Deliverable C3-1

TASK 53

Energy-Economy-Ecology-Evaluation Tool

T53E^4-Tool

Tool Description and introductory Manual

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IEA Solar Heating and Cooling Programme

The Solar Heating and Cooling Technology Collaboration 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 members of the IEA SHC 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.

Research topics and the associated Tasks in parenthesis include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54)
- Solar Cooling (Tasks 25, 38, 48, 53)
- Solar Heat for Industrial or Agricultural Processes (Tasks 29, 33, 49, 62)
- Solar District Heating (Tasks 7, 45, 55)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56, 59)
- Solar Thermal & PV (Tasks 16, 35, 60)
- Daylighting/Lighting (Tasks 21, 31, 50, 61)
- 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, 57)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42, 58)

In addition to our Task work, other activities of the IEA SHC include our:

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

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1 General Introduction

The T53E[4]-Tool is used for the assessment of Solar Heating and Cooling (SHC) Systems. The Tool allows a wide range of new generation solar heating and cooling systems for all kind of applications (space heating (SH), domestic hot water (DHW), cooling (C), etc.) to be analyzed and assessed. Solar includes solar thermal and solar electric (photovoltaic) driven systems. The key performance indicators are used to compare the entire SHC system with the Task 53 reference (Ref) system as well as with an individual chosen (specific) reference system.

The assessment is performed with technical and economic key figures based on monthly energy balances. Technical figures calculate the efficiency of the overall system or a subsystem (C, DHW, SH, etc.) based on any kind of renewable or non-renewable primary energy supply. Plenty derivative technical figures (e.g. component efficiency) can be calculated. A comprehensive economic examination with a set of standardized costs is included as well as a labelling of the system. The labelling refers to the "European Energy Labelling Guideline" [2010/30/EU 2010].

Each SHC system is evaluated under pre-defined Task 53 standard values (e.g. primary energy factor for electricity) but also under country-specific boundary conditions (e.g. Australia, location New Castle, etc.). If applicable, these values are also defined as monthly values. Compared to TASK 48 [task48.iea-shc.org] more complex systems can be evaluated and the labelling of the system and subsystems is extended.

To create the desirable SHC system following components and heating / cooling sources / sinks are included in the Tool. Each category allows to define individual (spec.) components.

- Solar sources:
  - Flat plate collector
  - Evacuated tube collector
  - Photovoltaic
- Heat sources:
  - Natural gas
  - Combined heat and power
  - Heat pump and reversible heat pump
  - Absorption heat pump and reversible absorption heat pump
  - District heating
  - Natural gas boiler
  - Condensing natural gas boiler
  - Electrical heater
  - Oil boiler
  - Pellet boiler
- Cold source:
  - Air or water cooled vapor compression chiller
  - Single effect absorption chiller
  - Double effect absorption chiller
  - Adsorption chiller
  - District cooling

- Cooling tower:
  - Wet cooling tower
  - Dry cooling
  - Hybrid cooling
- Storage:
  - Hot water storage
  - Cold water storage
  - Battery storage

Any combination of these components can be represented. The Tool is limited to one solar thermal collector field and one PV field, as well as to bivalent systems (two heating- and/or cooling sources). Two storage sizes of each storage type can be implemented. For any other configuration, components need to be merged and treated as one, with specific boundaries (efficiency, costs, etc.).

Within the Tool, the SHC plants are displayed on the basis of renewable and traded, non-renewable (NRE) energy flows. Technical key figures are calculated for different boundaries. The detailed economic analysis allows an in-depth view and a comparison of various system configurations. An overview of the energy flows is given in Figure 1.1.

The components are connected with arrows, which are labeled with the appropriate energy flow. Energy flows are represented in physical meaning, e.g. solar thermal collector (SC) to hot storage (HS) with “SC.HS”. A detailed overview of all energy flows is given in chapter 6. If there is a “1” or “2” in the energy flow description mentioned, it means that this energy flow refers to a primary (1) or a secondary (2) source. The information of Figure 1.1 is summarized as follows:

- Traded energy sources (grey): Electricity and energy carrier
  Electricity can be provided from the grid (El) as well as from photovoltaics (PV) and battery storage (BS). Thermal energy carrier (EC) is natural gas, biogas, pellets, etc.

- Renewable heat sources (green): Sun, ground, air, water and waste heat
  Free available sources are the sun (Su) or other environmental energy like geothermal (ground), ambient air, ground water or waste heat. The usage is possible either via collector (PV, ST) or heat exchanger (HX).

- Energy demand (red):
  The heat sinks domestic hot water (DHW / WD), heat distribution (HD) and district heating (DH) receive their energy from solar collector (SC), heat source (H) or hot storage (HS).
  Cold source / distribution can be implemented as energy into the heating and / or cooling system boundary. District cooling (DC) relates to cooling only.

- Domestic electricity demand (grey):

Domestic electricity consumption is provided by the electricity grid (El) or from the battery storage (BS).

- Subsystems for which evaluations can be performed (dashed lines):
  SYS (green): System boundary includes all possible SHC-components.
  DHW / HD / DH (red): Heat supply boundary includes heat sources and the hot storage, which distributes heat to the requesting sinks.
  CD / DC (blue): Cold supply boundary includes cold sources (C) and the cold storage (CS), which are also connected to the heating side.

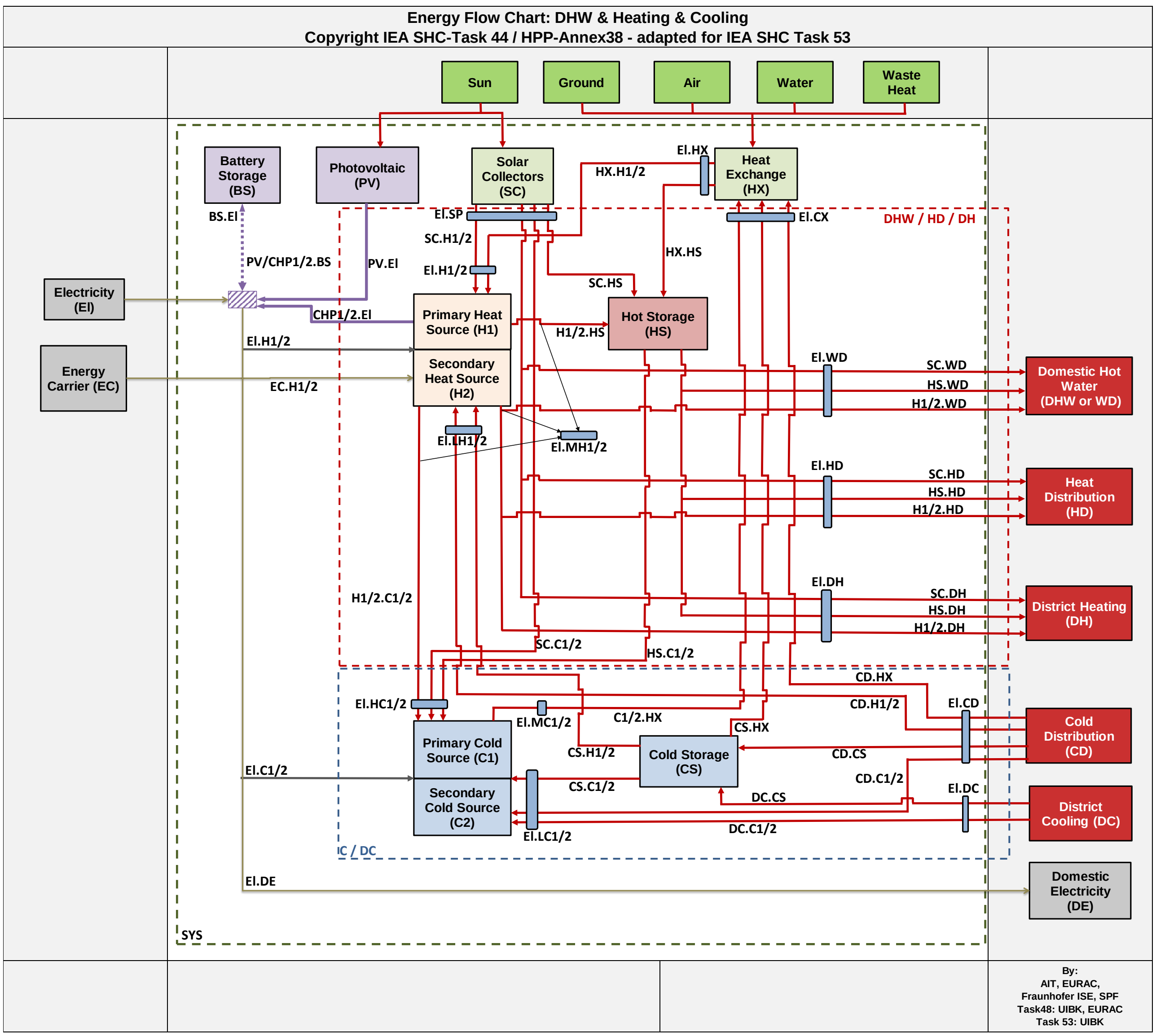


Figure 1.1: Energy flow chart of the total SHC system within TASK 53

Performance evaluation of integrated solar heating and cooling systems have to take into account distribution of both collected solar heat and backup energy sources into all of the relevant (i) space heating, (ii) domestic hot water and (iii) space cooling applications. Furthermore, the time based allocation of heat flows can be influenced significantly by the availability of hot and/or cold thermal storage. All these interactions can make performance assessments very complex. As a result, performance indicators can be calculated in many different ways, taking different system boundaries into account or using various energy quantities (e.g. non-renewable primary energy (PE_{NRE}), thermal- or electrical energy). Performance assessment requires a precise definition of system boundaries and performance indicators. The main indicators are the seasonal performance factor (SPF), primary energy ratio (PER), electrical equivalent seasonal performance factor (SPF_{equ}) and non-renewable primary energy savings (f_{sav}).

- *Seasonal Performance Factor (SPF)*

For a given system boundary, the SPF is generally defined as the ratio of useful energy (Q_{out}, supplied to satisfy the needs of the building or application) to energy effort to power the system (Q_{in}, $Q_{el.in}$). It includes all auxiliary components under the defined boundary and under fluctuating conditions over a defined period of time (e.g. annual or monthly). For a system with thermal and electric energy inputs, the thermal (Eq. 1.1) and electrical SPF (Eq. 1.2) can be provided.

$$SPF_{th} = \frac{\sum Q_{out}}{\sum Q_{in}} \quad \text{Eq. 1.1}$$

$$SPF_{el} = \frac{\sum Q_{out}}{\sum Q_{el,in}} \quad \text{Eq. 1.2}$$

The electrical SPF can give misleading results when a heat source is used as main driving power (e.g. for an absorption chiller) and only parasitic electricity (e.g. for pumps) is taken into account. Also the thermal SPF can give misleading results since no parasitic electricity is taken into account, which might be significant. Because Eq. 1.1 and Eq. 1.2 do not distinguish between useful heating and cooling derived from solar and other thermal backup sources or electricity,there is potential for both SPF to suggest high energy savings even when large amounts of fossil fuel (e.g. natural gas) back up or parasitic electricity is consumed with overall poor environmental outcomes. Therefor either the PER_{NRE} or SPF_{equ} provides a better overall comparison with a reference system, as introduced below.

- *Non-renewable Primary Energy Ratio (PER_{NRE})*

The primary energy ratio for non-renewable energies (PER_{NRE}) overcomes this problem by converting all non-renewable energy flows into primary energy equivalents. This provides appropriately comparable quality ratings for energy derived from alternative electricity and fossil fuel heat energy sources. PER_{NRE} is defined in Eq. 1.3 as the ratio of useful energy (supplied to satisfy the needs of the building) to consumed primary energy from external sources ($Q_{el.in}$, Q_{in}). Certain primary energy conversion factors (ε) for each type of energy source have to be provided to calculate the PER_{NRE}. The primary energy factors depend on local conditions (e.g. the source from which local electricity is derived).

$$PER_{NRE} = \frac{\sum Q_{out}}{\sum\left(\frac{Q_{el,in}}{\varepsilon_{el}} + \frac{Q_{in}}{\varepsilon_{in}}\right)} \quad \text{Eq. 1.3}$$

A high value for PER indicates that the buildings heating and cooling services are being obtained with a relatively small amount of non-renewable, fossil derived energy and is therefore an environmentally friendly system. However, values for PER are not directly comparable with any widely available industry figures of merit such as the SEER of a vapor compression chiller. Therefor the electrical equivalent seasonal performance factor (SPF_{equ}) is introduced and described below.

- *Electrical Equivalent Seasonal Performance Factor (SPF_{equ})*

The Electrical Equivalent Seasonal Performance Factor (SPF_{equ}) converts all consumed non-renewable primary energy into electrical equivalent units by dividing the entire primary energy ratio by the primary energy factor of electricity (Eq. 1.4).

$$SPF_{equ} = \frac{PER_{NRE}}{\varepsilon_{el}} = \frac{\sum Q_{out}}{\sum\left(Q_{el,in} + \frac{Q_{in}}{\varepsilon_{in}} * \varepsilon_{el}\right)} \quad \text{Eq. 1.4}$$

The Electrical Equivalent Seasonal Performance Factor for cooling ($SPF_{equ,C}$) can then be used to compare the overall cooling system with a vapor compression system (SEER), even when a hot backup is used as part of the heat supplied to a thermal chiller.

It has to be noted that, when the application has a small solar fraction the good performance of the SHC system may be swamped by the efficiency of the conventional components like compression chiller or natural gas boiler. In this case, the performance indicators (SPF or PER) of the building's SHC system will be similar to that of a conventional building, and it will be difficult to detect the impact of the SHC system. While an accurate reflection of the overall building heating and cooling system is possible, it does not say much about the quality of the SHC system as a stand-alone item. For these kind of assessments, the heating and cooling system is divided into subsystems and their related solar contributions.

All of the above defined efficiency indicators provide some insight into system performance, but in each case the efficiency (SPF, PER_{NRE} and SPF_{equ}) in heating mode is not strictly comparable with the efficiency in cooling mode. Typically, solar heating has significantly less equipment pending and thus associated parasitic loads. As a result, heating applications result in higher efficiency values than applications dominated by cooling. Overall system efficiency parameters may give confusing results because they combine heating and cooling into one performance indicator.

- *Primary Energy Savings (f_{sav})*

One final key performance indicator is Primary Energy Savings (f_{sav}). This represents the percentage reduction in non-renewable primary energy of the building heating and cooling system compared with a reference (business as usual) system (Eq. 1.5)

$$f_{sav.PER} = 1 - \frac{PER_{NRE-ref}}{PER_{NRE-i}}$$ **Eq. 1.5**

A f_{sav} value of 1 would indicate that 100% of building primary energy consumption has been eliminated, by substitution of all non-renewable primary energy with solar energy. Typically, the capital investment involved in putting in enough solar collector area to cover 100% of building demand is not justified, because there will be large periods of time when much of the available collected heat can't be fully used. While an admirable objective, high values of f_{sav} would not appear to be a suitable stand-alone parameter for design optimization.

The wide variety of possibilities enables the comparison of individual SHC and reference systems. The efficiency indicator calculation is done within an adequate system boundary. To determine relevant indicators, all necessary equations are explained in chapters 3 & 4.

2 Tool description

The Tool is based on an EXCEL-file and subdivided in 14 work sheets. Main clusters are (1) system definition, (2) energy balances, (3) EF-Chart, (4) results, (5) economic calculation and (6) summary. The results are calculated in several VBA-macros, only the economic analysis is directly implemented in the spreadsheet.

Keep in mind, that the Tool includes technical and economical complex calculations and structures. Therefor it is necessary that the user is focused on the Tool during data input. Results need to be scrutinized and interpreted with care.

The Tool is password protected but editing is possible. Simple country or project specific data can be implemented in the “yellow” cells. If a specific country is not included, the values for X1/X2 can be changed. The change of any names or the adding of any rows in the spreadsheet is challenging. Thus, changes can dismantle the calculation.

There are 5 main colors used in the Tool, they highlight the possibilities of changeable, standardized or specific values as following.

Tab. 2.1: Color description

Drop-down menu (grey)	Please select an option! Some options are just for information, others influence the results significantly!
Value to be filled in (pink)	Please fill in the certain value! ALL values are needed!
T53 Standard (green)	Input values referring to T53 Standard calculation are unchangeable, decided by the T53 members.
Specific value (orange)	Specific input values allow a country- or project specific calculation of both technical and economic key figures.
Editing specific values (yellow)	Cell to edit the specific value (x1, x2)
Calculated values (white)	Calculated unchangeable values

In the following, each worksheet (WS) is explained in detail. Technical and economical calculation procedures and equations are listed in chapters 3 & 4.

2.1 WS: Read me!

In this WS an overview of each single WS and its special remarks are summarized. Based on this summarized information and these remarks the usage of the Tool can be started.

2.2 WS: Input

On top there is a repetition of the colors and their meaning (compare Tab. 2.1). The structure is from left to right: Name of the parameter, abbreviation, drop down menu / input value, unit. The implementation of the entire system values starts in "GENERAL Information" (Tab. 2.2). In "Project location" several worldwide cities/countries can be chosen, x_1 / x_2 are placeholders for another specific country, which isn't listed so far and can be implemented individually (see WS "Conversion"). The precise location refers to the implemented annual/monthly factors used in the calculations (e.g. mean temperature for this location, primary energy factor, etc.).

Tab. 2.2: General Information

Project location (precise location)	- Austria (Vienna) - Australia (New Castle) - France (Perpignon) - Germany (Munich) - Italy (Rome)	- P.R. China (Beijing) - Spain (Madrid) - Singapore - x1 / x2	
Calculation method for CHP	Energy balance method		
Building category	- Residential - Public - Commercial - Office	- Hotel - Sanitary, Hospital - School - Other	
Cooled / heated area			m²
Distribution system	- Fan coil - Chilled ceiling - Concrete core activation	- Air duct - Other	

The CHP is calculated by the energy balance method only. In earlier versions, further calculation methods could be selected. Due to the new oncoming Standard [EN ISO 52000-1], only the energy balance method remained. If one of the other calculation methods should be taken into account, some updates in the programming are necessary (e.g. η_{el} has to be implemented again).

Next step is to choose the solar heating and cooling system including the back-up and the values for each component. If a system isn't present, 'no' has to be selected in the adequate category. There will also be a distinction if it is a primary or secondary system. It is possible to implement bivalent systems e.g. two heat sources and one cold source. This distinction allows a more detailed calculation for each component.

Make sure that system components chosen are representing the entire system; the Tool does not crosscheck the chosen inputs! A wide range of building categories enables a precise calculation of the chosen SHC system. In cooled / heated area, the value of the cooled / heated area has to be filled in.

It starts with the solar parts (Tab. 2.3). Solar thermal collectors can be a flat plate-, evacuated tube- or specific collector type. If “specific SC” or “specific PV” is chosen, the appropriate values have to be filled in the yellow, specific cells, which are placeholders for specific cases. For solar thermal use the area has to be filled in whereas for PV the nominal peak load is necessary.

Tab. 2.3: Solar components definition

Thermal collector type	- No collector - Flat plate collector (FPC)	- Evacuated tube collector (ETC) - Specific SC	
Thermal collector area			m²
Photovoltaic collector type	- No PV - PV	- Specific PV	
Photovoltaic peak load			kW_p

Tab. 2.4 displays all necessary inputs referring the heat sources. Eleven different renewable and non-renewable heat sources can be chosen. If either reversible heat pump or reversible absorption heat pump is selected, then it is automatically selected as primary cold/heat source. It is possible to choose another cold source, but it questions the usefulness of a reversible system! The note “Rev. pump for heating & cooling” is a remembrance to that fact.

The selection of *CHP* requires the input of the used amount of biogas in the cell beneath biogas fraction of CHP. The value can reach from 0, which is equal to 100% natural gas, to 1 for 100% biogas. For CHP the “boiler peak load” equals the electrical nominal capacity. Each heat source needs to be defined with its corresponding capacity. It is possible to use the heat source for thermal cooling purposes, if ‘yes’ is chosen. Boiler peak load and overall peak load (for the reference calculation, where only one single boiler is assumed) requires the corresponding values. Primary and secondary heat source can be set to ‘no’, then only a cold sink application is considered. If a heat source is set to ‘no’, then the corresponding value(s) for $Q_{EC.H1/2}$ in the worksheet Data has/have to be set to 0 or to be left blank.

If neither a primary nor a secondary cold source is chosen, then in WS Data the $Q_{C1/2.HX}$ – cells have to be set to 0 or left blank. The cooling tower selection affects only the *investment-material & installation* and in the determination of *total costs including operation cost for water (for wet coolers)*. If the system excludes cooling towers, make sure that the electrical consumption of the CT is also excluded in the inputs in the worksheet *Data*.

Tab. 2.4: Heat source definition

Primary & Secondary boiler type	- No heat source - Heat pump - Reversible heat pump - CHP - Condensing boiler - Electric heater - District heating	- Absorption heat pump - Reversible absorption heat pump - Natural gas - Oil boiler - Pellets	
Use of boiler for cooling?	- yes	- no	
Boiler peak load (SH / DHW)			kW
Overall peak load (Ref boiler)			kW

Available cooling technologies are mentioned in Tab. 2.5. If in the category heat sources "*rev. heat pump*" or "*rev. absorption heat pump*" is chosen, then the primary chiller type is set to one of these reversible systems automatically (see above explanation under heat source). The absorption chiller can either be single or double effect. Values have to be filled in for chiller capacity and cooling peak load.

Tab. 2.5: Cooling components definition

Primary & Secondary chiller type	- No chiller - Absorption chiller single effect (SE) - Absorption chiller double effect (DE) - Adsorption chiller - District cooling	- Absorption heat pump - Reversible absorption heat pump - Water cooled VCC[1)] - Air cooled VCC[2)]	
Chiller capacity			kW
Cooling peak load (Ref chiller)			kW

1) The VCC has an internal hydraulic water loop for transferring the heat from refrigerant to the heat sink (e.g. cooling tower, ground water, etc.).

