66,3
Heat rejection	Cooling tower	Cooling tower - wet	Cooling tower - dry	Cooling tower - hybrid	Cooling tower - wet	Cooling tower - wet	Cooling tower - wet	Cooling tower - wet	Cooling tower - wet	Cooling tower - wet	Cooling tower - wet
	Power (kW)	57,00	12,00	85,00	4.150,00	240,00	42,70	80,00	50,00	85,00	80,00
Energy flows (kWh/a)	Cold distribution to system $Q_{CD.System}$	15.577,43	3.266,00	9.394,00	948.977,00	47.141,90	7.129,18	18.170,00	16.895,10	23.422,91	75.322,00
	Space heating $Q_{HD.System}$	175.201,80	5.374,00	0,00	0,00	59.586,00	10.391,28	0,00	41.055,18	17.463,94	0,00
	Domestic hot water $Q_{WD.System}$	0,00	0,00	133.172,50	143.080,00	0,00	0,00	0,00	25.158,17	17.216,20	0,00
	Electricity demand $Q_{el.sys}$	5.429,45	521,97	5.489,00	149.442,40	7.784,35	7.386,07	6.671,50	5.423,91	10.307,99	18.965,00
	Energy carrier to hot backup EC.HB	85.554,50	0,00	31.027,50	0,00	25.447,00	0,00	0,00	48.624,75	16.463,20	0,00
Energy costs	Cost ratio (SHC/REF) (-)	0,91	2,19	1,02	1,19	1,51	2,35	1,14	1,16	2,01	1,80
Electrical SPF (-) for	system $SPF_{el.sys}$	35,14	16,55	25,97	7,31	13,71	2,37	2,72	15,32	5,64	3,97
	cooling $SPF_{el.C}$	5,01	9,84	4,43	5,82	6,38	2,41	2,72	3,98	3,50	3,97
	thermal cooling $SPF_{el.thC}$	5,01	9,84	4,43	5,82	6,38	2,35	3,64	13,59	5,30	6,33
	domestic hot water $SPF_{el.DHW}$	0,00	0,00	39,54	102,80	0,00	0,00	0,00	76,01	25,09	0,00
	space heating $SPF_{el.SH}$	75,46	36,12	0,00	0,00	151,87	2,36	0,00	48,33	8,10	0,00
Thermal SPF (-) for	system $SPF_{th.sys}$	0,36	0,33	0,60	0,67	0,66	0,27	0,29	0,55	0,33	0,45
	cooling $SPF_{th.C}$	0,61	0,63	0,60	0,67	0,66	0,54	0,43	0,62	0,46	0,51
Primary Energy Ratio (PER) (-) for	reference system $PER\_NRE_{ref.sys}$	0,79	1,64	0,78	1,10	0,93	0,78	1,24	0,80	0,54	1,24
	cooling reference system $PER\_NRE_{ref.C}$	0,88	0,75	1,26	1,18	1,24	0,79	1,24	0,88	1,08	1,24
	thermal cooling reference system $PER\_NRE_{ref.thC}$	0,80	0,80	1,20	1,20	1,24	0,80	1,20	0,80	1,20	1,20
	domestic hot water reference system $PER\_NRE_{ref.DHW}$	0,00	0,00	0,76	0,75	0,00	0,00	0,00	0,78	0,38	0,00
	space heating reference system $PER\_NRE_{ref.SH}$	0,78	5,96	0,00	0,00	0,78	0,78	0,00	0,78	0,42	0,00
PER (-) for	system PER_NRE_{sys}	8,62	6,62	2,96	2,92	1,52	0,95	1,09	1,23	0,99	1,59
	cooling PER_NRE_{C}	1,77	3,94	1,77	2,33	1,00	0,96	1,09	1,59	1,40	1,59
	thermal cooling PER_NRE_{thC}	1,77	3,94	1,77	2,33	1,00	0,94	1,46	5,44	2,12	2,53
	domestic hot water PER_NRE_{DHW}	0,00	0,00	3,10	41,12	0,00	0,00	0,00	1,18	1,17	0,00
	space heating PER_NRE_{SH}	13,13	14,45	0,00	0,00	2,56	0,94	0,00	1,15	0,69	0,00
fractional savings (-) for	system $fsav\__{NRE.PER.sys}$	0,91	0,75	0,74	0,62	0,39	0,18	-0,14	0,35	0,46	0,22
	cooling $fsav\__{NRE.PER.C}$	0,51	0,81	0,29	0,49	-0,24	0,18	-0,14	0,45	0,23	0,22
	thermal cooling $fsav\__{NRE.PER.thC}$	0,55	0,80	0,32	0,48	-0,24	0,15	0,18	0,85	0,43	0,53
	domestic hot water $fsav\__{NRE.PER.DHW}$	0,00	0,00	0,76	0,98	0,00	0,00	0,00	0,34	0,67	0,00
	space heating $fsav\__{NRE.PER.SH}$	0,94	0,59	0,00	0,00	0,70	0,17	0,00	0,32	0,40	0,00
SPF Equivalent (-) for	system $SPF_{equ.sys}$	21,55	16,55	7,39	7,31	3,79	2,37	2,72	3,07	2,47	3,97
	cooling $SPF_{equ.C}$	4,43	9,84	4,43	5,82	2,51	2,41	2,72	3,98	3,50	3,97
	thermal cooling $SPF_{equ.thC}$	4,43	9,84	4,43	5,82	2,51	2,35	3,64	13,59	5,30	6,33
	domestic hot water $SPF_{equ.DHW}$	0,00	0,00	7,76	102,80	0,00	0,00	0,00	2,95	2,92	0,00
	space heating $SPF_{equ.SH}$	32,83	36,12	0,00	0,00	6,39	2,36	0,00	2,88	1,73	0,00
Incremental Energy Saved of the Solar Collector (-) for	system $\Delta Ee.equ_{SC.sys}$	5.369	1.719	48.084	258.849	39.558	8.828	25.115.365	12.720	61.986	-11.309
	cooling $\Delta Ee.equ_{SC.C}$	4.200	1.407	1.147	188.856	-5.662	4.626	25.115.365	-685	18.521	-11.309
	thermal cooling $\Delta Ee.equ_{SC.thC}$	3.955	1.249	1.147	181.701	-5.662	1.293	357	2.690	810	2.826
	domestic hot water $\Delta Ee.equ_{SC.DHW}$	0	0	46.938	69.993	0	0	0	5.094	25.572	0
	space heating $\Delta Ee.equ_{SC.SH}$	1.169	312	0	0	45.220	4.201	0	8.312	17.894	0
Incremental SPF of the Solar Collector (-) for	system $\Delta SPF_{SC.sys}$	12,32	31,00	20,32	8,15	4,50	3,38	7,38	51,74	17,30	8,16
	cooling $\Delta SPF_{SC.C}$	4,06	8,51	4,73	7,05	2,26	3,62	3,64	13,52	4,14	6,33
	thermal cooling $\Delta SPF_{SC.thC}$	4,06	8,51	4,73	7,05	2,26	3,62	3,64	13,52	4,14	6,33