2) The VCC dissipates the heat from the refrigerant directly to the ambient air via a refrigerant/air cooling tower.

The volume of *hot* and *cold water storage* as well as the electrical storage capability of the *battery storage* can be defined according to (Tab. 2.6). Each type allows a maximum of two storages in the SHC system.

Tab. 2.6: Storage type definition

Primary / Secondary hot water storage	m^3
Primary / Secondary cold water storage	m^3
Primary / Secondary battery storage	kWh

Last input in the SHC section is the *electricity peak in operation* (kW). This value is used for the calculation of *Electricity Cost of renewable heating and cooling system for HVAC only* (WS: Cost_calc). Furthermore, it can be selected if the *cost calculation with electricity peak* is applicable.

The selection for the reference system configuration is similar to the structure of the SHC system. *Heat sources* are natural gas, pellets, condensing natural gas and oil boiler, electrical heater, heat pump and district heating. A difference to the SHC system is, that the heat source of the reference system can't be chosen for cooling purposes. Water and air cooled VCC's are the *chiller types* (or district cooling) of the reference system. Compared to the SHC system there is just one *hot* and one *cold water storage tank* available.

The category *Rest* shows calculated values for the reference system, which are determined and fixed referring to state of the art average values. Displayed are:

- Water consumption for heat rejection or air conditioning – REF System (m^3/a)
- Electricity peak in operation – REF system (kW)
- Daily domestic hot water consumption (DHW) (l/day)
- Set point of domestic hot water tank (°C)
- Ambient temperature of hot water tank (°C)
- Electrical consumption ref for SH & DHW (kWh_{el}/kWh_{th})

In section *calculation details* the value for *Reference for max performance time* (not used at the Moment) is changeable. *Switch capacity ACM* (kW) and *Reference ESEER to SPF* are defined and should not be changed. "*Switch capacity ACM"* defines the switching capacity from less efficient but cheaper compressor technology to turbo compressor (cf. conversion). "*Reference ESEER to SPF"* indicates the conversion factor between the theoretical SEER and the SPF for reference calculation and was fixed with industry partners and observed operation experience.

Due to the selections done, some conversion values are shown in columns K and L respectively. These values might change after the calculation, as some of them depend on the data implemented. More information is given in the further WS descriptions.

2.3 WS: Conversion

This worksheet contains base data for cooling and heating components (efficiencies, primary energy factors, temperature levels) as well as the complete content of the drop-down menus. Depending on the available data (see WS: Data) from measurements or simulations these factors are used to complete the calculation chain for of the SHC system and to do the calculations for the reference system respectively.

The first subsection cooling includes (seasonal) energy efficiency ratio (SEER/EER) for the reference vapor compression chiller (VCC). The EERs are depending on the nominal capacity and its underlying standard compressor technology (e.g. on/off screw for small scale, controlled turbo for large scale, etc.). The capacity is subdivided in two groups: 5 to 250 kW and 250 to 1'000 kW [TASK 48, B7]. The values are provided for air and water cooled VCCs. In the group5 to 250 kW the EER_{ref} and the $ESEER_{ref}$ for district cooling are defined with 2.8 and 6.0 for capacities exceeding 250 kW respectively.

2.3.1 Determination of η_{HB}, ε_{EC} and CO_2-factor for …

These three conversion factors are used to calculated the efficiency of the reference system (cf. chapter 3.5) and furthermore to calculate the PER_{NRE} (cf. chapter 3.6.1) and the non-renewable Primary energy demand and CO2 emissions (cf. chapter 3.7).

The subsection heat sources lists the country-specific boiler efficiency (η_{HB}), primary energy factor for a specific energy carrier (ε_{EC}) and CO_2-factors. If possible, the various values for each energy carrier are split into annual and monthly values. The Task 53 standard values were agreed by the Task 53 participants. If there aren't any specific values available for the chosen country, the Task 53 Standards are used.

In the following description the values for Austria for country specific are explained. The detailed determination of the monthly primary energy conversion factor for electricity is just implemented for Austria due to sufficient calculation basis [OIB RL6 2015], [e-control.at], [Kalt 2015].

1) … (non-condensing) natural gas fired boiler and pellet boiler

The boiler efficiency is calculated on monthly basis, depending on the supplied energy of the boiler. Main influence on the efficiency is given by the construction (thermal mass, etc.) and the operation hours (standby losses, etc.). All values are predefined (Tab. 2.7) and result in the calculation equation for the boiler efficiency in Eq. 3.284 and Eq. 3.285.

Tab. 2.7: Efficiency for natural gas boiler and pellet boiler and conversion factors for the energy carriers (EC) natural gas and pellet (based on final energy).

		Boiler efficiency		Primary energy factor - ε_{EC}		CO_2 - factor	
		-	base	kWh/kWh_{PE}	base	kg/kWh	base
Natural gas	T53 - standard	Calculated	Monthly	0.9	Annual	0.26	Annual
	Country spec. (E.g. Austria)	0.875	Annual	0.862	Annual	0.236	Annual
Pellet	T53 - standard	Calculated	Monthly	10	Annual	0.045	Annual
	Country spec. (E.g. Austria)	0.814	Annual	16.7	Annual	0.004	Annual

2) … heat pump (HP) and absorption heat pump (AHP)

If integrated in the system, detailed determination of heat pumps is done in the worksheet HP (2.4). The efficiency of a heat pump is defined with the coefficient of performance (COP) (see also chapter 3.5.2).

For an electrical driven heat pump the values depend on the heat source media temperature (air, water, brine, soil) and on the designed temperature of the heating system as heat sink. A constant electrical COP of 3.3 is preset as standard [Eiper 2014] but is revised when the HP calculation (see WS: HP) is used. Tab. 2.8 includes the values for each key figure.

The primary energy and CO2 demand for the electrical heat pump are calculated with the factors for electricity. Thus, for being able to keep the overall calculation structure of the tool (see chapter 3.1) the energy carrier values (An energy carrier in fact does not exist for an electrical heat pump!) are set to a very high value for the primary energy factor and very low value for the CO2-factor respectively.

The absorption heat pump has a predefined constant thermal COP of 1.5 [Kunz 2007]. Standard driving fuel is natural gas, thus the primary energy factor equals those of natural gas, if other sources are used the ε_{AHP} need to be changed accordingly. The values for the reversible AHP are equal to the common AHP and are displayed in Tab. 2.8.

Tab. 2.8: Efficiency and conversion factors for electric heat pump, reversible electric HP, absorption heat pump and reversible AHP

		COP (el / th)		Primary energy factor - ε		CO_2 - factor	
		-	base	kWh/kWh$_{PE}$	base	kg/kWh	base
El. Heat pump	T53 - standard	3.3 (el)	Annual (monthly in WS HP)	10^{14}	Annual	10^{-6}	Annual
	Country spec. (E.g. Austria)						
Reversible el. heat pump	T53 - standard			10^{14}	Annual		
	Country spec. (E.g. Austria)						
Absorption heat pump	T53 - standard	1.5 (th)	Annual (monthly in WS HP)	0.9	Annual	0.26	Annual
	Country spec. (E.g. Austria)			0.862	Annual	0.236	Annual
Reversible absorption heat pump	T53 - standard			0.9	Annual	0.26	Annual
	Country spec. (E.g. Austria)			0.862	Annual	0.236	Annual

3) … combined heat and power (CHP), district heating (DH), condensing natural gas boiler, oil boiler and electric heater

Tab. 2.9 includes the default values for the efficiency, primary energy factor and CO_2-factor for CHP, DH, condensing natural gas boiler and oil boiler as well as electric heater.

The thermal efficiency of a CHP unit is set to 0.56 and 0.35 for the electrical efficiency respectively [heizungsfinder.de]. The CHP can be fired with natural gas or biogas. The determination of the thermal and electrical primary energy factors of the CHP are based on energy balance. An energy balance method can also be found in the new standard [pre-EN ISO 52000-1], which is available as pre-version (see also chapter: 3.5.1).

The district heating is assumed to be provided by renewable energy sources. Thus, the primary energy factor and CO2 factors are set accordingly to Austrian standard value of [OIB RL6 2015]. Losses of district heating systems are depending on the energy demands, season, supply temperatures, etc. Losses are in the range between 5 and 25%. Simplified the efficiency of the district heating grid is set to 0.85, assuming 15% losses. The values of efficiency primary energy and CO2 factors should be changed if more details are available.

The efficiency of an electric heater is 1.0, all electrical energy is converted into usable heat. As T53 standard a primary energy factor of 0.4 kWh_{el}/kWh_{PE} and a CO_2-factor of 0.55 kg/kWh_{el} is chosen. For Austria, the annual primary energy factor of electricity is averaged to 0.59 kWh_{el}/kWh_{PE}. The annual CO_2-factor of electricity is averaged to 0.11 kg/kWh_{el}.

Tab. 2.9: Efficiency and conversion factors for CHP, DH, condensing- / oil boiler and electric heater

		Efficiency		Primary energy factor - ε_{EC}		CO_2 - factor	
		-	base	kWh/kWh_{PE}	base	kg/kWh	base
CHP	T53 – standard	0.56	Annual	2	Annual	10^{-6}	Annual
	Country spec. (E.g. Austria)						
DH	T53 – standard	0.85	Annual	3.57	Annual	0.051	Annual
	Country spec. (E.g. Austria)						
Condensing natural gas boiler	T53 – standard	0.9	Annual	0.9	Annual	0.26	Annual
	Country spec. (E.g. Austria)			0.862	Annual	0.236	Annual
Oil boiler	T53 - standard	0.835	Annual	0.813	Annual	0.311	Annual
	Country spec. (E.g. Austria)						
Electric heater	T53 - standard	1	Annual	0.4	Annual	0.55	Annual
	Country spec. (E.g. Austria)			Calculated	Monthly	Calculated	Monthly

2.3.2 Determination of electricity parameter

The subsection Electricity contains the primary energy factor and CO_2-factor for electricity, CHP and PV. Almost all country specific values are based on annual energy balances and therefore constant through the entire year.

In Austria statistical data of the annual course of all major electricity producers were available. The values are based on [e-control.at] and are deepening on the split of primary energy sources. The total conversion factors are recalculated including the monthly data from [Kalt 2015]. With this data the monthly weighting factors are calculated and multiplied with the actual non-renewable primary energy factor for the Austrian grid electricity (1.32 kWh_{PE}/kWh_{el} [OIB RL6 2015]). The CO_2-factor [e-control.at /1] is also treated in the same way. The resulting factors are shown in Figure 2.1. Due to high fractions of hydropower in summer, higher primary energy factor and lower CO_2-factors can be observed.

The primary energy factor (ε_{PV}) of a PV plant is infinite and therefore set to 10'000 kWh_{el}/kWh_{PE}. The CO_2-factor is 0.0 kg/kWh_{el}.

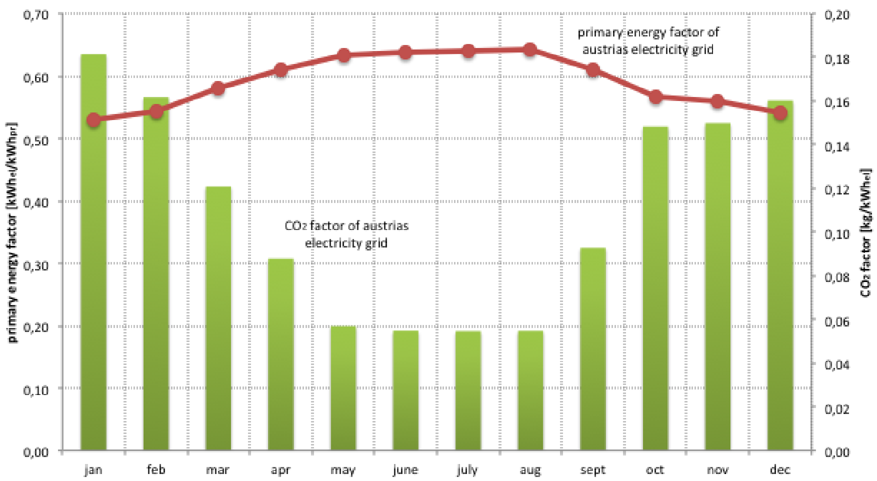


Figure 2.1: Monthly primary energy and CO_2-factors

2.4 WS: HP

Due to the complexity of the implementation of various heat pump types and heat sources, an additional worksheet for the heat pump calculation was added. The description of each step is given in Eq. 3.272 to Eq. 3.282.

2.5 WS: Data

Energy flows are filled into the Worksheet Data. Each thermal and electrical energy flow can be assigned per month or yearly. The coloring summarizes relating energy flows, e.g. light green for renewable energies. The energy flows can be the results of monitoring or simulation studies. The implementation of these values into the table has to be done with utmost care! An overview of all possible energy flows is given in chapter 6.

In cell A3 “show all” can be set, which enlarges the table and shows all possible energy flows. If this cell is “unset” the table collapses to only those lines which contain any data.

All lines BOLD formatted are summaries of lines above until the next BOLD line and will be calculated automatically. However, if the summary line is filled and in a specific line data are missing, the tool automatically will close the energy balance. It is up to the user to perform plausibility checks! If manually a line is filled with the value "0", this line is blocked and cannot be filled automatically.

If heat pump or electrical heater is chosen, the electricity demand has to be added in the row of *Switch Board Electricity to Primary/Secondary Heat Source* ($Q_{El.H1/2}$; rows 97/98). In this case the $Q_{EC.H1/2}$ (row 4/5) manually has to be set to a very small value (e.g. 0.00001 kWh). If not, values will be calculated automatically for $Q_{EC.H1/2}$. However, with the (unrealistic) high primary energy factors (see Tab. 2.8) the primary energy for Q_{EC} will end up with negligible small values!

- ➔ If the energy balances are completed, the calculation can be started by pressing the "run calculation" button in the left top corner.
- ➔ The calculation of the Tool is performed and (1) the conversion factors will be updated, (2) the technical and economic key figures will be calculated and (3) results for Task 53 standard and the specific boundaries will be listed in the results-sheets.
- ➔ The calculation is only successful, when all input data in "Inputs", "Conversion" and "Data" match each other.

2.6 WS: EFChart

This worksheet shows an "Energy Flow Chart" which shall assist to fill the WS Data correctly.

2.7 WS: Results

The results of the energetic calculations and the technical key figures are presented in the worksheets *Results*, *Results_T53, Results_spec.*, *Monthly PER (TASK 53)* and *Annual PER (TASK 53 vs. spec)*.

Results summaries the determined monthly and yearly thermal and electrical energy flows as well as the appropriate fractions that are necessary for the calculation of the subsystem key figures. Further the calculated reference energy flows are given.

Results_T53 includes the values that are determined with Task 53 conversion factors only. These results are PER_{NRE}, f_{sav} and SPF_{equ} for the entire total system but also for any subsystem. *Results_spec* lists the same structure as in *Results_T53*, but the results refer to the chosen country and other specific conversion factors.

An overview of the monthly PER's of the Task 53 Standard calculation and a comparison of the annual PER's (Task 53 vs. specific values) is shown in the diagrams of the worksheets *Monthly PER (TASK 53)* and *Annual PER (TASK 53 vs. spec)*.

2.8 WS: Labelling

The implemented energy labelling includes the following division in subsystems (Tab. 2.10). One overall performance (=System) and 5 subsystems are benchmarked against the Task 53 standard reference. For all 5 subsystems two different labels are shown: (1) for the overall subsystem and (2) only for the solar driven subsystem.

Tab. 2.10: Energy consumers considered in the labelling

- System	
- Cooling	- Solar Cooling
- Cooling Grid	- Solar Cooling Grid
- Domestic Hot Water	- Solar Domestic Hot Water
- Space Heating	- Solar Space Heating
- Heating Grid	- Solar Heating Grid

The labelling refers to the European energy labelling [2010/30/EU 2010]. The energy classes base on the f_{sav} and range from A^{+++} to G in 10 steps of 10%-saving classes (e.g.: G = 0% to 10% saving). The f_{sav} is a suitable parameter, due to its representation of reduction in non-renewable primary energy of the entire application. The savings are related to the predefined reference system (Eq. 1.5). The f_{sav} reflects the amount of substituted non-renewable primary energy. The higher the amount of renewable energy carrier is, the higher is the f_{sav} and thus the higher is the labelling class of the (sub)system.

2.9 WS: Eco_Base

The design values as base for investment costs are defined in "*INPUTS*" (nominal capacities, storage volumes, etc.). The energy costs as a result of the calculations are related to the energy balances defined in "data".

The economic base data need to be defined in "*Eco_base*". The predefined values in "*Eco_base*" differ in Task 53 Standard and (country-) specific values. If a country is unlisted, the values in column Q and/or R for x1/x2 can be filled. The description "x1"/"x2" (actually: cell Q13 and R13) MUST remain, otherwise difficulties in the code will occur if these references are renamed!

The subsection "economics" includes values for *period under consideration*, *credit period*, *inflation rate*, *market discount rate*, *credit interest rate*, *inflation rate for energy prices of electricity* and *gas*, *equity ratio* and *public funding's rate*. Further consumption-based prices (based on the energy balance) are defined for electricity, energy carrier prices and water consumption. For each energy carrier prices but also annual non-recurring prices are defined. Feed-in tariffs are defined for surplus electricity of PV or CHP supported systems but also for district heating/cooling inputs.

The feed-in renumeration of the CHP-electricity depends on the energy carrier (Tab. 2.11). If biogas is used and a total utilization ratio of 60% is exceeded, a higher feed-in tariff can be obtained. If natural gas is used, the market price of EEX-electricity exchange is used [RIS 2008]. If bio- and natural gas are mixed the compensation of electricity fed into the grid depends on the amount of biogas.

Tab. 2.11 Overview CHP feed-in remuneration

Bottleneck capacity	Biogas-CHP (€ct/kWh) for 2013 [RIS 2015]	CHP-Index EEX (€ct/kWh) 3rd quarter 2015 [eex.com]
< 250 kW	18.275	3.225
250 to 500 kW	15.705	3.225
500 to 750 kW	12.115	3.225
> 750 kW	11.705	3.225

The feed-in tariffs for PV, district heating (DH) and district cooling (DC) are listed in Tab. 2.12. For PV the feed-in tariff includes 13 years. Whereas tariffs for DH are given, values for DC had to be assumed. If grid utilization charge and monitoring fee is considered, the total costs for biogas are 7 €ct/kWh [TIGAS 2015]. District heating has a charge of 6.86 €ct/kWh [fernwaerme-murau.at]. The district cooling charges are assumed to be 1.5 times of the district heating charges.

Tab. 2.12: Feed-in tariffs for… (Task 53 Standard)

			Capacity		Source
PV	€ct/kW$_p$	11.500	kW$_p$	>5 to <200	
		3.225	kW$_p$	>200	RIS 2015
DH	€ct/kWh	4.0			Schubert 2011
DC	€ct/kWh	6.0			

In the next subsection *investment, material and installation*, *lifetime* and *maintenance, service and inspection percentage of invest* are listed. The values are defined for solar collectors and their auxiliaries, PV collectors, auxiliary heating system, solar cold production, heat rejection, storage and back-up cold production.

2.10 WS: Cost_calc

Within the WS *Cost_calc* the *investment-material and installation-*, *replacement-* and *maintenance costs*, as well as the *total costs* of each component, energy carrier and operation conditions are presented for the SHC-system and a Reference system and for both the results are shown based on (1) Task 53 Standards and (2) country specific values. Main results are visualized in diagrams below the listings of SHC- and Reference system at the very bottom of the WS.

2.11 WS: Summary

A summarized presentation of the main results based on “Task 53 Standard” and “country specific” boundary conditions are given here.

At the top “System information” displays general inputs, heat sources and cooling, as well as energy flows, efficiency and transformation factors and information about the chosen reference system. On the right side the energy label of the system and the energy flow chart is given.

Further below “Results” show the most important values of overall primary energy demand, CO_2 emissions, as well as technical and economical key figures, energy costs and avoidance costs for primary energy and CO_2.

3 Calculations of technical key figures

Within this chapter the calculation of technical and economical key figures is explained. Relevant auxiliary calculations are listed, but by far not all of them. The technical key figures are originated in the VBA code, whereas the economical key figures are defined in each cell.

The following structure is orientated towards the VBA code, Module 8. Focus is on the equations and their boundary conditions. For intermediate steps referring to the programming an overview is given.

First step in MAIN_Calc2() is the definition of local and global variables, setting of all worksheets and clear the results-worksheets from previous results (Figure 3.1). CALL Style_sheet activates all defined style sheets, which are used in the whole Tool. **Currently the Style_sheet is deactivated**.

PROCESS_DATA1() implements input data from worksheets INPUTS, Conversion and Data into VBA code. If a=1 worksheet for Task 53 and if a=2 worksheet for specific values is set. Independently of this choice PROCESS_DATA2() is the next step. Last steps are hiding empty rows, updating the screen as well as the energy label picture.

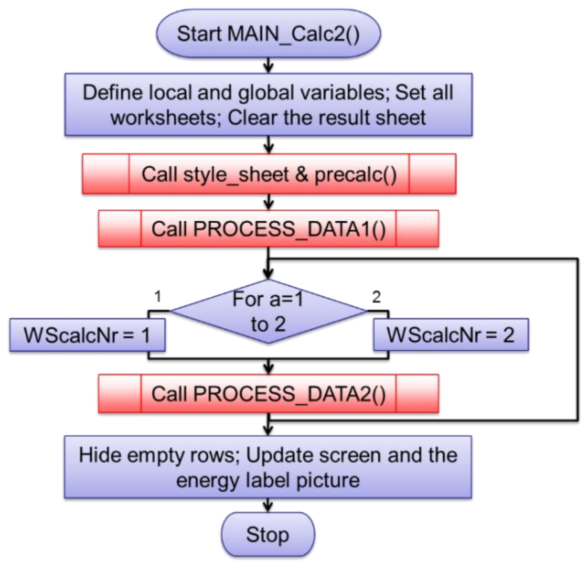


Figure 3.1: Graphic representation of MAIN_Calc2()

3.1 Pre-calculations

precalc() defines and declares types and variables (Figure 3.2). Type T is used to activate the appropriate equation/-s if the condition is fulfilled and helps to avoid double designations. E.g. TH1 is 1, then a primary heat source is given and this H1 is assumed in further calculations, depending on the choice in the drop down menu.

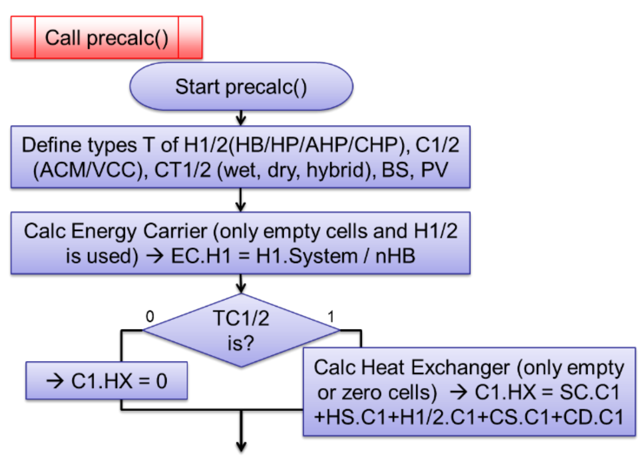


Figure 3.2:Graphic representation of precalc() (type definition, calc EC and calc of HX)

If there is just yearly data available, no monthly calculation will be performed. If only monthly values are implemented the energy flow will be summed up to the annual energy flows.

If $Q_{EC.H1/H2}$ is not implemented (be zero or blank) and an energy flow from one heat source to at least one component ($Q_{H1.sys}$>0 or $Q_{H2.sys}$>0) is defined, the energy carrier inputs is calculated with the defined efficiency of on component accordingly (Eq. 3.1).

Energy carrier (EC) of primary / secondary heat source (H1/2) in (kWh):

$$Q_{EC.H1/2} = \frac{Q_{H1/2.System}}{\eta_{HB}} \qquad \text{Eq. 3.1}$$

If there is a cooling source and energy flow to heat exchangers are not defined, $Q_{C1.HX}$ is determined by Eq. 3.2. This is working only if the appropriate cells (row 44 and row 45) are empty or zero in worksheet DATA.

Primary / secondary cold source (C1/2) to heat exchanger (HX) in (kWh):

$$Q_{C1/2.HX} = Q_{CS.C1/2} + Q_{HS.C1/2} + Q_{H1/2.C1/2} + Q_{CS.C1/2} + Q_{DC.C1/2} \qquad \text{Eq. 3.2}$$

If a PV system is included and connected to primary, secondary heat source or any other component; the determination of energy provided by PV is done by Eq. 3.3; representing the sum of rows 65-72.

Sum of energy flow provided by the PV system:

$$\Sigma_{PV} = Q_{PV.H1} * TH1 + Q_{PV.H2} * TH2 + Q_{PV.HS} + Q_{PV.C1} * TC1 + Q_{PV.C2} * TC2 + Q_{PV.BS} * TBS + Q_{PV.Pumps} + Q_{PV.DE} \qquad \text{Eq. 3.3}$$

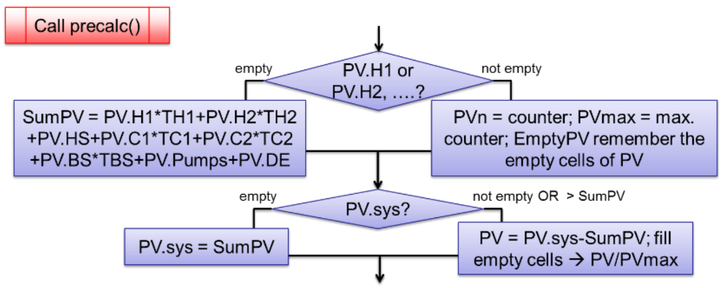


Figure 3.3:Graphic representation of precalc() (PV)

Otherwise the PV electricity distribution is assumed / calculated as follows:

If the cells of row 65-72 in the worksheet DATA are empty, then $Q_{PV.sys} = \Sigma_{PV}$ is taken and distributed to the certain components (H1, H1, …) equally. Considering the ratio of $Q_{PV.comp} = \frac{Q_{PV}}{\sum components}$.

If there are values filled in but electricity given from the PV ($Q_{PV.sys}$, row 73) is greater than the sum of PV system (rows 65-72), then the difference of Q_{PV} (Eq. 3.6, rows 65-72) is used to split into left components instead.

$$Q_{PV} = Q_{PV.sys} - \Sigma Q_{pv.comp} \qquad \text{Eq. 3.4}$$

If one heat source is a CHP unit then Eq. 3.5 (sum of rows 74-81 (H1) or rows 83-90 (H2)) is used to calculate the sum of provided energy.

Without monthly values (cells blank or 0), the number of components is counted and the energy provided is divided into appropriate (sum of components in the system: H1, H2, C1,…) monthly averages.

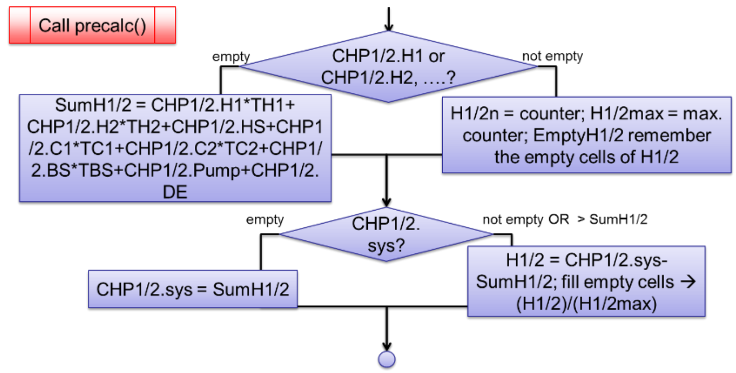


Figure 3.4:Graphic representation of precalc() (CHP)

Sum of energy flow provided by the CHP unit:

$$\Sigma Q_{H1/2} = Q_{CHP1/2.H1} * TH1 + Q_{CHP1/2.H2} * TH2 + Q_{CHP1.HS} + Q_{CHP2.HS} + Q_{CHP1/2.C1} * TC1 + Q_{CHP1/2.C2} * TC2 + Q_{CHP1.BS} * TBS + Q_{CHP2.BS} * TBS + Q_{CHP1.Pump} + Q_{CHP2.Pump} + Q_{CHP1.DE} + Q_{CHP2.DE}$$ **Eq. 3.5**

Are values implemented for one component or $\Sigma Q_{H1/2}$ is greater than the monthly $Q_{CHP1/2.sys}$, then the difference(Eq. 3.6) is determined. The $Q_{H1/H2}$ are split into the previous empty cells under consideration of the ratio $Q_{CHP1/2.comp} = \frac{Q_{H1/2}}{\sum components}$.

$$Q_{H1/2} = Q_{CHP1/2.sys} - \Sigma Q_{H1/2}$$ **Eq. 3.6**

For further calculations the variable El_{sys} is determined, which is just a supporting variable (Eq. 3.7). Pr_{sys} is the sum of the total electrical energy delivered by the system only. Therefore: Electricity from the grid is excluded and unconsidered in Eq. 3.8! Now it is divided into electricity from the public grid into the system ($Q_{GD.el}$) and electricity fed into the public grid ($Q_{El.GD}$).

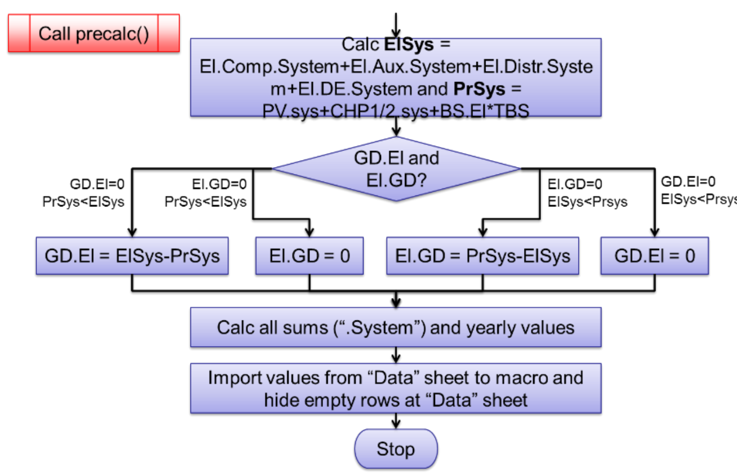


Figure 3.5:Graphic representation of precalc() (Calc ElSys and sums)

Total electricity consumers within the system (supporting variable):

$$El_{sys} = Q_{El.Comp.System} + Q_{El.Aux.System} + Q_{El.Distr.System} + Q_{El.DE.System}$$ **Eq. 3.7**

Sum of total electricity delivered by the system:

$$Pr_{sys} = Q_{PV.sys} + Q_{CHP.sys} + Q_{BS.el} * TBS$$ **Eq. 3.8**

If electricity from the public grid is zero ($Q_{GD.el} = 0$) and the sum of total electricity delivered by the system is lower than the sum of the total electricity consumers of the system ($Pr_{sys} < El_{sys}$) then the difference is imported from the public grid into the SHC system (Eq. 3.9).

$$Q_{GD.el} = El_{sys} - Pr_{sys} \quad \text{Eq. 3.9}$$

If there is no electricity fed into the public grid ($Q_{El.GD} = 0$) and the sum of total electricity delivered by the system is lower than the sum of the total electricity consumers of the system ($Pr_{sys} < El_{sys}$) then all electricity is used by the system itself (Eq. 3.10).

$$Q_{El.GD} = 0 \quad \text{Eq. 3.10}$$

If electricity fed into the public grid is manually set to zero ($Q_{El.GD} = 0$), but the sum of total electricity delivered by the system is greater than the sum of the total electricity consumed by the system ($Pr_{sys} > El_{sys}$) then the surplus of electrical energy is fed into the public grid (Eq. 3.11) and the cells for $Q_{El.GD}$ are overwritten.

$$Q_{El.GD} = Pr_{sys} - El_{sys} \quad \text{Eq. 3.11}$$

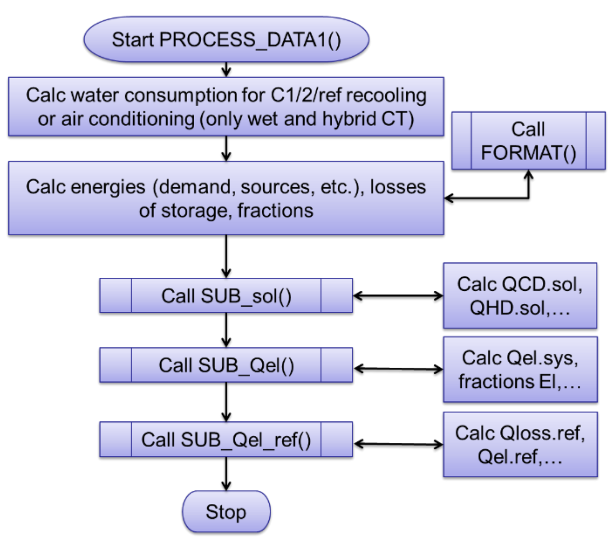
If electricity from the public grid is set to zero ($Q_{GD.el} = 0$) and the sum of total electricity delivered by the system is greater than the sum of the total electricity consumers of the system ($Pr_{sys} > El_{sys}$) then no electricity is fed into the public grid. Therefore, all converted electrical energy is used by the system itself.

$$Q_{GD.el} = 0 \quad \text{Eq. 3.12}$$

Last step is to calculate the subtotal "Q_{system}". Exceptions are $Q_{PV.sys}$, $Q_{CHP1.sys}$ and $Q_{CHP2.sys}$, which are summarized earlier. Basing on the monthly sums the annual sum is determined by taking the monthly sums into account. No calculation is necessary, when just annual values are implemented. The section 'declaration' enables to fill the adequate cells with the appropriate energy flow values. If all cells in the WS Data are edited, empty rows are hidden und just the relevant energy flows are shown in the WS Data.

The next subprogram is PROCESS_DATA1() (Figure 3.6). It starts with a pre-calculation for the WS Input, which refers to the water consumption for wet or hybrid cooling tower (Eq. 3.13 - Eq. 3.15).

Following definitions of energy flows Q 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. Further information can be found in [TASK 48, B7.2] (Eq. 3.16 - Eq. 3.139). Calculation of solar fractions to



heat and cold sources is done in SUB_sol (Eq. 3.140-Eq. 3.156).

Figure 3.6:Graphic representation of PROCESS_DATA1() (Calc water consumption and energies, call SUB's)

SUB_Qel includes the electricity calculations (Eq. 3.157-Eq. 3.250). SUB_Qel_ref determines the key figures for the reference system (Eq. 3.251-Eq. 3.255).

- Water consumption of a wet and hybrid heat rejection unit of C1 / C2 / ref in (m^3/a)

$$V_{HR.1} = 0.001 \frac{m^3}{kWh_{th}} * (Q_{CD.HX} + Q_{C1.HX})$$ Eq. 3.13

$$V_{HR.2} = 0.001 \frac{m^3}{kWh_{th}} * (Q_{C2.HX})$$ Eq. 3.14

$$V_{HR.\mathrm{ref}} = 0.001 \frac{m^3}{kWh_{th}} * (Q_{CD.HX} + Q_{C1.HX} + Q_{C2.HX})$$ Eq. 3.15

3.2 Thermal energy treatment

Calculation of total cooling demand ($Q_{CD.system}$) provided by cold sources:

$$Q_{CD.system} = Q_{CD.C1} + Q_{CD.C2} + Q_{CD.CS} + Q_{CD.H1} + Q_{CD.H2} + Q_{CD.HX}$$ Eq. 3.16

Calculation of the total heating demand ($Q_{HD.system}$) provided by all heat sources:

$$Q_{HD.system} = Q_{SC.HD} + Q_{HS.HD} + Q_{H1.HD} + Q_{H2.HD}$$ Eq. 3.17

Calculation of the total domestic hot water demand ($Q_{WD.system}$) provided by all heat sources:

$$Q_{WD.system} = Q_{SC.WD} + Q_{HS.WD} + Q_{H1.WD} + Q_{H2.WD}$$ Eq. 3.18

Calculation of the total district cooling demand ($Q_{DC.system}$) provided by all cold sources:

$$Q_{DC.system} = Q_{DC.C1} + Q_{DC.C2} + Q_{DC.CS}$$ Eq. 3.19

Calculation of the total district heating demand ($Q_{DH.system}$) provided by all heat sources:

$$Q_{DH.system} = Q_{SC.DH} + Q_{H1.DH} + Q_{H2.DH} + Q_{HS.DH}$$ Eq. 3.20

Resulting in the total distributed energy of Q_{system}

$$Q_{system} = Q_{CD.system} + Q_{HD.system} + Q_{WD.system} + Q_{DC.system} + Q_{DH.system}$$ Eq. 3.21

- Sum of energy supplied or distributed by main components and energy sources

Energy provided by thermal collector to system:

$$Q_{SC.system} = Q_{SC.HS} + Q_{SC.H1} + Q_{SC.H2} + Q_{SC.C1} + Q_{SC.C2} + Q_{SC.DH} + Q_{SC.HD} + Q_{SC.WD}$$ Eq. 3.22

Energy provided by heat exchanger to system as sink for cooling:

$$Q_{HX.in} = Q_{C1.HX} + Q_{C2.HX} + Q_{CS.HX} + Q_{CD.HX}$$ Eq. 3.23

Energy provided by heat exchanger to system as source for heating:

$$Q_{HX.out} = Q_{HX.H1} + Q_{HX.H2} + Q_{HX.HS}$$ Eq. 3.24

Energy provided by primary heat source to system:

$$Q_{H1.system} = Q_{H1.HS} + Q_{H1.C1} + Q_{H1.C2} + Q_{H1.DH} + Q_{H1.HD} + Q_{H1.WD}$$ Eq. 3.25

Energy provided by secondary heat source to system:

$$Q_{H2.system} = Q_{H2.HS} + Q_{H2.C1} + Q_{H2.C2} + Q_{H2.DH} + Q_{H2.HD} + Q_{H2.WD}$$ Eq. 3.26

Energy provided by primary cold source to system:

$$Q_{C1.system} = Q_{CS.C1} + Q_{CD.C1} + Q_{DC.C1}$$ Eq. 3.27

Energy provided by secondary cold source to system:

$$Q_{C2.system} = Q_{CS.C2} + Q_{CD.C2} + Q_{DC.C2}$$ Eq. 3.28

Energy input to hot storage from system heat sources:

$$Q_{HS.in} = Q_{SC.HS} + Q_{H1.HS} + Q_{H2.HS} + Q_{El.HS}$$ Eq. 3.29

Energy provided by hot storage to system:

$$Q_{HS.out} = Q_{HS.H1} + Q_{HS.H2} + Q_{HS.C1} + Q_{HS.C2} + Q_{HS.DH} + Q_{HS.HD} + Q_{HS.WD}$$ Eq. 3.30

Energy input to cold storage from system cold sources:

$$Q_{CS.in} = Q_{CD.CS} + Q_{DC.CS}$$ Eq. 3.31

Energy provided by cold storage to system:

$$Q_{CS.out} = Q_{CS.H1} + Q_{CS.H2} + Q_{CS.C1} + Q_{CS.C2} + Q_{CS.HX}$$ Eq. 3.32

The total energy flows of all heat and cold source to the system:

$$Q_{Source} = Q_{SC.HS} + Q_{SC.HD} + Q_{SC.WD} + Q_{SC.DH} + Q_{H1.System} + Q_{H2.System} + Q_{C1.System} + Q_{C2.System}$$ Eq. 3.33

- Hot (Q_{hloss}) and cold (Q_{closs}) storage losses

$$Q_{hloss} = Q_{HS.in} - Q_{HS.out}$$ Eq. 3.34

$$Q_{closs} = Q_{CS.out} - Q_{CS.in}$$ Eq. 3.35

- Fraction calculation for each application / distribution subsystem related to overall delivered energy (Q_{system}):

Fraction of cold distribution: $\%_{CD.sys} = \frac{Q_{CD.system}}{Q_{system}}$ **Eq. 3.36**

Fraction of heat distribution: $\%_{HD.sys} = \frac{Q_{HD.system}}{Q_{system}}$ **Eq. 3.37**

Fraction of domestic hot water: $\%_{WD.sys} = \frac{Q_{WD.system}}{Q_{system}}$ **Eq. 3.38**

Fraction of district cooling: $\%_{DC.sys} = \frac{Q_{DC.system}}{Q_{system}}$ **Eq. 3.39**

Fraction of district heating: $\%_{DH.sys} = \frac{Q_{DH.system}}{Q_{system}}$ **Eq. 3.40**

- Fraction calculation of distribution of heat/cold source (Q_{source}):

…of Primary heat source (H1) $\%_{H1.System} = \frac{Q_{H1.System}}{Q_{Source}}$ **Eq. 3.41**

…of Secondary heat source (H2) $\%_{H2.System} = \frac{Q_{H2.System}}{Q_{Source}}$ **Eq. 3.42**

… of solar thermal to hot storage $\%_{HS.System} = \frac{Q_{SC.HS}}{Q_{Source}}$ **Eq. 3.43**

… of solar thermal to space heating $\%_{HD.System} = \frac{Q_{SC.HD}}{Q_{Source}}$ **Eq. 3.44**

… of solar thermal collector to domestic hot water $\%_{WD.System} = \frac{Q_{SC.WD}}{Q_{Source}}$ **Eq. 3.45**

… of solar thermal collector to district heating $\%_{DH.System} = \frac{Q_{SC.DH}}{Q_{Source}}$ **Eq. 3.46**

… of Primary cold source (C1) $\%_{C1.System} = \frac{Q_{C1.System}}{Q_{Source}}$ **Eq. 3.47**

… of Secondary cold source (C2) $\%_{C2.System} = \frac{Q_{C2.System}}{Q_{Source}}$ **Eq. 3.48**

- Fraction of energy flow from heat exchanger (HX_{out}) to…

… primary heat source (H1): $\%_{HX.H1} = \frac{Q_{HX.H1}}{Q_{HX.out}}$ **Eq. 3.49**

… secondary heat source (H2): $\%_{HX.H2} = \frac{Q_{HX.H2}}{Q_{HX.out}}$ **Eq. 3.50**

… hot storage (HS): $\%_{HX.HS} = \frac{Q_{HX.HS}}{Q_{HX.out}}$ **Eq. 3.51**

- Fraction of energy flow to heat exchanger (HX_{in}) from cold source:

Primary cold source (C1): $\%_{C1.HXC} = \frac{Q_{C1.HX}}{Q_{HX.in}}$ **Eq. 3.52**

Secondary cold source: $\%_{C2.HXC} = \frac{Q_{C2.HX}}{Q_{HX.in}}$ **Eq. 3.53**

Cold storage (CS): $\%_{CS.HXC} = \frac{Q_{CS.HX}}{Q_{HX.in}}$ **Eq. 3.54**

Cold distribution (CD): $\%_{CD.HXC} = \frac{Q_{CD.HX}}{Q_{HX.in}}$ **Eq. 3.55**

- Fraction calculations referring to hot storage inputs (Q_{HSin}) and output (Q_{HSout}):

Distribution to primary heat source (H1): $\%_{HS.H1} = \frac{Q_{HS.H1}}{Q_{HS.out}}$ **Eq. 3.56**

Distribution to secondary heat source (H2): $\%_{HS.H2} = \frac{Q_{HS.H2}}{Q_{HS.out}}$ **Eq. 3.57**

Distribution to primary cold source (C1): $\%_{HS.C1} = \frac{Q_{HS.C1}}{Q_{HS.out}}$ **Eq. 3.58**

Distribution to secondary cold source (C2): $\%_{HS.C2} = \frac{Q_{HS.C2}}{Q_{HS.out}}$ **Eq. 3.59**

Distribution to district heating (DH): $\%_{HS.DH} = \frac{Q_{HS.DH}}{Q_{HS.out}}$ **Eq. 3.60**

Distribution to domestic hot water (WD): $\%_{HS.WD} = \frac{Q_{HS.WD}}{Q_{HS.out}}$ **Eq. 3.61**

Distribution to heat distribution (HD): $\%_{HS.HD} = \frac{Q_{HS.HD}}{Q_{HS.out}}$ **Eq. 3.62**

Fraction of losses (loss): $\%_{HS.LO} = \frac{Q_{hloss}}{Q_{HS.out}}$ **Eq. 3.63**

There is a need to distinguish between systems that allow heat sources to drive a thermal chiller and systems that avoid this energy flow. H14C and H24C indicates this system characteristic: H14C/H24C equals 0 if H1/H2 is not used for cooling. If it is used for cooling, the values are set to 1 accordingly.