Figure 18: Overview and summarized results of ten best practice examples tested with the Excel tool

7. Summary & Conclusions

A detailed review of representation schemes, calculation methods and key figures for technical and economic efficiency ratios has been carried out. For non-experts it seems impossible to compare different systems or single components, because each figure is related to its boundary conditions and valid under these conditions only. The dependency of system efficiencies on demands and local conditions is unavoidable.

Nomenclature and system representation in Task 48 is following IEA SHC Task 44. The source-sink approach was adapted to the needs of this Task and its activities. Every element is fully identified by a two-letter code: first two letters of the name (Sun = Su) or first initials of a composite name (Solar Collectors = SC). In this way every component is marked with an intuitive abbreviation. All necessary boundaries of the system and subsystems can be represented on the diagram and input/output fluxes can be detected, justifying the performance figures calculation and the meters needed for the acquisition of the needed data.

Seasonal Performance Factor (SPF), Primary Energy Ratio (PER) and Fractional Savings (f_{sav}) are chosen to represent the system performance. These factors can be calculated for different boundaries, which have to be defined properly. Five system boundaries are defined in Subtask B, B7.

- Overall system (including cooling, domestic hot water and space heating)
- Cooling (overall performance of the cooling system)
- Thermal cooling (performance of the ab-/adsorption chiller)
- Space heating (including backup)
- Domestic hot water (including backup)

However, these key figures allow an in-depth analysis of the system and subsystem performance, but need a lot of expertise to interpret and are hardly comparable to other known performance figures. Therefore four new figures are invented, trying to convert the above mentioned ratios into equivalent figures for comparison. The main idea is to convert the non-renewable primary energy into electrical equivalent units and then calculating following figures.

- Equivalent Seasonal Energy Performance (SPF_{equ})
- Incremental Energy Saved (ΔE_{e-equ})
- Incremental Seasonal Performance (ΔSPF_{SHC})
- Incremental Solar Cooling Capacity (CAP_{solar})

While the SPF_{equ} is a performance metrics based on all energy flows incurred in delivering a complete heating and cooling system, the incremental performance metrics deal only with the energy flows that deviate from common values.

For a detailed comparison with reference systems some effort was made to calculate the performance of vapor compression chillers. The performance and costs were calculated for different capacities based on the state of the art system with its components, control strategies and layouts.

On the level of economical assessment different cost figures are calculated. The annuity method is used to run detailed calculations. It accounts for installation costs, financing costs, taxes, operation and maintenance costs, incentives, revenue requirements and quantity of electricity or any type of backup energy. Main figures are the annualized (levelized) energy production costs and the avoidance costs for primary energy and CO_2 emissions.

The Excel Tool of IEA SHC Task 44 was adapted and developed to implement all necessary input data, draw a unified energy flow chart, collect the data on monthly and annual bases and calculate the defined key figures and its derivatives. In this Tool a “Task 48 Standard” and specific project or country-specific calculation is available. The Task 48 Standard sets indicative values for each input (e.g. technical like $ESEER_{ref}$, environmental like conversion factors for primary energy and economics like investment costs). Its aim is to harmonize the key figures and make them comparable from this point of view. For a detailed project specific calculation values can be manipulated manually and individually in the assign cells. The Tool will to be updated while the Task is ongoing, especially the economical input values (investment costs) needs further investigations and updates.

Overall system performance figures depend on the ratio of cooling, space heating and domestic hot water and need to be discussed, evaluated and rated under these conditions. Following activities like the assessment and benchmarking (Subtask C, activity C2) has to qualify the different possibilities and choose the most suitable for different purposes.

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