The fractions of storage output to C1/C2 result then in

C1 driven by H1: $\%_{HS.C1:H1} = \%_{HS.C1} * \frac{Q_{H1.HS}}{Q_{HS.in}} * H14C$ **Eq. 3.64**

C2 driven by H1: $\%_{HS.C1:H2} = \%_{HS.C1} * \frac{Q_{H2.HS}}{Q_{HS.in}} * H24C$ Eq. 3.65

C1 driven by H2: $\%_{HS.C2:H1} = \%_{HS.C2} * \frac{Q_{H1.HS}}{Q_{HS.in}} * H14C$ Eq. 3.66

C2 driven by H2: $\%_{HS.C2:H2} = \%_{HS.C2} * \frac{Q_{H2.HS}}{Q_{HS.in}} * H24C$ Eq. 3.67

- Fraction calculations referring to cold storage inputs (Q_{CSin}) and output (Q_{CSout}):

Input from primary heat source (H1): $\%_{CS.H1} = \frac{Q_{CS.H1}}{Q_{CS.out}}$ Eq. 3.68

Input from secondary heat source (H2): $\%_{CS.H2} = \frac{Q_{CS.H2}}{Q_{CS.out}}$ Eq. 3.69

Input from primary cold source (C1): $\%_{CS.C1} = \frac{Q_{CS.C1}}{Q_{CS.out}}$ Eq. 3.70

Input from secondary cold source (C2): $\%_{CS.C2} = \frac{Q_{CS.C2}}{Q_{CS.out}}$ Eq. 3.71

Input from heat exchanger (HX): $\%_{CS.HX} = \frac{Q_{CS.HX}}{Q_{CS.out}}$ Eq. 3.72

Cold storage losses: $\%_{CS.LO} = \frac{Q_{closs}}{Q_{CS.in}}$ Eq. 3.73

- Cold distribution:

The cold distribution can be divided into cold from heat sources (e.g. source for HP; H1/H2), free cooling (HX) and cold from thermal or electrical driven chillers (C1/C2). Cold storage losses are taken into account and split according to inputs by the cold sources.

Fraction of CS at total CD: $\%_{CD.CS} = \frac{Q_{CD.CS}}{Q_{CD.system}}$ Eq. 3.74

Fraction of H1 at total CD: $\%_{CD.H1} = \frac{Q_{CD.H1}}{Q_{CD.system}} + \%_{CS.H1} * (\%_{CD.CS} + \%_{CS.LO})$ Eq. 3.75

Fraction of H2 at total CD: $\%_{CD.H2} = \frac{Q_{CD.H2}}{Q_{CD.system}} + \%_{CS.H2} * (\%_{CD.CS} + \%_{CS.LO})$ Eq. 3.76

Fraction of C1 at total CD: $\%_{CD.C1} = \frac{Q_{CD.C1}}{Q_{CD.system}} + \%_{CS.C1} * (\%_{CD.CS} + \%_{CS.LO})$ Eq. 3.77

Fraction of C2 at total CD: $\%_{CD.C2} = \frac{Q_{CD.C2}}{Q_{CD.system}} + \%_{CS.C2} * (\%_{CD.CS} + \%_{CS.LO})$ Eq. 3.78

Fraction of HX at total CD: $\%_{CD.HX} = \frac{Q_{CD.HX}}{Q_{CD.system}} + \%_{CS.HX} * (\%_{CD.CS} + \%_{CS.LO})$ Eq. 3.79

- Fraction of district cooling including cold losses:

Fraction of DC referring to CS: $\%_{DC.CS} = \frac{Q_{DC.CS}}{Q_{DC.system}}$ **Eq. 3.80**

Fraction of C1 at total DC: $\%_{DC.C1} = \frac{Q_{DC.C1}}{Q_{DC.system}} + \%_{CS.C1} * (\%_{DC.CS} + \%_{CS.LO})$ **Eq. 3.81**

Fraction of C2 at total DC: $\%_{DC.C2} = \frac{Q_{DC.C2}}{Q_{DC.system}} + \%_{CS.C2} * (\%_{DC.CS} + \%_{CS.LO})$ **Eq. 3.82**

- Usage of solar thermal energy in…

…primary heat source (H1): $\%_{SC.H1} = \frac{Q_{SC.H1}}{Q_{SC.out}}$ **Eq. 3.83**

…secondary heat source (H2): $\%_{SC.H2} = \frac{Q_{SC.H2}}{Q_{SC.out}}$ **Eq. 3.84**

…primary cold source (C1): $\%_{SC.C1} = \frac{Q_{SC.C1}}{Q_{SC.out}}$ **Eq. 3.85**

…secondary cold source (C2): $\%_{SC.C2} = \frac{Q_{SC.C2}}{Q_{SC.out}}$ **Eq. 3.86**

…hot storage (HS): $\%_{SC.HS} = \frac{Q_{SC.HS}}{Q_{SC.out}}$ **Eq. 3.87**

…district heating (DH): $\%_{SC.DH} = \frac{Q_{SC.DH}}{Q_{SC.out}}$ **Eq. 3.88**

…heat distribution (HD): $\%_{SC.HD} = \frac{Q_{SC.HD}}{Q_{SC.out}}$ **Eq. 3.89**

…domestic hot water (WD): $\%_{SC.WD} = \frac{Q_{SC.WD}}{Q_{SC.out}}$ **Eq. 3.90**

Losses of collector due to hot storage losses :

$\%_{SC.LO} = (\%_{SC.HS} + \%_{SC.H1} * \%_{H1.HS} + \%_{SC.H2} * \%_{H2.HS}) * \%_{HS.LO}$ **Eq. 3.91**

- Usage of heat source (H1/H2) in…

…primary cold source (C1): $\%_{H1.C1} = \frac{Q_{H1.C1}}{Q_{H1.out}}$ **Eq. 3.92**

…secondary cold source (C2): $\%_{H1.C2} = \frac{Q_{H1.C2}}{Q_{H1.out}}$ **Eq. 3.93**

…hot storage (HS): $\%_{H1.HS} = \frac{Q_{H1.HS}}{Q_{H1.out}}$ **Eq. 3.94**

…district heating (DH): $\%_{H1.DH} = \frac{Q_{H1.DH}}{Q_{H1.out}}$ **Eq. 3.95**

…heat distribution (HD): $\%_{H1.HD} = \frac{Q_{H1.HD}}{Q_{H1.out}}$ Eq. 3.96

…domestic hot water (WD): $\%_{H1.WD} = \frac{Q_{H1.WD}}{Q_{H1.out}}$ Eq. 3.97

Primary heat source losses due to hot storage losses: $\%_{H1.LO} = \%_{H1.HS} * \%_{HS.LO}$ Eq. 3.98

…primary cold source (C1): $\%_{H2.C1} = \frac{Q_{H2.C1}}{Q_{H2.out}}$ Eq. 3.99

…secondary cold source (C2): $\%_{H2.C2} = \frac{Q_{H2.C2}}{Q_{H2.out}}$ Eq. 3.100

…hot storage (HS): $\%_{H2.HS} = \frac{Q_{H2.HS}}{Q_{H2.out}}$ Eq. 3.101

…district heating (DH): $\%_{H2.DH} = \frac{Q_{H2.DH}}{Q_{H2.out}}$ Eq. 3.102

…heat distribution (HD): $\%_{H2.HD} = \frac{Q_{H2.HD}}{Q_{H2.out}}$ Eq. 3.103

…domestic hot water (WD): $\%_{H2.WD} = \frac{Q_{H2.WD}}{Q_{H2.out}}$ Eq. 3.104

Secondary heat source losses due to hot storage losses:

$\%_{H2.LO} = \%_{H2.HS} * \%_{HS.LO}$ Eq. 3.105

- Fraction of cooling energy utilization / supply

Supply of CD through CS: $\%_{C.CS} = \frac{Q_{CD.CS}}{Q_{CS.in}}$ Eq. 3.106

Supply of DC through CS: $\%_{\mathrm{CG.CS}} = \frac{\mathrm{Q_{DC.CS}}}{\mathrm{Q_{CS.in}}}$ Eq. 3.107

Supply of CD through C1: $\%_{C.C1} = \frac{Q_{CD.C1}}{Q_{C1.in}} + \frac{Q_{CS.C1}}{Q_{C1.in}} * \%_{C.CS}$ Eq. 3.108

Supply of DC through C1: $\%_{CG.C1} = \frac{Q_{DC.C1}}{Q_{C1.in}} + \frac{Q_{CS.C1}}{Q_{C1.in}} * \%_{CG.CS}$ Eq. 3.109

Supply of CD through C2: $\%_{C.C2} = \frac{Q_{CD.C2}}{Q_{C2.in}} + \frac{Q_{CS.C2}}{Q_{C2.in}} * \%_{C.CS}$ Eq. 3.110

Supply of DC through C2: $\%_{CG.C2} = \frac{Q_{DC.C2}}{Q_{C2.in}} + \frac{Q_{CS.C2}}{Q_{C2.in}} * \%_{CG.CS}$ Eq. 3.111

- Fraction of heat demand if no cooling system is included

Heat distribution: $$\%_{HD.nC} = \frac{Q_{HD.System}}{Q_{HD.System}+Q_{WD.System}+Q_{DH.System}}$$ **Eq. 3.112**

Domestic hot water: $$\%_{WD.nC} = \frac{Q_{WD.System}}{Q_{HD.System}+Q_{WD.System}+Q_{DH.System}}$$ **Eq. 3.113**

District heating: $$\%_{DH.nC} = \frac{Q_{DH.System}}{Q_{HD.System}+Q_{WD.System}+Q_{DH.System}}$$ **Eq. 3.114**

- Fraction of solar thermal energy utilization:

For a detailed calculation of this fraction (incl. losses) a pre-calculation is necessary.

Pre-calculation solar collector utilization for cooling (C):

$$\%_{pre.SC.C} = [(\%_{SC.C1} + \%_{SC.H1} * \%_{H1.C1} + \%_{SC.H2} * \%_{H2.C1} + (\%_{SC.H1} * \%_{H1.HS} + \%_{SC.H2} * \%_{H2.HS} + \%_{SC.HS}) * \%_{HS.C1}) * \%_{C.C1} + (\%_{SC.C2} + \%_{SC.H1} * \%_{H1.C2} + \%_{SC.H2} * \%_{H2.C2} + (\%_{SC.H1} * \%_{H1.HS} + \%_{SC.H2} * \%_{H2.HS} + \%_{SC.HS}) * \%_{HS.C2}) * \%_{C.C2}]$$

Eq. 3.115

Total solar thermal energy supply for cooling (C):

$$\%_{SC.C} = \left[\left(\%_{SC.C1} + \%_{SC.H1} * \%_{H1.C1} * H14C + \%_{SC.H2} * \%_{H2.C1} * H24C + (\%_{SC.H1} * \%_{H1.HS} * H14C + \%_{SC.H2} * \%_{H2.HS} * H24C + \%_{SC.HS}) * \%_{HS.C1} * (1 + \%_{HS.LO})\right) * \%_{C.C1} + \left(\%_{SC.C2} + \%_{SC.H1} * \%_{H1.C2} * H14C + \%_{SC.H2} * \%_{H2.C2} * H24C + (\%_{SC.H1} * \%_{H1.HS} * H14C + \%_{SC.H2} * \%_{H2.HS} * H24C + \%_{SC.HS}) * \%_{HS.C2} * (1 + \%_{HS.LO})\right) * \%_{C.C2}\right] * \frac{1}{(1+\%_{HS.LO})}$$

Eq. 3.116

Pre-calculation solar collector utilization for cooling grid (CG):

$$\%_{pre.SC.CG} = [(\%_{SC.C1} + \%_{SC.H1} * \%_{H1.C1} + \%_{SC.H2} * \%_{H2.C1} + (\%_{SC.H1} * \%_{H1.HS} + \%_{SC.H2} * \%_{H2.HS} + \%_{SC.HS}) * \%_{HS.C1}) * \%_{CG.C1} + (\%_{SC.C2} + \%_{SC.H1} * \%_{H1.C2} + \%_{SC.H2} * \%_{H2.C2} + (\%_{SC.H1} * \%_{H1.HS} + \%_{SC.H2} * \%_{H2.HS} + \%_{SC.HS}) * \%_{HS.C2}) * \%_{CG.C2}]$$

Eq. 3.117

Total solar thermal energy supply for cooling grid (CG):

$$\%_{SC.CG} = \left[\left(\%_{SC.C1} + \%_{SC.H1} * \%_{H1.C1} * H14C + \%_{SC.H2} * \%_{H2.C1} * H24C + (\%_{SC.H1} * \%_{H1.HS} * H14C + \%_{SC.H2} * \%_{H2.HS} * H24C + \%_{SC.HS}) * \%_{HS.C1} * (1 + \%_{HS.LO})\right) * \%_{CG.C1} + \left(\%_{SC.C2} + \%_{SC.H1} * \%_{H1.C2} * H14C + \%_{SC.H2} * \%_{H2.C2} * H24C + (\%_{SC.H1} * \%_{H1.HS} * H14C + \%_{SC.H2} * \%_{H2.HS} * H24C + \%_{SC.HS}) * \%_{HS.C2} * (1 + \%_{HS.LO})\right) * \%_{CG.C2}\right] * \frac{1}{(1+\%_{HS.LO})}$$

Eq. 3.118

Total solar thermal energy supply for space heating (SH):

$$\%_{SC.SH} = [\%_{SC.HD} + \%_{SC.H1} * \%_{H1.HD} + \%_{SC.H2} * \%_{H2.HD} + (\%_{SC.H1} * \%_{H1.HS} + \%_{SC.H2} * \%_{H2.HS} + \%_{SC.HS}) * \%_{HS.HD} * (1 + \%_{HS.LO})] * \frac{1}{(1+\%_{HS.LO})} + \left(\left(\%_{pre.SC.C} - \%_{SC.C}\right) + \left(\%_{pre.SC.CG} - \%_{SC.CG}\right)\right) * \%_{HD.nC}$$

Eq. 3.119

Total solar thermal energy supply for domestic hot water (DHW):

$$\%_{SC.DHW} = [\%_{SC.WD} + \%_{SC.H1} * \%_{H1.WD} + \%_{SC.H2} * \%_{H2.WD} + (\%_{SC.H1} * \%_{H1.HS} + \%_{SC.H2} * \%_{H2.HS} + \%_{SC.HS}) * \%_{HS.WD} * (1 + \%_{HS.LO})] * \frac{1}{(1+\%_{HS.LO})} + \left(\left(\%_{pre.SC.C} - \%_{SC.C}\right) + \left(\%_{pre.SC.CG} - \%_{SC.CG}\right)\right) * \%_{WD.nC}$$

Eq. 3.120

Total solar thermal energy supply for heating grid (HG):

$$\%_{SC.HG} = [\%_{SC.DH} + \%_{SC.H1} * \%_{H1.DH} + \%_{SC.H2} * \%_{H2.DH} + (\%_{SC.H1} * \%_{H1.HS} + \%_{SC.H2} * \%_{H2.HS} + \%_{SC.HS}) * \%_{HS.DH} * (1 + \%_{HS.LO})] * \frac{1}{(1+\%_{HS.LO})} + \left(\left(\%_{pre.SC.C} - \%_{SC.C}\right) + \left(\%_{pre.SC.CG} - \%_{SC.CG}\right)\right) * \%_{DH.nC}$$

Eq. 3.121

- Fraction of energy from heat source (H1) to distribution / applications:

… pre-calculation for H1 if energy is unused for cooling (C):

$$\%_{pre.H1.C} = \left[\left(\%_{H1.C1} + \%_{H1.HS} * \%_{HS.C1} * (1 + \%_{HS.LO})\right) * \%_{C.C1} + \left(\%_{H1.C2} + \%_{H1.HS} * \%_{HS.C2} * (1 + \%_{HS.LO})\right) * \%_{C.C2}\right] * \frac{1}{(1+\%_{HS.LO})}$$ **Eq. 3.122**

… pre-calculation for H1 if energy is unused for cooling grid (CG):

$$\%_{pre.H1.CG} = \left[\left(\%_{H1.C1} + \%_{H1.HS} * \%_{HS.C1} * (1 + \%_{HS.LO})\right) * \%_{CG.C1} + \left(\%_{H1.C2} + \%_{H1.HS} * \%_{HS.C2} * (1 + \%_{HS.LO})\right) * \%_{CG.C2}\right] * \frac{1}{(1+\%_{HS.LO})}$$ **Eq. 3.123**

Heat source no cooling (HnC): Primary heat source (H1) for cooling (C): True if H14C = 1 and QH1(i) <>0.

$$\%_{HnC.H1.C} = \%_{pre.H2.C} * \frac{QH2}{QH1} * (1 - H24C)$$ **Eq. 3.124**

Heat source no cooling (HnC): Primary heat source (H1) for cooling grid (CG): True if H14C = 1 and QH1(i) <>0.

$$\%_{HnC.H1.CG} = \%_{pre.H2.CG} * \frac{QH2}{QH1} * (1 - H24C)$$ **Eq. 3.125**

Primary heat source supply of cooling (C):

$$\%_{H1.C} = (\%_{pre.H1.C} + \%_{HnC.H1.C}) * H14C$$ **Eq. 3.126**

Primary heat source supply of cooling grid (CG):

$$\%_{H1.CG} = (\%_{pre.H1.CG} + \%_{HnC.H1.CG}) * H14C$$ **Eq. 3.127**

Primary heat source supply of space heating (SH):

$$\%_{H1.SH} = [\%_{H1.HD} + \%_{H1.HS} * \%_{HS.HD} * (1 + \%_{HS.LO})] * \frac{1}{(1+\%_{HS.LO}*\%_{H1.HS})} + \left(\%_{pre.H1.C} + \%_{pre.H1.CG}\right) * (1 - H14C) * \%_{HD.nC} - (\%_{HnC.H1.C} + \%_{HnC.H1.CG}) * \%_{HD.nC}$$ **Eq. 3.128**

Primary heat source supply of domestic hot water (DHW):

$$\%_{H1.DHW} = [\%_{H1.WD} + \%_{H1.HS} * \%_{HS.WD} * (1 + \%_{HS.LO})] * \frac{1}{(1+\%_{HS.LO}*\%_{H1.HS})} + \left(\%_{pre.H1.C} + \%_{pre.H1.CG}\right) * (1 - H14C) * \%_{WD.nC} - (\%_{HnC.H1.C} + \%_{HnC.H1.CG}) * \%_{WD.nC}$$ **Eq. 3.129**

Primary heat source supply of heating grid (HG):

$$\%_{H1.HG} = [\%_{H1.DH} + \%_{H1.HS} * \%_{HS.DH} * (1 + \%_{HS.LO})] * \frac{1}{(1+\%_{HS.LO}*\%_{H1.HS})} + \left(\%_{pre.H1.C} + \%_{pre.H1.CG}\right) * (1 - H14C) * \%_{DH.nC} - (\%_{HnC.H1.C} + \%_{HnC.H1.CG}) * \%_{DH.nC}$$ **Eq. 3.130**

- Fraction of energy from heat source (H2) to distribution / applications:

… pre-calculation for H2 if energy is unused for cooling (C):

$$\%_{pre.H2.C} = \left[\left(\%_{H2.C1} + \%_{H2.HS} * \%_{HS.C1} * (1 + \%_{HS.LO})\right) * \%_{C.C1} + \left(\%_{H2.C2} + \%_{H2.HS} * \%_{HS.C2} * (1 + \%_{HS.LO})\right) * \%_{C.C2}\right] * \frac{1}{(1+\%_{HS.LO})}$$ **Eq. 3.131**

… pre-calculation for H2 if energy is unused for cooling (CG):

$$\%_{pre.H2.CG} = \left[\left(\%_{H2.C1} + \%_{H2.HS} * \%_{HS.C1} * (1 + \%_{HS.LO})\right) * \%_{CG.C1} + \left(\%_{H2.C2} + \%_{H2.HS} * \%_{HS.C2} * (1 + \%_{HS.LO})\right) * \%_{CG.C2}\right] * \frac{1}{(1+\%_{HS.LO})}$$ **Eq. 3.132**

(HnC) Secondary heat source (H2) for cooling (C): True if H24C = 1 and QH2(i) <>0.

$$\%_{HnC.H2.C} = \%_{pre.H1.C} * \frac{QH1}{QH2} * (1 - H14C)$$ **Eq. 3.133**

(HnC) Secondary heat source (H2) for cooling grid (CG): True if H24C = 1 and QH2(i) <>0.

$$\%_{HnC.H2.CG} = \%_{pre.H1.CG} * \frac{QH1}{QH2} * (1 - H14C)$$ **Eq. 3.134**

Secondary heat source supply of cooling (C):

$$\%_{H2.C} = (\%_{pre.H2.C} + \%_{HnC.H2.C}) * H24C$$ **Eq. 3.135**

Secondary heat source supply of cooling grid (CG):

$$\%_{H2.CG} = (\%_{pre.H2.CG} + \%_{HnC.H2.CG}) * H24C$$ **Eq. 3.136**

Secondary heat source supply of space heating (SH):

$$\%_{H2.SH} = [\%_{H2.HD} + \%_{H2.HS} * \%_{HS.HD} * (1 + \%_{HS.LO})] * \frac{1}{(1+\%_{HS.LO}*\%_{H2.HS})} + \left(\%_{pre.H2.C} + \%_{pre.H2.CG}\right) * (1 - H24C) * \%_{HD.nC} - (\%_{HnC.H2.C} + \%_{HnC.H2.CG}) * \%_{HD.nC}$$ **Eq. 3.137**

Secondary heat source supply of domestic hot water (DHW):

$$\%_{H2.DHW} = [\%_{H2.WD} + \%_{H2.HS} * \%_{HS.WD} * (1 + \%_{HS.LO})] * \frac{1}{(1+\%_{HS.LO}*\%_{H2.HS})} + \left(\%_{pre.H2.C} + \%_{pre.H2.CG}\right) * (1 - H24C) * \%_{WD.nC} - (\%_{HnC.H2.C} + \%_{HnC.H2.CG}) * \%_{WD.nC}$$ **Eq. 3.138**

Secondary heat source supply of heating grid (HG):

$$\%_{H2.HG} = [\%_{H2.DH} + \%_{H2.HS} * \%_{HS.DH} * (1 + \%_{HS.LO})] * \frac{1}{(1+\%_{HS.LO}*\%_{H2.HS})} + \left(\%_{pre.H2.C} + \%_{pre.H2.CG}\right) * (1 - H24C) * \%_{DH.nC} - (\%_{HnC.H2.C} + \%_{HnC.H2.CG}) * \%_{DH.nC}$$ **Eq. 3.139**

- Calculation of solar contribution / solar fraction with regarding pre-calculations:

Total input energy flow to heat / cold source:

Primary heat source (H1): $Q_{H1.In} = Q_{SC.H1} + Q_{HS.H1} + Q_{CS.H1} + Q_{CD.H1}$ **Eq. 3.140**

Secondary heat source (H2): $Q_{H2.In} = Q_{SC.H2} + Q_{HS.H2} + Q_{CS.H2} + Q_{CD.H2}$ **Eq. 3.141**

Primary cold source (C1): $Q_{C1.In} = Q_{SC.C1} + Q_{HS.C1} + Q_{H1.C1} + Q_{H2.C1}$ **Eq. 3.142**

Secondary cold source (C2): $Q_{C2.In} = Q_{SC.C2} + Q_{HS.C2} + Q_{H1.C2} + Q_{H2.C2}$ **Eq. 3.143**

Input energy flows related to solar thermal energy:

Primary heat source (H1): $Q_{H1.In.sol} = Q_{SC.H1} + Q_{HS.H1} * \%_{SC.HS}$ **Eq. 3.144**

Secondary heat source (H2): $Q_{H2.In.sol} = Q_{SC.H2} + Q_{HS.H2} * \%_{SC.HS}$ **Eq. 3.145**

Primary cold source (C1): $Q_{C1.In.sol} = Q_{SC.C1} + Q_{HS.C1} * \%_{SC.HS} + Q_{H1.C1} * (\%_{SC.HS} * \%_{HS.H1} + \%_{SC.H1}) + Q_{H2.C1} * (\%_{SC.HS} * \%_{HS.H2} + \%_{SC.H2})$ **Eq. 3.146**

Secondary cold source (C2): $Q_{C2.In.sol} = Q_{SC.C2} + Q_{HS.C2} * \%_{SC.HS} + Q_{H1.C2} * (\%_{SC.HS} * \%_{HS.H1} + \%_{SC.H1}) + Q_{H2.C2} * (\%_{SC.HS} * \%_{HS.H2} + \%_{SC.H2})$ **Eq. 3.147**

- Solar fraction by components:

primary heat source (H1): $\%_{H1:SC} = \frac{Q_{H1.In.sol}}{Q_{H1.In}}$ **Eq. 3.148**

secondary heat source (H2): $\%_{H2:SC} = \frac{Q_{H2.In.sol}}{Q_{H2.In}}$ **Eq. 3.149**

primary cold source (C1): $\%_{C1:SC} = \frac{Q_{C1.In.sol}}{Q_{C1.In}}$ **Eq. 3.150**

secondary cold source (C2): $\%_{C2:SC} = \frac{Q_{C2.In.sol}}{Q_{C2.In}}$ **Eq. 3.151**

- Calculation of solar energy for:

cold distribution: $Q_{CD.sol} = Q_{CD.System} * (\%_{CD.C1} * \%_{C1:SC} + \%_{CD.C2} * \%_{C2:SC})$ **Eq. 3.152**

space heating: $Q_{HD.sol} = Q_{HD.System} * (\%_{H1.SH} * \%_{H1:SC} + \%_{H2.SH} * \%_{H2:SC}) + Q_{SC.System} * (\%_{SC.HS} * \%_{HS.HD} + \%_{SC.HD})$ **Eq. 3.153**

domestic hot water: $Q_{WD.sol} = Q_{SC.System} * (\%_{H1.DHW} * \%_{H1:SC} + \%_{H2.DHW} * \%_{H2:SC}) + Q_{SC.System} * (\%_{SC.HS} * \%_{HS.WD} + \%_{SC.WD}$ **Eq. 3.154** district cooling: $Q_{DC.sol} = Q_{SC.System} * (\%_{DC.C1} * \%_{C1:SC} + \%_{DC.C2} * \%_{C2:SC}$ Eq. 3.155

district heating: $Q_{DH.sol} = Q_{SC.System} * (\%_{H1.HG} * \%_{H1:SC} + \%_{H2.HG} * \%_{H2:SC}) + Q_{SC.System} * (\%_{SC.HS} * \%_{HS.DH} + \%_{SC.DH}$ Eq. 3.156

3.3 Electricity treatment

Electricity supply to battery (BS):

$$Q_{el.BS} = Q_{PV.BS} + Q_{CHP1.BS} + Q_{CHP2.BS} \quad \text{Eq. 3.157}$$

Total electricity demand of the system ($Q_{el.sys}$):

$$Q_{el.sys} = Q_{El.Comp.System} + Q_{El.Aux.System} + Q_{El.Distr.System} + Q_{El.DE} \quad \text{Eq. 3.158}$$

Total electricity demand of HVAC ($Q_{el.HVAC}$):

$$Q_{el.HVAC} = Q_{El.Comp.System} + Q_{El.Aux.System} + Q_{El.Distr.System} \quad \text{Eq. 3.159}$$

Total parasitic electricity demand ($Q_{el.PAR}$):

$$Q_{el.PAR} = Q_{El.Comp.System} + Q_{El.Aux.System} \quad \text{Eq. 3.160}$$

Electricity demand of primary heat source ($Q_{el.H1}$, incl. pumps):

$$Q_{el.H1} = Q_{el.HH1} + Q_{el.MH1} + Q_{el.LH1} + Q_{el.H1} + Q_{el.HX} * \%_{HX.H1} \quad \text{Eq. 3.161}$$

Electricity demand of secondary heat source ($Q_{el.H2}$, incl. pumps):

$$Q_{el.H2} = Q_{el.HH2} + Q_{el.MH2} + Q_{el.LH2} + Q_{el.H2} + Q_{el.HX} * \%_{HX.H2} \quad \text{Eq. 3.162}$$

Electricity demand of primary cold source ($Q_{el.C1}$, incl. pumps):

$$Q_{el.C1} = Q_{el.HC1} + Q_{el.MC1} + Q_{el.LC1} + Q_{el.C1} + Q_{el.CX} * \%_{C1.HXC} \quad \text{Eq. 3.163}$$

Electricity demand of secondary cold source ($Q_{el.C2}$, incl. pumps):

$$Q_{el.C2} = Q_{el.HC2} + Q_{el.MC2} + Q_{el.LC2} + Q_{el.C2} + Q_{el.CX} * \%_{C2.HXC} \quad \text{Eq. 3.164}$$

Electricity demand for cooling ($Q_{el.C}$):

$$Q_{el.C} = Q_{el.SP} * \%_{SC.C} + Q_{el.C1} * \%_{C.C1} + Q_{el.C2} * \%_{C.C2} + Q_{El.CX} * (\%_{CD.HXC} + \%_{CS.HXC} * \%_{C.CS}) + Q_{el.H1} * \%_{H1.C} + Q_{el.H2} * \%_{H2.C} \quad \text{Eq. 3.165}$$

Electricity demand for district cooling ($Q_{el.CG}$):

$$Q_{el.CG} = Q_{el.SP} * \%_{SC.CG} + Q_{el.C1} * \%_{CG.C1} + Q_{el.C2} * \%_{CG.C2} + Q_{el.H1} * \%_{H1.CG} + Q_{el.H2} * \%_{H2.CG} \quad \text{Eq. 3.166}$$

Electricity demand for space heating ($Q_{el.SH}$):

$$Q_{el.SH} = Q_{el.SP} * \%_{SC.SH} + Q_{el.H1} * \%_{H1.SH} + Q_{el.H2} * \%_{H2.SH} \quad \text{Eq. 3.167}$$

Electricity demand for domestic hot water ($Q_{el.DHW}$):

$$Q_{el.DHW} = Q_{el.SP} * \%_{SC.DHW} + Q_{el.H1} * \%_{H1.DHW} + Q_{el.H2} * \%_{H2.DHW} \quad \text{Eq. 3.168}$$

Electricity demand for district heating ($Q_{el.HG}$):

$$Q_{el.HG} = Q_{el.SP} * \%_{SC.HG} + Q_{el.H1} * \%_{H1.HG} + Q_{el.H2} * \%_{H2.HG}$$ Eq. 3.169

Electricity demand for solar cooling ($Q_{el.Csol}$):

$$Q_{el.Csol} = Q_{el.SP} * \%_{SC.C} + Q_{el.C1} * \%_{C.C1} * \%_{C1:SC} + Q_{el.C2} * \%_{C.C2} * \%_{C2:SC} + Q_{el.H1} * \%_{H1.C} * \%_{H1:SC} + Q_{el.H2} * \%_{H2.C} * \%_{H2:SC}$$ Eq. 3.170

Electricity demand for solar district cooling ($Q_{el.CGsol}$):

$$Q_{el.CGsol} = Q_{el.SP} * \%_{SC.CG} + Q_{el.C1} * \%_{CG.C1} * \%_{C1:SC} + Q_{el.C2} * \%_{CG.C2} * \%_{C2:SC} + Q_{el.H1} * \%_{H1.CG} * \%_{H1:SC} + Q_{el.H2} * \%_{H2.CG} * \%_{H2:SC}$$ Eq. 3.171

Electricity demand for solar domestic hot water preparation ($Q_{el.DHWsol}$):

$$Q_{el.DHWsol} = Q_{el.SP} * \%_{SC.DHW} + Q_{el.H1} * \%_{H1.DHW} * \%_{H1:SC} + Q_{el.H2} * \%_{H2.DHW} * \%_{H2:SC}$$ Eq. 3.172

Electricity demand for solar space heating ($Q_{el.SHsol}$):

$$Q_{el.SHsol} = Q_{el.SP} * \%_{SC.SH} + Q_{el.H1} * \%_{H1.SH} * \%_{H1:SC} + Q_{el.H2} * \%_{H2.SH} * \%_{H2:SC}$$ Eq. 3.173

Electricity demand for solar district heating ($Q_{el.HGsol}$):

$$Q_{el.HGsol} = Q_{el.SP} * \%_{SC.HG} + Q_{el.H1} * \%_{H1.HG} * \%_{H1:SC} + Q_{el.H2} * \%_{H2.HG} * \%_{H2:SC}$$ Eq. 3.174

- Input electricity fraction:

…of photovoltaic (PV): $$\%_{PV.el} = \frac{Q_{PV.sys} + Q_{PV.Bs} * \eta_{Bs}}{Q_{el.sys}}$$ Eq. 3.175

…of primary combined heat and power unit (CHP1): $$\%_{CHP1.el} = \frac{Q_{CHP1.sys} + Q_{CHP1.Bs} * \eta_{Bs}}{Q_{el.sys}}$$ Eq. 3.176

…of secondary combined heat and power unit (CHP2): $$\%_{CHP2.el} = \frac{Q_{CHP2.sys} + Q_{CHP2.Bs} * \eta_{Bs}}{Q_{el.sys}}$$ Eq. 3.177

…of grid (GD): $$\%_{GD.el} = \frac{Q_{GD.el}}{Q_{el.sys}}$$ Eq. 3.178

Incl. the electrical efficiency (η) of the battery (BS): $$\eta_{BS} = \frac{Q_{BS.el}}{Q_{el.BS}}$$ Eq. 3.179

and the surplus electricity fraction to grid: $$\%_{el.GD} = -\frac{Q_{el.GD}}{Q_{el.sys}}$$ Eq. 3.180

- Electricity amount of pump, which can be assigned to…

  The sum of all $\%_{Pumps}$ has to be equal 1.

… primary heat source (H1):

$$\%_{Pumps.H1} = \frac{Q_{el.HH1}+Q_{el.MH1}+Q_{el.LH1}+Q_{el.HX}*\%_{HX.H1}+(Q_{El.Distr}+Q_{el.SP})*\%_{H1.System}}{Q_{El.Aux}+Q_{El.Distr}}$$ Eq. 3.181

… secondary heat source (H2):

$$\%_{Pumps.H2} = \frac{Q_{el.HH2}+Q_{el.MH2}+Q_{el.LH2}+Q_{el.HX}*\%_{HX.H2}+(Q_{El.Distr}+Q_{el.SP})*\%_{H2.System}}{Q_{El.Aux}+Q_{El.Distr}}$$ Eq. 3.182

… hot storage (HS): $$\%_{Pumps.HS} = \frac{(Q_{El.Distr}+Q_{el.SP})*\%_{HS.System}}{Q_{El.Aux}+Q_{El.Distr}}$$ Eq. 3.183

… space heating (HD): $$\%_{Pumps.HD} = \frac{(Q_{El.Distr}+Q_{el.SP})*\%_{HD.System}}{Q_{El.Aux}+Q_{El.Distr}}$$ Eq. 3.184

… domestic hot water (DHW): $$\%_{Pumps.WD} = \frac{(Q_{El.Distr}+Q_{el.SP})*\%_{WD.System}}{Q_{El.Aux}+Q_{El.Distr}}$$ Eq. 3.185

… district heating (DH): $$\%_{Pumps.DH} = \frac{(Q_{El.Distr}+Q_{el.SP})*\%_{DH.System}}{Q_{El.Aux}+Q_{El.Distr}}$$ Eq. 3.186

… primary cold source (C1):

$$\%_{Pumps.C1} = \frac{Q_{el.HC1}+Q_{el.MC1}+Q_{el.LC1}+Q_{el.CX}*\%_{C1.HXC}+(Q_{El.Distr}+Q_{el.SP})*\%_{C1.System}}{Q_{El.Aux}+Q_{El.Distr}}$$ Eq. 3.187

… secondary cold source (C2):

$$\%_{Pumps.C2} = \frac{Q_{el.HC2}+Q_{el.MC2}+Q_{el.LC2}+Q_{el.CX}*\%_{C2.HXC}+(Q_{El.Distr}+Q_{el.SP})*\%_{C2.System}}{Q_{El.Aux}+Q_{El.Distr}}$$ Eq. 3.188

- Electricity of photovoltaic (PV) for…

… primary heat source (H1): $$\%_{PV.H1} = \frac{Q_{PV.H1}+Q_{PV.Pumps}*\%_{Pumps.H1}}{Q_{el.sys}}$$ Eq. 3.189

… secondary heat source (H2): $$\%_{PV.H2} = \frac{Q_{PV.H2}+Q_{PV.Pumps}*\%_{Pumps.H2}}{Q_{el.sys}}$$ Eq. 3.190

… hot storage (HS): $$\%_{PV.HS} = \frac{Q_{PV.HS}+Q_{PV.Pumps}*\%_{Pumps.HS}}{Q_{el.sys}}$$ Eq. 3.191

… space heating (HD): $$\%_{PV.HD} = \frac{Q_{PV.Pumps}*\%_{Pumps.HD}}{Q_{el.sys}}$$ Eq. 3.192

… domestic hot water (WD): $$\%_{PV.WD} = \frac{Q_{PV.Pumps}*\%_{Pumps.WD}}{Q_{el.sys}}$$ Eq. 3.193

… district heating (DH): $$\%_{PV.DH} = \frac{Q_{PV.Pumps}*\%_{Pumps.DH}}{Q_{el.sys}}$$ Eq. 3.194

… primary cold source (C1): $$\%_{PV.C1} = \frac{Q_{PV.C1}+Q_{PV.Pumps}*\%_{Pumps.C1}}{Q_{el.sys}}$$ Eq. 3.195

… secondary cold source (C2): $$\%_{PV.C2} = \frac{Q_{PV.C2}+Q_{PV.Pumps}*\%_{Pumps.C2}}{Q_{el.sys}}$$ Eq. 3.196

… domestic electricity (DE): $$\%_{PV.DE} = \frac{Q_{PV.DE}}{Q_{el.sys}}$$ Eq. 3.197

- Electricity of primary CHP1 for…

… primary heat source (H1): $$\%_{CHP1.H1} = \frac{Q_{CHP1.H1}+Q_{CHP1.Pumps}*\%_{Pumps.H1}}{Q_{el.sys}}$$ Eq. 3.198

… secondary heat source (H2): $$\%_{CHP1.H2} = \frac{Q_{CHP1.H2}+Q_{CHP1.Pumps}*\%_{Pumps.H2}}{Q_{el.sys}}$$ Eq. 3.199

… hot storage (HS): $$\%_{CHP1.HS} = \frac{Q_{CHP1.HS}+Q_{CHP1.Pumps}*\%_{Pumps.HS}}{Q_{el.sys}}$$ Eq. 3.200

… space heating (HD): $$\%_{CHP1.HD} = \frac{Q_{CHP1.Pumps}*\%_{Pumps.HD}}{Q_{el.sys}}$$ Eq. 3.201

… domestic hot water (WD): $$\%_{CHP1.WD} = \frac{Q_{CHP1.Pumps}*\%_{Pumps.WD}}{Q_{el.sys}}$$ Eq. 3.202

… district heating (DH): $$\%_{CHP1.DH} = \frac{Q_{CHP1.Pumps}*\%_{Pumps.DH}}{Q_{el.sys}}$$ Eq. 3.203

… primary cold source (C1): $$\%_{CHP1.C1} = \frac{Q_{CHP1.C1}+Q_{CHP1.Pumps}*\%_{Pumps.C1}}{Q_{el.sys}}$$ Eq. 3.204

… secondary cold source (C2): $$\%_{CHP1.C2} = \frac{Q_{CHP1.C2}+Q_{CHP1.Pumps}*\%_{Pumps.C2}}{Q_{el.sys}}$$ Eq. 3.205

… domestic electricity (DE): $$\%_{CHP1.DE} = \frac{Q_{CHP1.DE}}{Q_{el.sys}}$$ Eq. 3.206

- Electricity of secondary CHP2 for…

… primary heat source (H1): $$\%_{CHP2.H1} = \frac{Q_{CHP2.H1}+Q_{CHP2.Pumps}*\%_{Pumps.H1}}{Q_{el.sys}}$$ Eq. 3.207

… secondary heat source (H2): $$\%_{CHP2.H2} = \frac{Q_{CHP2.H2}+Q_{CHP2.Pumps}*\%_{Pumps.H2}}{Q_{el.sys}}$$ Eq. 3.208

… hot storage (HS): $$\%_{CHP2.HS} = \frac{Q_{CHP2.HS}+Q_{CHP2.Pumps}*\%_{Pumps.HS}}{Q_{el.sys}}$$ Eq. 3.209

… space heating (HD): $$\%_{CHP2.HD} = \frac{Q_{CHP2.Pumps}*\%_{Pumps.HD}}{Q_{el.sys}}$$ Eq. 3.210

… domestic hot water (WD): $$\%_{CHP2.WD} = \frac{Q_{CHP2.Pumps}*\%_{Pumps.WD}}{Q_{el.sys}}$$ Eq. 3.211

… district heating (DH): $$\%_{CHP2.DH} = \frac{Q_{CHP2.Pumps}*\%_{Pumps.DH}}{Q_{el.sys}}$$ Eq. 3.212

… primary cold source (C1): $$\%_{CHP2.C1} = \frac{Q_{CHP2.C1}+Q_{CHP2.Pumps}*\%_{Pumps.C1}}{Q_{el.sys}}$$ Eq. 3.213

… secondary cold source (C2): $$\%_{CHP2.C2} = \frac{Q_{CHP2.C2}+Q_{CHP2.Pumps}*\%_{Pumps.C2}}{Q_{el.sys}}$$ Eq. 3.214

… domestic electricity (DE): $$\%_{CHP2.DE} = \frac{Q_{CHP2.DE}}{Q_{el.sys}}$$ Eq. 3.215

- Grid electricity (GD) for…

Pre-calculation for electricity from grid (GD) for pumps (pumps):

$$Q_{GD.Pumps} = Q_{el.Aux} + Q_{el.Distr} - (Q_{PV.Pumps} + Q_{CHP1.Pumps} + Q_{CHP2.Pumps}) \quad \text{Eq. 3.216}$$

… primary heat source (H1): $$\%_{GD.H1} = \frac{Q_{El.H1} - (Q_{PV.H1} + Q_{CHP1.H1} + Q_{CHP2.H1}) + Q_{GD.Pumps} * \%_{Pumps.H1}}{Q_{el.sys}} \quad \text{Eq. 3.217}$$

… secondary heat source (H2): $$\%_{GD.H2} = \frac{Q_{El.H2} - (Q_{PV.H2} + Q_{CHP1.H2} + Q_{CHP2.H2}) + Q_{GD.Pumps} * \%_{Pumps.H2}}{Q_{el.sys}} \quad \text{Eq. 3.218}$$

… hot storage (HS): $$\%_{GD.HS} = \frac{Q_{El.HS} - (Q_{PV.HS} + Q_{CHP1.HS} + Q_{CHP2.HS}) + Q_{GD.Pumps} * \%_{Pumps.HS}}{Q_{el.sys}} \quad \text{Eq. 3.219}$$

… space heating (HD): $$\%_{GD.HD} = \frac{Q_{GD.Pumps} * \%_{Pumps.HD}}{Q_{el.sys}} \quad \text{Eq. 3.220}$$

… domestic hot water (WD): $$\%_{GD.WD} = \frac{Q_{GD.Pumps} * \%_{Pumps.WD}}{Q_{el.sys}} \quad \text{Eq. 3.221}$$

… district heating (DH): $$\%_{GD.DH} = \frac{Q_{GD.Pumps} * \%_{Pumps.DH}}{Q_{el.sys}} \quad \text{Eq. 3.222}$$

… primary cold source (C1): $$\%_{GD.C1} = \frac{Q_{El.C1} - (Q_{PV.C1} + Q_{CHP1.C1} + Q_{CHP2.C1}) + Q_{GD.Pumps} * \%_{Pumps.C1}}{Q_{el.sys}} \quad \text{Eq. 3.223}$$

… secondary cold source (C2): $$\%_{GD.C2} = \frac{Q_{El.C2} - (Q_{PV.C2} + Q_{CHP1.C2} + Q_{CHP2.C2}) + Q_{GD.Pumps} * \%_{Pumps.C2}}{Q_{el.sys}} \quad \text{Eq. 3.224}$$

… domestic electricity (DE): $$\%_{GD.DE} = \frac{Q_{El.DE} - (Q_{PV.DE} + Q_{CHP1.DE} + Q_{CHP2.DE})}{Q_{el.sys}} \quad \text{Eq. 3.225}$$

- Electricity of photovoltaic (PV) for…

… cooling (C):

$$\%_{PV.C} = (\%_{PV.HS} * \%_{HS.C1} + \%_{PV.C1}) * \%_{C.C1} + (\%_{PV.HS} * \%_{HS.C2} + \%_{PV.C2}) * \%_{C.C2} + \%_{PV.H1} * \%_{H1.C} + \%_{PV.H2} * \%_{H2.C} \quad \text{Eq. 3.226}$$

… cooling grid (CG):

$$\%_{PV.CG} = (\%_{PV.HS} * \%_{HS.C1} + \%_{PV.C1}) * \%_{CG.C1} + (\%_{PV.HS} * \%_{HS.C2} + \%_{PV.C2}) * \%_{CG.C2} + \%_{PV.H1} * \%_{H1.CG} + \%_{PV.H2} * \%_{H2.CG} \quad \text{Eq. 3.227}$$

… space heating (SH):

$$\%_{PV.SH} = \%_{PV.HS} * \%_{HS.HD} + \%_{PV.H1} * \%_{H1.SH} + \%_{PV.H2} * \%_{H2.SH} + \%_{PV.HD} \quad \text{Eq. 3.228}$$

… domestic hot water (DHW):

$$\%_{PV.DHW} = \%_{PV.HS} * \%_{HS.WD} + \%_{PV.H1} * \%_{H1.DHW} + \%_{PV.H2} * \%_{H2.DHW} + \%_{PV.WD} \quad \text{Eq. 3.229}$$

… heating grid (HG):

$$\%_{PV.HG} = \%_{PV.HS} * \%_{HS.DH} + \%_{PV.H1} * \%_{H1.HG} + \%_{PV.H2} * \%_{H2.HG} + \%_{PV.DH}$$ Eq. 3.230

- Electricity of CHP1 for…

… cooling (C):

$$\%_{CHP1.C} = (\%_{CHP1.HS} * \%_{HS.C1} + \%_{CHP1.C1}) * \%_{C.C1} + (\%_{CHP1.HS} * \%_{HS.C2} + \%_{CHP1.C2}) * \%_{C.C2} + \%_{CHP1.H1} * \%_{H1.C} + \%_{CHP1.H2} * \%_{H2.C}$$ Eq. 3.231

… cooling grid (CG):

$$\%_{CHP1.CG} = (\%_{CHP1.HS} * \%_{HS.C1} + \%_{CHP1.C1}) * \%_{CG.C1} + (\%_{CHP1.HS} * \%_{HS.C2} + \%_{CHP1.C2}) * \%_{CG.C2} + \%_{CHP1.H1} * \%_{H1.CG} + \%_{CHP1.H2} * \%_{H2.CG}$$ Eq. 3.232

… space heating (SH):

$$\%_{CHP1.SH} = \%_{CHP1.HS} * \%_{HS.HD} + \%_{CHP1.H1} * \%_{H1.SH} + \%_{CHP1.H2} * \%_{H2.SH} + \%_{CHP1.HD}$$ Eq. 3.233

… domestic hot water (DHW):

$$\%_{CHP1.DHW} = \%_{CHP1.HS} * \%_{HS.WD} + \%_{CHP1.H1} * \%_{H1.DHW} + \%_{CHP1.H2} * \%_{H2.DHW} + \%_{CHP1.WD}$$ Eq. 3.234

… heating grid (HG):

$$\%_{CHP1.HG} = \%_{CHP1.HS} * \%_{HS.DH} + \%_{CHP1.H1} * \%_{H1.HG} + \%_{CHP1.H2} * \%_{H2.HG} + \%_{CHP1.DH}$$ Eq. 3.235

- Electricity of CHP2 for…

… cooling (C):

$$\%_{CHP2.C} = (\%_{CHP2.HS} * \%_{HS.C1} + \%_{CHP2.C1}) * \%_{C.C1} + (\%_{CHP2.HS} * \%_{HS.C2} + \%_{CHP2.C2}) * \%_{C.C2} + \%_{CHP2.H1} * \%_{H1.C} + \%_{CHP2.H2} * \%_{H2.C}$$ Eq. 3.236

… cooling grid (CG):

$$\%_{CHP2.CG} = (\%_{CHP2.HS} * \%_{HS.C1} + \%_{CHP2.C1}) * \%_{CG.C1} + (\%_{CHP2.HS} * \%_{HS.C2} + \%_{CHP2.C2}) * \%_{CG.C2} + \%_{CHP2.H1} * \%_{H1.CG} + \%_{CHP2.H2} * \%_{H2.CG}$$ Eq. 3.237

… space heating (SH):

$$\%_{CHP2.SH} = \%_{CHP2.HS} * \%_{HS.HD} + \%_{CHP2.H1} * \%_{H1.SH} + \%_{CHP2.H2} * \%_{H2.SH} + \%_{CHP2.HD}$$ Eq. 3.238

… domestic hot water (DHW):

$$\%_{CHP2.DHW} = \%_{CHP2.HS} * \%_{HS.WD} + \%_{CHP2.H1} * \%_{H1.DHW} + \%_{CHP2.H2} * \%_{H2.DHW} + \%_{CHP2.WD}$$ Eq. 3.239

… heating grid (HG):

$$\%_{CHP2.HG} = \%_{CHP2.HS} * \%_{HS.DH} + \%_{CHP2.H1} * \%_{H1.HG} + \%_{CHP2.H2} * \%_{H2.HG} + \%_{CHP2.DH}$$ Eq. 3.240

- Electricity of grid (GD) for…

… cooling (C):

$$\%_{GD.C} = (\%_{GD.HS} * \%_{HS.C1} + \%_{GD.C1}) * \%_{C.C1} + (\%_{GD.HS} * \%_{HS.C2} + \%_{GD.C2}) * \%_{C.C2} + \%_{GD.H1} * \%_{H1.C} + \%_{GD.H2} * \%_{H2.C}$$ Eq. 3.241

… cooling grid (CG):

$$\%_{GD.CG} = (\%_{GD.HS} * \%_{HS.C1} + \%_{GD.C1}) * \%_{CG.C1} + (\%_{GD.HS} * \%_{HS.C2} + \%_{GD.C2}) * \%_{CG.C2} + \%_{GD.H1} * \%_{H1.CG} + \%_{GD.H2} * \%_{H2.CG}$$ Eq. 3.242

… space heating (SH):

$$\%_{GD.SH} = \%_{GD.HS} * \%_{HS.HD} + \%_{GD.H1} * \%_{H1.SH} + \%_{GD.H2} * \%_{H2.SH} + \%_{GD.HD}$$ Eq. 3.243

… domestic hot water (DHW):

$$\%_{GD.DHW} = \%_{GD.HS} * \%_{HS.WD} + \%_{GD.H1} * \%_{H1.DHW} + \%_{GD.H2} * \%_{H2.DHW} + \%_{GD.WD}$$ Eq. 3.244

… heating grid (HG):

$$\%_{GD.HG} = \%_{GD.HS} * \%_{HS.DH} + \%_{GD.H1} * \%_{H1.HG} + \%_{GD.H2} * \%_{H2.HG} + \%_{GD.DH}$$ Eq. 3.245

- Total electricity for…

… cooling (C): $\%_{El.C} = \%_{PV.C} + \%_{CHP1.C} + \%_{CHP2.C} + \%_{GD.C}$ Eq. 3.246

… cooling grid (CG): $\%_{El.CG} = \%_{PV.CG} + \%_{CHP1.CG} + \%_{CHP2.CG} + \%_{GD.CG}$ Eq. 3.247

… space heating (SH): $\%_{El.SH} = \%_{PV.SH} + \%_{CHP1.SH} + \%_{CHP2.SH} + \%_{GD.SH}$ Eq. 3.248

… domestic (DHW): $\%_{El.DHW} = \%_{PV.DHW} + \%_{CHP1.DHW} + \%_{CHP2.DHW} + \%_{GD.DHW}$ Eq. 3.249

… heating grid (HG): $\%_{El.HG} = \%_{PV.HG} + \%_{CHP1.HG} + \%_{CHP2.HG} + \%_{GD.HG}$ Eq. 3.250

3.4 Reference losses and parasitic electricity demand

- Heat losses of reference system ($Q_{loss.ref}$) [TASK 48, B7]:

The calculation distinguishes between monthly and annual calculation for the calculated averaged domestic hot water demand (DHW, V_D in (liter / day). For monthly calculation d = 30 days and t = 730 hours; for annual calculation d = 365 days and t = 8760 hours.

$$V_D = \frac{Q_{WD.System,i} * 1000}{1.16 * (T_T - 10) * \mathrm{d}}$$ **Eq. 3.251**

$$Q_{loss_{ref}} = 0.00016 * \sqrt{0.75 * V_D} * (T_T - T_a) * \mathrm{t}$$ **Eq. 3.252**

- Parasitic electricity consumption of reference system ($Q_{el.ref}$) (e.g. boiler, pumps, etc.):

Is a simplified calculation of the parasitic electricity demand for space heating (SH), domestic hot water (DHW) and its reference losses.

… for SH and DHW $Q_{el\_ref} = HB_{el.ref} * (Q_{HD.system} + Q_{WD.system} + Q_{loss_{ref}})$ **Eq. 3.253**

… for DHW: $Q_{el.ref.DHW} = HB_{el.ref} * (Q_{WD.system} + Q_{loss_{ref}})$ **Eq. 3.254**

… for SH: $Q_{el.ref.SH} = HB_{el.ref} * (Q_{HD.system})$ **Eq. 3.255**

Where for the reference gas boiler: $HB_{el.ref} = 0.02$ kW_{el}/kWh_{th}

3.5 Efficiency of components

The structure of PROCESS_DATA2 is shown in Figure 3.7. In the beginning project location, boiler peak load, peak load capacity, chiller capacity, cooling peak load and efficiencies are implemented from worksheet INPUT.

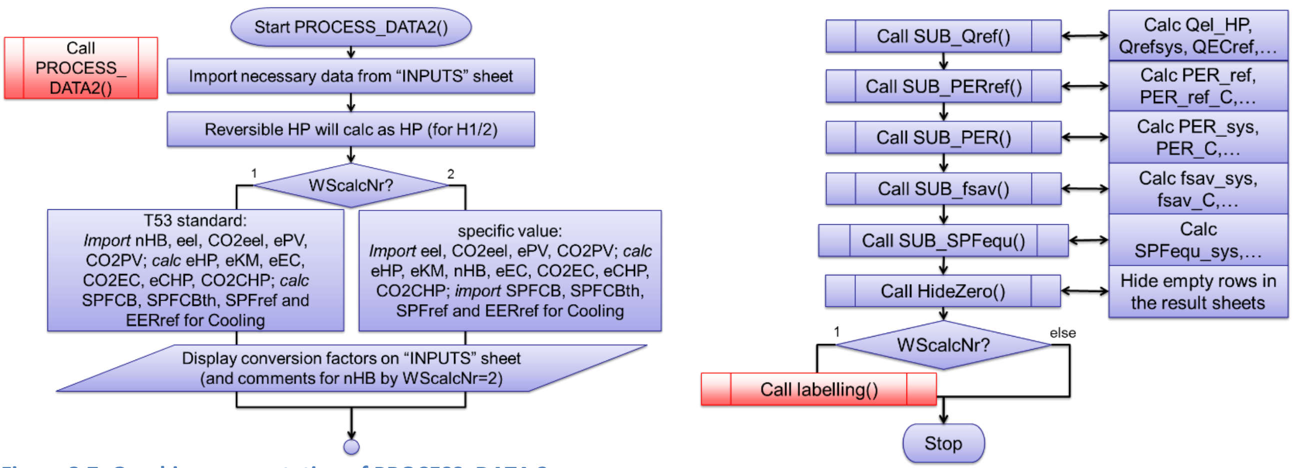


Figure 3.7: Graphic representation of PROCESS_DATA 2

The reversible heat pump / reversible absorption heat pump is calculated as HP / AHP for the moment. Depending on the allocation of Task 53 Standard (Eq. 3.256 - Eq. 3.282) or specific value, the primary energy factor, efficiency, CO_2-factor, SPF and EER are imported or calculated, respectively. The results are mainly determined in the subprograms:

- Q_{ref} (Eq. 3.286 - Eq. 3.288),
- PER_{ref} (Eq. 3.289 - Eq. 3.294),
- PER (Eq. 3.295 - Eq. 3.311),
- f_{sav} (Eq. 3.312 - Eq. 3.322) and
- SPF_{equ} (Eq. 3.323 - Eq. 3.333).

The evaluation for "specific values" considers the individual boundary conditions, e.g. country, specific month, etc. For each heat source the efficiency is calculated. η_{HB} for heat pump, absorption heat pump, CHP unit and natural gas/pellets boilers are calculated in more detail and explained in the section below.

For all other sources the default value, defined in the worksheet CONVERSION is used (district heating, electric heater, condensing natural gas boiler and oil boiler.

3.5.1 CHP calculations

The CHP calculation is shown exemplarily for primary heat source. Secondary heat source calculation is identical to the primary heat source calculation. The primary energy factor (ε) for CHP is depending on energy carrier (EC) composition (percentage allocation of natural gas and biogas).

$$\varepsilon_{EC.CHP} = \varepsilon_{EC\ (biogas)} * \%_{biogas} + \varepsilon_{EC\ (natural\ gas)} * (1 - \%_{biogas})$$ Eq. 3.256

Here: $\varepsilon_{EC\ (=spec.\ energy\ carrier)}$ is the default value in WS Conversions. The CO_2 – factor for the CHP depends on the same composition (percentage allocation of natural gas and biogas).

$$CO2_{EC.CHP} = CO2_{EC\ (=biogas)} * \%_{biogas} + CO2_{EC\ (=natural\ gas)} * (1 - \%_{biogas})$$ Eq. 3.257

Based on the energy balance of heat and electricity outputs of the CHP, the primary energy and the CO2-factor for sub-system calculation can be calculated.

Electrical efficiency (η) of CHP $$\eta_{CHP.EC} = \frac{Q_{CHP1.sys}}{Q_{EC.H1}}$$ Eq. 3.258

Heat efficiency (η) of CHP $$\eta_{H.EC} = \frac{Q_{H1.system}}{Q_{EC.H1}}$$ Eq. 3.259

Losses of CHP: $$\eta_{prop} = 1 - (\eta_{CHP.EC} + \eta_{H.EC})$$ Eq. 3.260

Efficiency ratio sum (η) *(Currently set to 1!)*: $$\eta_{sum} = 1 - \eta_{prop} * \left(\frac{\eta_{H.EC}}{\eta_{H.EC} * \eta_{CHP.EC}}\right)$$ Eq. 3.261

The primary energy demand for heating and cooling follow with the subdivided losses

Primary energy demand for CHP ($Q_{PE.CHP}$): $$Q_{PE.CHP} = \frac{Q_{EC.H1}}{\varepsilon_{EC.CHP}}$$ Eq. 3.262

Primary energy for heating ($Q_{PE.CHP\_th}$): $$Q_{PE.CHP\_th} = \frac{Q_{H1.system}}{\eta_{sum} * \varepsilon_{EC.CHP}}$$ Eq. 3.263

Primary energy for electricity ($Q_{PE.CHP\_el}$): $$Q_{PE.CHP\_el} = Q_{PE.CHP} - Q_{PE.CHP\_th}$$ Eq. 3.264

Following the primary energy factor for heating and cooling can be expressed as

Thermal primary energy factor (ε) of CHP: $$\varepsilon_{EC} = \frac{Q_{H1.system}}{Q_{PE.H\_th}}$$ Eq. 3.265

Electrical primary energy factor (ε) of CHP: $$\varepsilon_{CHP} = \frac{Q_{CHP1.sys}}{Q_{PE.H\_el}}$$ Eq. 3.266

The CO_2-factor (CO_2) for the CHP is supposed to be $CO2_{EC.CHP} > 0.00001$ if not the values are fixed to the minimum of $CO2_{EC} = 0.00001$ and $CO2_{CHP} = 0.00001$) respectively. The CO2 production for heating and cooling are calculated

CO2 emissions for CHP: $$CO2_{H1.CHP} = \frac{Q_{EC.H1}}{CO2_{EC.CHP}}$$ Eq. 3.267

CO2 emissions for heating: $CO2_{H1.CHP.th} = \frac{Q_{H1.system}}{\eta_{sum} * CO2_{EC.CHP}}$ **Eq. 3.268**

CO2 emissions for electricity: $CO2_{H1.CHP.el} = CO2_{H1.CHP} - CO2_{H1.CHP.th}$ **Eq. 3.269**

And the CO_2-factors for heating and cooling results finally in

Thermal CO_2-factor of CHP: $CO2_{EC} = \frac{Q_{H1.system}}{CO2_{H1.CHP.th}}$ **Eq. 3.270**

Electrical CO_2-factor of CHP: $CO2_{CHP} = \frac{Q_{CHP1.sys}}{CO2_{H1.CHP.el}}$ **Eq. 3.271**

3.5.2 Electrical and thermal driven heat pumps:

The efficiency for the heat pumps (electrical and thermal) are calculated with the Carnot efficiency method on monthly basis. The source and sink temperatures can be set accordingly. It is distinguished between "Air based" heat pumps (which sets the monthly average temperature of the defined city as source/sink) and "water/soil based" heat pumps (where the entire temperature can be set in the WS HP). Beside the sink/source temperature differences of the heat exchangers can be set if applicable. The absolute temperatures are the calculated as follows.

Low temperature (HP_{LT}) $HP_{LT} = HP_{tLT} - HP_{dLT} + 237.15$ **Eq. 3.272**

Medium temperature (HP_{MT}) $HP_{MT} = HP_{tMT} + HP_{dMT} + HP_{del} + 237.15)$ **Eq. 3.273**

And if primary (TH1AHP) or secondary (TH2AHP) heat source is an absorption heat pump then the

High temperature (HP_{HT}) $HP_{HT} = HP_{tHT} + HP_{dHT} + 237.15$ **Eq. 3.274**

The Coefficient of Performance (COP) is then calculated taking the temperatures and a self-defined Carnot efficiency (HP_{carnot}) in to account

COP (ε) for absorption heat pumps $\varepsilon_{HP} = \frac{1-\frac{HP_{HT}}{HP_{MT}}}{\frac{HP_{LT}}{HP_{HT}}-1} HP_{Carnot}$ **Eq. 3.275**

COP (ε) for electrical heat pumps: $\varepsilon_{HP} = \frac{HP_{MT}}{HP_{MT}-HP_{LT}} HP_{Carnot}$ **Eq. 3.276**

If the heat pump is used reversible and thus used for cooling as well the temperature differences need to be re-considered and the Energy Efficiency ratios (EER) are then given by

EER (ε) of absorption chiller: $\varepsilon_{KM} = \frac{1-\frac{HP_{HT}}{HP_{MT}}}{\frac{HP_{MT}}{HP_{LT}}-1} HP_{Carnot}$ **Eq. 3.277**

EER (ε) of electrical chiller: $$\varepsilon_{KM} = \frac{HP_{LT}}{HP_{MT} - HP_{LT}} HP_{Carnot}$$ **Eq. 3.278**

Moreover, the electricity demand for the heat pumps is calculated for primary or secondary heat source (H1/H2) and cold source (C1/C2) and the corresponding row in the WS Data ($Q_{el.H1/H2}$ / $Q_{el.C1/C2}$) is set to this value if no values are implemented.

$$Q_{el.HP} = \frac{Q_{H1/2}}{\varepsilon_{HP}}$$ **Eq. 3.279**

$$Q_{el.HP} = \frac{Q_{C1/2}}{\varepsilon_{KM}}$$ **Eq. 3.280**

The calculation of the reference follows the same procedure, the temperatures, temperature differences and Carnot efficiency can be set in the WS HP accordingly. The reference electricity demand for the heat pump results then as following.

$$Q_{el.HP} = \frac{Q_{HD} + Q_{WD} + Q_{DH}}{\varepsilon_{HP}}$$ **Eq. 3.281**

If an air-cooled or water-cooled vapor compression chiller is chosen, the calculation follows another approach. The efficiency (SPF/EER) is taken from a pre-calculated table. The look up approach takes the capacity of C1/C2 or the REF into account. The company Cofely Kältetechnik realized the performance calculation during IEA SHC Task 48 with best practice technologies. There is only an interpolation between the given values performed, no extrapolation is done, the last value is taken instead.

$$EER_{ref} = EER_{up.i} + \left(\frac{EER_{lo.i} - EER_{up.i}}{(P_{lo.i} - P_{up.i})} * (P_{cold} - P_{up.i})\right)$$ **Eq. 3.282**

$$SPF_C = ESEER_{ref.to.SPF} * \left(ESEER_{up.i} + \left(\frac{ESEER_{lo.i} - ESEER_{up.i}}{(P_{lo.i} - P_{up.i})} * (P_{cold} - P_{up.i})\right)\right)$$ **Eq. 3.283**

3.5.3 Natural gas and pellets boiler

The efficiency calculation obtains for the primary heat source $Q_{\eta_{HB}} = Q_{H1}$, for the secondary heat source $Q_{\eta_{HB}} = Q_{H2}$ and for the reference system $Q_{\eta_{HB}} = Q_{HD} + Q_{WD} + Q_{loss_{ref}}$.

The first term in the denominator is the ratio of energy flow of the heat source to the factor 0.95 for natural gas and 0.9 for pellets, which refer to the nominal boiler efficiency. n_{hours} characterizes the hours of a month and 0.2 refer to the standby losses. The term $0.0024 * P_{H1/h2} + 0.2235$ is based on the standby losses referring to the nominal power of a pellets boiler [josephinum.at]. $f_{2_{gas}}$ is a correction factor, which takes the power of a natural gas boiler into account and is between 0.2 for a power lower than 20 kW and 0.5 for a power greater than 100 kW. For pellets boiler $f_{2_{pellets}}$ is assumed to be 1 [Thuer 2015].

... natural gas: $\eta_{HB} = \frac{Q_{\eta_{HB}}}{\frac{Q_{\eta_{HBV}}}{0.95}+n_{hours}*0.2*f_{2_{gas}}*\frac{P_{H1/H2}-\frac{Q_{\eta_{HB}}}{n_{hours}}}{P_{hot}}}$ Eq. 3.284

... pellets: $\eta_{HB} = \frac{Q_{\eta_{HB}}}{\frac{Q_{\eta_{HBV}}}{0.9}+n_{hours}*(0.0024*P_{H1/H2}+0.2235)*f_{2_{pellets}}*\frac{P_{H1/H2}-\frac{Q_{\eta_{HB}}}{n_{hours}}}{P_{hot}}}$ Eq. 3.285

In SUB_Qref the energy flows of the reference system are assigned or determined.

Thermal energy: $Q_{ref.sys} = Q_{HD} + Q_{WD} + Q_{DH} + Q_{loss_{ref}}$ Eq. 3.286

Energy carrier: $Q_{EC.ref} = \frac{Q_{ref.sys}}{\eta_{HB}}$ Eq. 3.287

Electrical energy $Q_{el.ref} = \frac{Q_{CD}+Q_{DC}}{SPF_{C.th}} + Q_{el.DE} + Q_{el.ref.SH} + Q_{el.ref.DHW}$ Eq. 3.288

3.6 Technical key figures

The main technical key figures are the Primary Energy Ratio (PER), the Primary Energy Saving (f_{sav}) and the Equivalent Seasonal Performance Factor (SPF_{equ}) which are described in detail in the following chapters.

3.6.1 Primary energy ratio (PER)

PER is calculated with non-renewable primary energy only.

- Reference system:

Reference non-renewable primary energy ratio …

… for the total system (sys):

$$PER_{NRE.ref.sys} = \frac{Q_{CD.System}+Q_{HD.System}+Q_{WD.System}+Q_{DC.System}+Q_{DH.System}+Q_{el.DE}}{\frac{Q_{HD.System}+Q_{WD.System}+Q_{DH.System}+Q_{loss.ref}}{\varepsilon_{EC.ref}*\eta_{HB.ref}}+\frac{Q_{CD.System}+Q_{DC.System}}{SPF_{C.ref}*\varepsilon_{el}}+\frac{Q_{el.ref}+Q_{el.DE}}{\varepsilon_{el}}} \quad \text{Eq. 3.289}$$

… for cooling (C): $$PER_{NRE.ref.C} = SPF_{C.ref} * \varepsilon_{el} \quad \text{Eq. 3.290}$$

… for cooling grid (CG): $$PER_{NRE.ref.CG} = SPF_{C.ref} * \varepsilon_{el} \quad \text{Eq. 3.291}$$

… for domestic hot water (DHW): $$PER_{NRE.ref.DHW} = \frac{Q_{WD.System}}{\frac{Q_{WD.System}+Q_{loss.ref}}{\varepsilon_{EC.ref}*\eta_{HB.ref}}+\frac{Q_{el.ref.DHW}}{\varepsilon_{el}}} \quad \text{Eq. 3.292}$$

… for space heating (SH): $$PER_{NRE.ref.SH} = \frac{Q_{HD.System}}{\frac{Q_{HD.System}}{\varepsilon_{EC.ref}*\eta_{HB.ref}}+\frac{Q_{el.ref.SH}}{\varepsilon_{el}}} \quad \text{Eq. 3.293}$$

… for heating grid (HG): $$PER_{NRE.ref.HG} = \varepsilon_{EC.ref} * \eta_{HB.ref} \quad \text{Eq. 3.294}$$

- Overall system including CHPs, calculated with the energy balance method (EB)

non-renewable primary energy ratio for the total system (sys) …

…if primary and secondary heat source are a CHP

$$PER_{NRE,sys\_EB} = \frac{Q_{CD.System}+Q_{DC.System}+Q_{HD.System}+Q_{WD.System}+Q_{DH.System}+Q_{el.DE}}{\frac{Q_{EC.H1}}{\varepsilon_{EC.CHP}}+\frac{Q_{EC.H2}}{\varepsilon_{EC.CHP}}+\frac{Q_{GD.el}}{\varepsilon_{el}}} \quad \text{Eq. 3.295}$$

…if just the primary heat source is a CHP

$$PER_{NRE,sys\_EB} = \frac{Q_{CD.System}+Q_{DC.System}+Q_{HD.System}+Q_{WD.System}+Q_{DH.System}+Q_{el.DE}}{\frac{Q_{EC.H1}}{\varepsilon_{EC.CHP}}+\frac{Q_{EC.H2}}{\varepsilon_{EC2}}+\frac{Q_{GD.el}}{\varepsilon_{el}}} \quad \text{Eq. 3.296}$$

…if just the secondary heat source is a CHP

$$PER_{NRE,sys\_EB} = \frac{Q_{CD.System}+Q_{DC.System}+Q_{HD.System}+Q_{WD.System}+Q_{DH.System}+Q_{el.DE}}{\frac{Q_{EC.H1}}{\varepsilon_{EC1}}+\frac{Q_{EC.H2}}{\varepsilon_{EC.CHP}}+\frac{Q_{GD.el}}{\varepsilon_{el}}} \quad \text{Eq. 3.297}$$

- Overall system

non-renewable primary energy ratio for the total system (sys) …

$$PER_{NRE,sys} = \frac{Q_{CD.System}+Q_{DC.System}+Q_{HD.System}+Q_{WD.System}+Q_{DH.System}+Q_{el.DE}}{\frac{Q_{EC.H1}}{\varepsilon_{EC1}}+\frac{Q_{EC.H2}}{\varepsilon_{EC2}}+Q_{el.sys}*\left(\frac{\%_{GD.el}}{\varepsilon_{el}}+\frac{\%_{PV.el}*TPV}{\varepsilon_{PV.el}}\right)} \quad \text{Eq. 3.298}$$

If the primary energy factor for the primary heat source is zero, then

$$PER_{NRE,sys} = \frac{Q_{CD.System}+Q_{DC.System}+Q_{HD.System}+Q_{WD.System}+Q_{DH.System}+Q_{el.DE}}{\frac{Q_{EC.H2}}{\varepsilon_{EC2}}+Q_{el.sys}*\left(\frac{\%_{GD.el}}{\varepsilon_{el}}+\frac{\%_{PV.el}*TPV}{\varepsilon_{PV.el}}\right)} \quad \text{Eq. 3.299}$$

If the primary energy factor for the secondary heat source is zero, then

$$PER_{NRE,sys} = \frac{Q_{CD.System}+Q_{DC.System}+Q_{HD.System}+Q_{WD.System}+Q_{DH.System}+Q_{el.DE}}{\frac{Q_{EC.H1}}{\varepsilon_{EC1}}+Q_{el.sys}*\left(\frac{\%_{GD.el}}{\varepsilon_{el}}+\frac{\%_{PV.el}*TPV}{\varepsilon_{PV.el}}\right)} \quad \text{Eq. 3.300}$$

If the primary energy factor for the primary and secondary heat source is zero, then

$$PER_{NRE,sys} = \frac{Q_{CD.System}+Q_{DC.System}+Q_{HD.System}+Q_{WD.System}+Q_{DH.System}+Q_{el.DE}}{Q_{el.sys}*\left(\frac{\%_{GD.el}}{\varepsilon_{el}}+\frac{\%_{PV.el}*TPV}{\varepsilon_{PV.el}}\right)} \quad \text{Eq. 3.301}$$

- Sub-system cooling

non-renewable primary energy ratio for the sub-system cooling (C) …

$$PER_{NRE,C} = \frac{Q_{CD.System}}{\frac{Q_{EC.H1}*\%_{H1.C}}{\varepsilon_{EC1}}+\frac{Q_{EC.H2}*\%_{H2.C}}{\varepsilon_{EC2}}+Q_{el.sys}*\left(\frac{\%_{GD.C}}{\varepsilon_{el}}+\frac{\%_{PV.C}*TPV}{\varepsilon_{PV.el}}\right)} \quad \text{Eq. 3.302}$$

If just one or none heat source is a CHP, the terms ε_{EC} in the denominator are adjusted accordingly.

non-renewable primary energy ratio for the sub-system solar cooling (Csol) …

$$PER_{NRE,Csol} = \frac{Q_{CD.sol}}{Q_{el.Csol}*\left(\frac{\%_{GD.C}}{\%_{EL.C}*\varepsilon_{el}}\right)} \quad \text{Eq. 3.303}$$

- Sub-system district cooling

non-renewable primary energy ratio for the sub-system district cooling (CG) …

$$PER_{NRE,CG} = \frac{Q_{DC.System}}{\frac{Q_{EC.H1}*\%_{H1.CG}}{\varepsilon_{EC1}}+\frac{Q_{EC.H2}*\%_{H2.CG}}{\varepsilon_{EC2}}+Q_{el.sys}*\left(\frac{\%_{GD.CG}}{\varepsilon_{el}}+\frac{\%_{PV.CG}*TPV}{\varepsilon_{PV.el}}\right)} \quad \text{Eq. 3.304}$$

non-renewable primary energy ratio for the sub-system solar district cooling (CGsol) …

$$PER_{NRE,CGsol} = \frac{Q_{DC.sol}}{Q_{el.CGsol}*\left(\frac{\%_{GD.CG}}{\%_{EL.CG}*\varepsilon_{el}}\right)} \quad \text{Eq. 3.305}$$

- Sub-system domestic hot water

non-renewable primary energy ratio for the sub-system domestic hot water (DHW) …

$$PER_{NRE.DHW} = \frac{Q_{WD.System}}{\frac{Q_{EC.H1}*\%_{H1.DWH}}{\varepsilon_{EC1}} + \frac{Q_{EC.H2}*\%_{H2.DWH}}{\varepsilon_{EC2}} + Q_{el.sys}*\left(\frac{\%_{GD.DHW}}{\varepsilon_{el}} + \frac{\%_{PV.DHW}*TPV}{\varepsilon_{PV.el}}\right)}$$ Eq. 3.306

non-renewable primary energy ratio for the sub-system solar domestic hot water (DHWsol) …

$$PER_{NRE.DHWsol} = \frac{Q_{WD.sol}}{Q_{el.DHWsol}*\left(\frac{\%_{GD.DHW}}{\%_{EL.DHW}*\varepsilon_{el}}\right)}$$ Eq. 3.307

- Sub-system space heating

non-renewable primary energy ratio for the sub-system space heating (SH) …

$$PER_{NRE.SH} = \frac{Q_{HD.System}}{\frac{Q_{EC.H1}*\%_{H1.SH}}{\varepsilon_{EC1}} + \frac{Q_{EC.H2}*\%_{H2.SH}}{\varepsilon_{EC2}} + Q_{el.sys}*\left(\frac{\%_{GD.SH}}{\varepsilon_{el}} + \frac{\%_{PV.SH}*TPV}{\varepsilon_{PV.el}}\right)}$$ Eq. 3.308

non-renewable primary energy ratio for the sub-system solar space heating (SHsol) …

$$PER_{NRE.SHsol} = \frac{Q_{HD.sol}}{Q_{el.SHsol}*\left(\frac{\%_{GD.SH}}{\%_{EL.SH}*\varepsilon_{el}}\right)}$$ Eq. 3.309

- Sub-system space heating

non-renewable primary energy ratio for the sub-system district heating (HG) …

$$PER_{NRE.HG} = \frac{Q_{DH.System}}{\frac{Q_{EC.H1}*\%_{H1.HG}}{\varepsilon_{EC1}} + \frac{Q_{EC.H2}*\%_{H2.HG}}{\varepsilon_{EC2}} + Q_{el.sys}*\left(\frac{\%_{GD.HG}}{\varepsilon_{el}} + \frac{\%_{PV.HG}*TPV}{\varepsilon_{PV.el}}\right)}$$ Eq. 3.310

non-renewable primary energy ratio for the sub-system solar district heating (HGsol) …

$$PER_{NRE.HGsol} = \frac{Q_{DH.sol}}{Q_{el.HGsol}*\left(\frac{\%_{GD.HG}}{\%_{EL.HG}*\varepsilon_{el}}\right)}$$ Eq. 3.311

3.6.2 Fractional savings (f_{sav})

… for the total system ($_{sys}$): $$f_{sav.NRE.PER.sys} = 1 - \frac{PER_{NRE.ref.sys}}{PER_{NRE.sys}}$$ Eq. 3.312

… for cooling (C): $$f_{sav.NRE.PER.C} = 1 - \frac{PER_{NRE.ref.C}}{PER_{NRE.C}}$$ Eq. 3.313

… for solar cooling (Csol): $$f_{sav.NRE.PER.Csol} = 1 - \frac{PER_{NRE.ref.C}}{PER_{NRE.Csol}}$$ Eq. 3.314

… for cooling grid (CG): $$f_{sav.NRE.PER.CG} = 1 - \frac{PER_{NRE.ref.CG}}{PER_{NRE.CG}}$$ Eq. 3.315

… for solar cooling grid (CGsol): $$f_{sav.NRE.PER.CGsol} = 1 - \frac{PER_{NRE.ref.CG}}{PER_{NRE.CGsol}}$$ Eq. 3.316

… for domestic hot water (DHW): $$f_{sav.NRE.PER.DHW} = 1 - \frac{PER_{NRE.ref.DHW}}{PER_{NRE.DHW}}$$ Eq. 3.317

… for solar domestic hot water (DHWsol): $$f_{sav.NRE.PER.DHWsol} = 1 - \frac{PER_{NRE.ref.DHW}}{PER_{NRE.DHWsol}}$$ Eq. 3.318

… for space heating (SH): $$f_{sav.NRE.PER.SH} = 1 - \frac{PER_{NRE.ref.SH}}{PER_{NRE.SH}}$$ Eq. 3.319

… for solar space heating (SHsol): $$f_{sav.NRE.PER.SHsol} = 1 - \frac{PER_{NRE.ref.SH}}{PER_{NRE.SHsol}}$$ Eq. 3.320

… for heating grid (HG): $$f_{sav.NRE.PER.HG} = 1 - \frac{PER_{NRE.ref.HG}}{PER_{NRE.HG}}$$ Eq. 3.321

… for solar heating grid (HGsol): $$f_{sav.NRE.PER.HGsol} = 1 - \frac{PER_{NRE.ref.HG}}{PER_{NRE.HGsol}}$$ Eq. 3.322

3.6.3 Seasonal Performance Factor Equivalent (SPF_{equ})

… for the total system ($_{sys}$): $$SPF_{equ.sys} = \frac{PER_{NRE,sys}}{\varepsilon_{el}}$$ Eq. 3.323

… for cooling (C): $$SPF_{equ.C} = \frac{PER_{NRE,C}}{\varepsilon_{el}}$$ Eq. 3.324

… for solar cooling (Csol): $$SPF_{equ.Csol} = \frac{PER_{NRE,Csol}}{\varepsilon_{el}}$$ Eq. 3.325

… for cooling grid (CG): $$SPF_{equ.CG} = \frac{PER_{NRE,CG}}{\varepsilon_{el}}$$ Eq. 3.326

… for solar cooling grid (CGsol): $$SPF_{equ.CGsol} = \frac{PER_{NRE,CGsol}}{\varepsilon_{el}}$$ Eq. 3.327

… for domestic hot water (DHW): $$SPF_{equ.DHW} = \frac{PER_{NRE,DHW}}{\varepsilon_{el}}$$ Eq. 3.328

… for solar domestic hot water (DHWsol): $$SPF_{equ.DHWsol} = \frac{PER_{NRE,DHWsol}}{\varepsilon_{el}}$$ Eq. 3.329

… for space heating (SH): $$SPF_{equ.SH} = \frac{PER_{NRE,SH}}{\varepsilon_{el}}$$ Eq. 3.330

… for solar space heating (SHsol): $$SPF_{equ.SHsol} = \frac{PER_{NRE,SHsol}}{\varepsilon_{el}}$$ Eq. 3.331

… for heating grid (HG): $$SPF_{equ.HG} = \frac{PER_{NRE,HG}}{\varepsilon_{el}}$$ Eq. 3.332

… for solar heating grid (HGsol): $$SPF_{equ.HGsol} = \frac{PER_{NRE,HGsol}}{\varepsilon_{el}}$$ Eq. 3.333

3.7 Summary

In this worksheet all important values to characterize the system and its comparison to the standard reference system are shown. Further, some more results are calculated as follows.

- Overall primary energy demand:

…Solar heating and cooling: $$PE_{NRE.SHC} = \frac{Q_{el.GD}}{\varepsilon_{el}} + \sum_1^2 \frac{Q_{EC.Hi}}{\varepsilon_{ECi}}$$ Eq. 3.334

…Reference system: $$PE_{NRE.REF} = \frac{Q_{el.ref}}{\varepsilon_{el}} + \frac{Q_{EC.ref}}{\varepsilon_{EC_{ref}}}$$ Eq. 3.335

- CO_2 Emissions:

…Solar heating and cooling: $$CO2_{SHC} = Q_{el.GD} * CO_{2_{el}} + \sum_1^2 Q_{EC.Hi} * CO_{2_{EC}}$$ Eq. 3.336

…Reference system: $$CO2_{REF} = Q_{el.ref} * CO_{2_{el}} + Q_{EC.ref} * CO_{2_{EC_{ref}}}$$ Eq. 3.337

4 Calculation of economic key figures

The economic calculation is performed in the two work sheets "eco_base" and "Cost_Calc". The approach follows the procedure of IEA SHC Task 48 and was complemented by the new component information (e.g. reversible HP, district heating & cooling, etc.) and some more detailed calculations.

4.1 Economic basic data

All parameters influencing the economic figures are defined and fixed in WS "eco_base". Some of these parameters are challenging and details could be discussed extensively. The aim of these calculations and definitions is to generate reasonable cut-off 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 inspecific values for x1, x2.

- Economics

The basic economic parameters mainly influence the discounting and annualizing of all cost categories.

Economics	Unit	Abbr.	T53 - Standard
Period under consideration	a	N	25
Credit period	a	NL	10
Inflation rate	%	i	2
Market discount rate	%	d	2
Credit interest rate	%	m	3
Inflation rate for energy prices electricity	%	iee	3
Inflation rate for energy prices	%	ieg	3
Fraction of initial investment without financing	%	fL	0
Public funding's rate	%	p	0

- Consumption based prices for electricity, energy carrier and water:

Electricity	Unit	Abbr.	T53- Standard
Electricity consumption	€/kWh	$C_{el.c}$	0.10
Electricity peak power	€/(kW.a)	C_{Pel}	80.0
Feed-in tariff for CHP (only 15 years)	€/kWh	C_{CHP}	0.03
Tariff duration for CHP	a	C_{CHP_a}	15.0
Feed-in tariff for PV (only 13 years)	€/kWh	C_{PV}	0.03

Tariff duration for PV	a	C_{PV_a}	13.0
Feed-in without subsidies	€/kWh	$C_{feed\text{-}in\ w/o\ sub}$	0.03
Energy carrier			
Natural gas consumption	€/kWh	$C_{gas.c}$	0.05
Natural gas annual fix	€/a	$C_{gas.a}$	70.0
Biogas consumption	€/kWh	$C_{biogas.c}$	0.07
Biogas annual fix	€/a	$C_{biogas.a}$	170.93
Pellets consumption	€/kWh	$C_{pellets.c}$	0.05
Pellets annual	€/a	$C_{pellets.a}$	40.0
Oil consumption	€/kWh	$C_{oil.c}$	0.06
Oil annual	€/a	$C_{oil.a}$	167.0
District heating consumption	€/kWh	$C_{DH.c}$	0.07
District heating annual	€/a	$C_{DH.a}$	0.00
District cooling consumption	€/kWh	$C_{DC.c}$	0.10
District cooling annual	€/a	$C_{DC.a}$	0.00
Feed-in tariff for district heating	€/kWh	C_{fiT_DH}	0.04
Feed-in tariff for district cooling	€/kWh	C_{fiT_DC}	0.06
Water consumption			
Water consumption	€/m³	$C_{WA.c}$	2.50

Some of the tariffs are calculated depending on capacity:

Electricity feed-in tariff for CHPs for a given capacity

< 250 kW: $$C_{CHP/kW} = 0.03225 + 0.18275 * (\%_{biogas.H1} + \%_{biogas.H2})$$ **Eq. 4.1**

< 500 kW: $$C_{CHP/kW} = 0.03225 + 0.15705 * (\%_{biogas.H1} + \%_{biogas.H2})$$ **Eq. 4.2**

< 750 kW: $$C_{CHP/kW} = 0.03225 + 0.18275 * (\%_{biogas.H1} + \%_{biogas.H2})$$ **Eq. 4.3**

> 750 kW: $$C_{CHP/kW} = 0.03225 + 0.11705 * (\%_{biogas.H1} + \%_{biogas.H2})$$ **Eq. 4.4**

Energy carrier

District heating annual: $$C_{DH.a} = (11.03 + 1.782 * (P_{H1} + P_{H2})) * 12 * 1.2$$ **Eq. 4.5**

District cooling annual: $$C_{DC.a} = (11.03 + 1.782 * (P_{C1} + P_{C2})) * 12 * 1.2$$ **Eq. 4.6**

- Investment-material & installation:

Eq. 4.7 and Eq. 4.8 are used to calculate the economy of scale for the different components. Exemplarily, Eq. 4.7 shows the determination of the economy of scale for a flat plate collector and Eq. 4.8 is used for the determination referring to heat rejection.

$$C_{xx} = \mathrm{d} + c * \mathrm{CAP}^{e_{FPC}} \quad \text{Eq. 4.7}$$

$$C_{xx} = c * \mathrm{CAP} + e_{HR} \quad \text{Eq. 4.8}$$

Each category considers the primary and secondary device. The abbreviations are listed in the following table.

Abbr.	Description	Unit
d	Minimal price per component	€/unit
c	Cost for first unit and capacity	€/unit.capacity, e.g. €/m²
e	Decreasing coefficient	-
CAP	Capacity	e.g. m², kW, etc.
	lifetime	a
$\%_{main.comp}$	Maintenance per component	-

Collectors	CAP	EQU	Abbr.	d	c	e	lifetime	$\%_{main.comp}$
Flat plate collector (FPC)	A_{SC}	Eq. 4.7	C_{sol/m^2}	210	400	-0.50	20	0.02
Evacuated tube (ETC)	A_{SC}			230	740	-0.32	18	0.02
Solar auxiliaries FPC	A_{SC}	Eq. 4.7	C_{sol_aux/m^2}	-	815	-0.36	20	0.03
Solar auxiliaries ETC	A_{SC}			-	5500	-0.70	20	0.03
PV collector	A_{PV}	Eq. 4.7	$C_{sol/kWp}$	-	1830	-0.07	20	0.02
Auxiliary heating systems								
Natural gas boiler	P_H	Eq. 4.7	$C_{aux.H/kW}$	-	600	-0.29	15	0.04
Condensing boiler				-	357.93	-0.39	20	0.03
Oil Boiler				-	4287.5	-0.98	12	0.12
Electric heater				-	154.8	-0.67	20	0.03
Pellets				-	2231.0	-0.49	15	0.03
Heat pump				-	380.11	-0.18	18	0.03
Reversible HP				-	2173.3	-0.44	18	0.03
Absorption heat pump				-	3700.0	-0.45	18	0.03
Reversible heat pump				-	3700.0	-0.45	18	0.03
CHP				-	15648.0	-0.54	15	0.08
District heating				-	297.79	-0.16	30	0.03
Solar cold production								
Absorption chiller SE	P_C	Eq. 4.7	$C_{aux.C/kW}$	-	3700	-0.45	18	0.03
Absorption chiller DE				-	4300	-0.46	18	0.03

Adsorption Chiller				-	3700	-0.45	18	0.03
District Cooling				-	297.79	-0.16	30	0.03
Heat rejection								
Cooling tower – wet	P_{CT}	Eq. 4.8	C_{CT}	-	21.19	1649.4	15	0.04
Cooling tower – dry				-	46.76	2628.6	20	0.02
Cooling tower – hybrid				-	593.53	593.53	15	0.03
Hot/Cold tank								
Hot tank	$V_{HS/CS}$	Eq. 4.7	C_{store/m^3}	-	2500.0	-0.28	20	0.02
Cold tank				-	2135.0	-0.30	20	0.02
Battery	BS	Eq. 4.7	$C_{store/kW}$	-	393.26	-0.29	10	0.02
Vapor compression chillers								
Water cooled VCC < 250 kW	P_C	Eq. 4.7	$C_{aux.C/kW}$	-	3096.0	-0.51	15	0.04
Water cooled VCC > 250 kW				-	6543.5	-0.534	15	0.04
Air cooled VCC < 250 kW				-	1258	-0.30	15	0.04
Air cooled VCC > 250 kW				-	1530.9	-0.258	15	0.04

- Other costs:

		Abbr.	SHC	REF
Auxiliaries heating	% of boiler		0.50	0.50
Auxiliaries cooling	% of chiller		0.50	0.50
Control, electricity and monitoring	% of Material	$\%_{cem}$	0.10	0.07
	Sum equals the total material costs			
Design, planning and commissioning	% of total Material	$\%_{dpc}$	0.20	0.15
General costs associated to works	% of total Material	$\%_{work}$	0.30	0.30
Indirect costs and industrial benefits	% of total Material	$\%_{ben}$	0.05	0.05

4.2 Annualized costs

The calculation of the “Levelized Cost of Energy” is performed in Worksheet “Cost_calc”. The reference calculation refers to reference values, whereas the SHC calculation is based on inputs for the SHC system.

The TASK 53 reference system includes a natural gas driven heating system, an air cooled VCC and a cold tank. This system configuration was fixed by the TASK 53 members and is always calculated, independently of the actual chosen reference system configuration.

4.2.1 Investment-material & installation:

Initially the absolute investment cost is calculated for each main component. The sum takes the results of all component costs into account (Eq. 4.9 - Eq. 4.16; Eq. 4.18 - Eq. 4.21).

Solar collectors $C_{SC} = C_{Sol/m^2} * A_{SC}$ Eq. 4.9

Solar collectors auxiliaries $C_{SC} = C_{Sol\_aux/m^2} * A_{SC}$ Eq. 4.10

PV collectors $C_{PV} = C_{Sol/kW_p} * A_{PV}$ Eq. 4.11

Heating system $C_{AUX.H} = \sum_1^2 C_{aux.h/kW} * P_H$ Eq. 4.12

Cold production $C_{AUX.C} = \sum_1^2 C_{aux.c/kW} * P_C$ Eq. 4.13

Heat rejection $C_{HR} = \sum_1^2 C_{CT}$ Eq. 4.14

Hot/Cold water storage $C_{HS/CS} = \sum_1^2 C_{store/m^3} * V_{HS/CS}$ Eq. 4.15

Battery storage $C_{BS} = \sum_1^2 C_{store/kW} * BS$ Eq. 4.16

Sum of investment-material & installation $C_{mat} = \sum C_{comp}$ Eq. 4.17

If a reversible heat pump or reversible absorption heat pump is chosen, the costs for auxiliary heating/cooling are manipulated under consideration of the different possible configurations.

If in primary boiler type and primary chiller type 'rev. HP' or 'rev. AHP' is chosen, then

$$C_{AUX.H} = C_{\substack{Aux/kW \\ primary\ HB}} * P_{H1} + C_{\substack{Aux/kW \\ primary\ C}} * P_{C1}$$ Eq. 4.18

If in secondary boiler type and primary chiller type 'rev. HP' or 'rev. AHP' is chosen, then

$$C_{AUX.H} = C_{\substack{Aux/kW \\ secondary\ HB}} * P_{H2} + C_{\substack{Aux/kW \\ primary\ C}} * P_{C1}$$ Eq. 4.19

If primary or secondary chiller type is 'rev. HP' or 'rev. AHP' then

$$C_{AUX.H} = C_{\substack{Aux/kW \\ primary\ C}} * P_{C1}$$ Eq. 4.20

$$C_{AUX.H} = C_{\substack{Aux/kW \\ secondary\ C}} * P_{C2}$$ Eq. 4.21

When the sum of investment is evaluated the additional other costs are calculated (Eq. 4.22 - Eq. 4.28):

Control, electricity and monitoring: $C_{cem} = \%_{cem} * C_{mat}$ Eq. 4.22

Total investment material: $C_{mat.tot} = C_{cem} + C_{mat}$ Eq.
4.23Investment – Design/planning: $C_{dpc} = \%_{dpc} * C_{mat.tot}$ Eq.
4.24General costs associated to works: $C_{work} = \%_{work} * C_{mat.tot}$ Eq.
4.25Indirect costs and industrial benefits: $C_{ben} = \%_{ben} * C_{mat.tot}$ Eq. 4.26

TOTAL Investment costs: $C_{inv} = \sum C_{mat.tot} + C_{work} + C_{ben}$ Eq. 4.27

Investment costs less public funding's: $C_{inv.fun} = C_{inv} * (1 - p)$ Eq. 4.28

Spec. costs (Eq. 4.29 - Eq. 4.30) are displayed for the sum of capacities for heating and cooling for…

… total material cost: $$c_{mat.tot} = \frac{C_{mat.tot}}{P_{H1}+P_{H2}+P_{C1}+P_{C2}}$$ Eq. 4.29

… total cost of the system $$c_{inv} = \frac{C_{inv}}{P_{H1}+P_{H2}+P_{C1}+P_{C2}}$$ Eq. 4.30

4.2.2 Replacement costs

The calculation of replacement cost is done for each main component that was calculated in chapter 4.2.1. In this format the cost for replacement (Eq. 4.31) and its residual value (Eq. 4.32) are calculated separately and summed up in the end (Eq. 4.33).

Replacement cost: $$C_{rep} = \frac{C_{mat}}{N} * \frac{\left(\frac{(1+i)^n}{(1+d)^n}\right)^{k_1} - 1}{\left(\frac{(1+i)^n}{(1+d)^n}\right) - 1} * \frac{1}{1+d}$$ Eq. 4.31

Residual value: $$C_{res} = \frac{C_{mat}}{N} * \frac{\left(\frac{(1+i)^n}{(1+d)^n}\right)^{k_2} - 1}{\left(\frac{(1+i)^n}{(1+d)^n}\right) - 1} * \frac{1}{1+d}$$ Eq. 4.32

Sum of costs $C_{re} = C_{rep} - C_{res}$ Eq. 4.33

4.2.3 Maintenance costs

For each component (Eq. 4.34), a percentage for maintenance costs per year is fixed in relation to its investment costs. Eq. 4.35 is the sum of all costs per component.

Cost per component $C_{main.comp} = \%_{main.comp} * C_{comp}$ Eq. 4.34

Sum of costs $C_{main} = \sum C_{main.comp}$ Eq. 4.35

4.2.4 Total costs

Here annualized costs but also operational (consumption based) costs are calculated.

- Electricity cost for HVAC
- The sum of electricity from grid equals

$$\%GD.HVAC = \%GD.H1 + \%GD.H2 + \%GD.HS + \%GD.HD + \%GD.WD + \%GD.DH + \%GD.C1 + \%GD.C2 \quad \text{Eq. 4.36}$$

and the electricity cost sum up considering costs of energy and also average peak power costs if applicable (PC = 1).

$$C_{el.op} = \mathrm{PC} * \left(\mathrm{P}_{el\,op} * C_{Pel}\right) + \frac{(Q_{el.GD} * \%_{GD.HVAC})}{\%_{GD.HVAC} + \%_{GD.DE}} * C_{el.C} \quad \text{Eq. 4.37}$$

- Feed-in tariffs electrical power:

To lower the sum of the annualized costs the feed-in revenues are characterized with negative prefix.

Electricity to grid $$Q_{el.fi} = Q_{el.GD} + Q_{el.CHP} + Q_{el.PV} - Q_{el.sys} \quad \text{Eq. 4.38}$$

CHP part $$\%_{el.CHP/PV} = \frac{Q_{el.CHP}}{Q_{el.CHP} + Q_{el.PV}} \quad \text{Eq. 4.39}$$

PV part $$\%_{el.PV/CHP} = \frac{Q_{el.PV}}{Q_{el.CHP} + Q_{el.PV}} \quad \text{Eq. 4.40}$$

If there is surplus electricity, which is fed into the grid ($Q_{el.fi} > 0$) and the feed-in tariffs last longer than the period under consideration ($C_{CHP\_a} > N$ or $C_{PV\_a} > N$) the feed-in revenue charge to

$$C_{fi.el} = -1 * Q_{el.fi} * \left(\left(C_{CHP} * \%_{el.CHP/PV} * \frac{N}{N}\right) + \left(C_{PV} * \%_{el.PV/CHP} * \frac{N}{N}\right)\right) \quad \text{Eq. 4.41}$$

Else (subsidies for a period lesser than the whole period under review)

$$C_{fi.el} = -1 * Q_{el.fi} * \left(\left(C_{CHP} * \%_{el.CHP/PV} * \frac{C_{CHP\_a}}{N}\right) + \left(C_{PV} * \%_{el.PV/CHP} * \frac{C_{PV\_a}}{N}\right)\right) \quad \text{Eq. 4.42}$$

- Feed-in NO subsidies:

If there is a period left with surplus electricity but subsidies run out ($C_{CHP\_a} < N$ or $C_{PV\_a} < N$), there are three cases to be distinguished:

if $\left(C_{CHP\_a}\right) < N$ and $(Q_{el.PV}) = 0$ then

$$C_{fi.w/o} = Q_{el.fi} * \left(C_{CHP} * \%_{el.CHP/PV} * \left(1 - \frac{C_{CHP\_a}}{N}\right)\right) \quad \text{Eq. 4.43}$$

if $\left(C_{PV\_a}\right) < N$ and $(Q_{el.CHP}) = 0$ then

$$C_{fi.w/o} = Q_{el.fi} * \left(C_{PV} * \%_{el.PV/CHP} * \left(1 - \frac{C_{PV\_a}}{N}\right)\right) \quad \textbf{Eq. 4.44}$$

If $(C_{CHP\_a}) < N$ and $(C_{PV\_a}) < N$ then

$$C_{fi.w/o} = Q_{el.fi} * \left(C_{CHP} * \%_{el.CHP/PV} * \left(1 - \frac{C_{CHP\_a}}{N}\right) + C_{PV} * \%_{el.PV/CHP} * \left(1 - \frac{C_{PV\_a}}{N}\right)\right) \quad \textbf{Eq. 4.45}$$

- Feed-in district heating/cooling:

Feed-in revenues can also be obtained due to surplus heat feed into the district heating or cooling network respectively (Eq. 4.46)

$$C_{fi.DH/DC} = -1 * (C_{fiT\_DH} * Q_{DH.sys} + C_{fiT\_DC} * Q_{DC.sys}) \quad \textbf{Eq. 4.46}$$

- EC costs SHC System….

Costs of energy carrier can only be calculated if H_1 or H_2 has an energy flow from EC. No other component can obtain energy carrier directly. Thus, if a direct-fired absorption chiller is used, the energy carrier is only taken into account if H_1 or H_2 is providing its energy to C_1/C_2. The different cases include energy but also annual costs for the entire primary energy source (Eq. 4.47 - Eq. 4.54).

If no heat source, heat pump or reversible heat pump (considered under electricity costs) is chosen

$$C_{EC} = 0 \quad \textbf{Eq. 4.47}$$

CHP: $$C_{EC} = C_{biogas.a} + Q_{EC.H1} * \left(C_{biogas.c} * \%_{biogas} + C_{gas.c} * (1 - \%_{biogas})\right) \quad \textbf{Eq. 4.48}$$

Absorption heat pump, reversible AHP, condensing boiler, natural gas boiler:

$$C_{EC} = C_{gas.a} + Q_{EC.H1} * C_{gas.c} \quad \textbf{Eq. 4.49}$$

Oil boiler: $$C_{EC} = C_{oil.a} + Q_{EC.H1} * C_{oil.c} \quad \textbf{Eq. 4.50}$$

Pellets boiler: $$C_{EC} = C_{pellets.a} + Q_{EC.H1} * C_{pellets.c} \quad \textbf{Eq. 4.51}$$

Electric heater: $$C_{EC} = Q_{EC.H1} * C_{el.c} \quad \textbf{Eq. 4.52}$$

District heating: $$C_{EC} = C_{DH.a} + Q_{EC.H1} * C_{DH.c} \quad \textbf{Eq. 4.53}$$

District cooling $$C_{EC} = C_{DC.a} + Q_{CD.system} * C_{DC.c} \quad \textbf{Eq. 4.54}$$

- Operation-Water:

The water costs (Eq. 4.55) sum up for wet and hybrid cooling towers. If another water demand is given (e.g. humidification, etc.), V_{HR} needs to be adapted. Water costs should include fresh water as well as dumping costs.

Water cost of cooling tower: $C_{water.CT} = C_{WA.c} * V_{HR}$ **Eq. 4.55**

- Domestic-electricity:

The domestic electricity takes only the electricity demand from a certain profile into account. The electricity to run the HVAC system is treated separately. Furthermore, only energy costs are calculated, assuming that the reference system has the same peak load as the entire SHC system (Eq. 4.56). If this is false (e.g. peak load reduction through CHP, etc.), the electricity peak for the SHC and Ref need to be adapted accordingly (WS inputs).

Electricity cost of domestic electricity: $C_{el.DE} = Q_{el.GD} * \%_{GD.DE} * C_{el.C}$ **Eq. 4.56**

- Annualizing of each cost categories

The absolute sum of each cost category is annualized according to the boundaries set in economics (Eq. 4.57 - Eq. 4.64). Main distinguish is made whether the inflation rates (i, iee, iec) equals the market discount rate or not.

…investment cost $$C_{an.invest} = \frac{C_{inv.fund} * f_L + \left(C_{inv.fund} * (1 - f_L)\right) * NL}{\frac{1}{m} * \left(1 - \left(\frac{1}{1+m}\right)\right)^{NL}} * N^{-1}$$ **Eq. 4.57**

…electricity costs for HVAC & domestic electricity, Feed-in, Feed-in NO subsidies

If d = iee $$C_{an.el} = \frac{C_{el.DE}}{1+iee}$$ **Eq. 4.58**

Else… $$C_{an.el} = \frac{C_{el.DE}}{N} * \left(\frac{1 - \left(\frac{1+iee}{1+d}\right)^N}{d - iee}\right)$$ **Eq. 4.59**

…Feed-in district heating/cooling, Energy carrier costs,

If d = ieg $$C_{an.EC.SHC} = \frac{C_{EC.SHC1/2}}{1+ieg}$$ **Eq. 4.60**

Else… $$C_{an.EC.SHC} = \frac{C_{EC.SHC1/2}}{N} * \left(\frac{1 - \left(\frac{1+ieg}{1+d}\right)^N}{d - ieg}\right)$$ **Eq. 4.61**

…water costs, maintenance

if d = i $$C_{an.op} = \frac{C_{op}}{1+i}$$ **Eq. 4.62**

Else… $$C_{an.op} = \frac{C_{op}}{N} * \left(\frac{1 - \left(\frac{1+i}{1+d}\right)^N}{d - i}\right)$$ **Eq. 4.63**

The total annualized cost for the entire system sum up to

$$C_{an.tot} = \sum_1^9 C_{an.i}$$ **Eq. 4.64**

4.3 Economic key figures

The key figures (Eq. 4.65 - Eq. 4.68) are calculated for the "T53 Standard" but also the "specific values".

- Cost ratio:

$$CR = \frac{C_{an.tot.SHC}}{C_{an.tot.Ref}} \quad \text{Eq. 4.65}$$

- Levelized cost of energy

$$\text{LCOE} = \frac{C_{an.tot}}{Q_{CD.sys}+Q_{DC.sys}+Q_{HD.sys}+Q_{WD.sys}+Q_{DH.sys}+Q_{el.DE}} \quad \text{Eq. 4.66}$$

- Avoidance costs for Primary energy: $\mathrm{C}_{AC.PE} = \frac{C_{an.tot.SHC}-C_{an.tot.REF}}{PE_{NRE.SHC}-PE_{NRE.SHC}}$ Eq. 4.67

- Avoidance costs for CO2 emissions: $\mathrm{C}_{AC.CO2} = \frac{C_{an.tot.SHC}-C_{an.tot.REF}}{CO2_{SHC}-CO2_{REF}}$ Eq. 4.68

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6 Nomenclature

Abbreviation	Description
ACM	Ab-/Adsorption Chiller
AHP	Absorption heat pump
BS	Battery storage
BS.El	Battery storage to Switch board electricity
C	Cooling
$C_{AV.PE}$	Avoidance costs for primary energy
$C_{AC.CO2}$	Avoidance costs for CO_2 emissions
CAP	Capacity (W)
C.System	Total cold source to System
C_{an}	Overall annualized costs (€/a)
C_{use}	Levelized costs (€/$kWh_{useful\ energy}$)
CB	Cold backup
CD	Cold distribution
CD.CS	Cold distribution to Cold storage
CD.C1/2	Cold distribution to Primary (1) / Secondary (2) cold source
CD.HX	Cold distribution to Heat exchanger (free-cooling)
CD.H1/2	Cold distribution to Primary (1) / Secondary (2) heat source (AHP)
CD.System	Total cold distribution to system
CG	Cooling grid
CHP unit	Combined Heat and Power unit
CHP	Combined Heat and Power
CHP1/2.BS	Primary (1) / Secondary (2) CHP to Battery storage
CHP1/2.C1	Primary (1) / Secondary (2) CHP to Primary cold source
CHP1/2.C2	Primary (1) / Secondary (2) CHP to Secondary cold source
CHP1/2.DE	Primary (1) / Secondary (2) CHP to Domestic electricity
CHP1/2.H1	Primary (1) / Secondary (2) CHP to Primary heat source
CHP1/2.H2	Primary (1) / Secondary (2) CHP to Secondary heat source
CHP1/2.HS	Primary (1) / Secondary (2) CHP to Hot storage
CHP1/2.Pumps	Primary (1) / Secondary (2) CHP to Pumps (El.Aux and El.Distr)
CHP1/2.Sys	Total Primary (1) / Secondary (2) (only CHP) to System
CHPC	Combined Heat, Power and Cold (Trigeneration)
COP	Coefficient of Performance (-)
CO_2	Carbon dioxide
CO_{2EC}	Thermal CO_2-factor of CHP
CO_{2CHP}	Electrical CO_2-factor of CHP
$CO2_{H1.CHP}$	CO_2 emissions for CHP (kg_{CO2})
$CO2_{H1.CHP.th}$	CO_2 emissions for heating (kg_{CO2})
$CO2_{H1.CHP.el}$	CO_2 emissions for electricity kg_{CO2})

CS	Cold storage
CS.C1/2	Cold storage to Primary (1) / Secondary (2) cold source
CS.H1/2	Cold storage to Primary (1) / Secondary (2) heat source
CS.HX	Cold storage to heat exchanger
CS.System	Total cold source to System
CT	Cooling Tower
C1/2.HX	Primary (1) / Secondary (2) cold source to Heat exchanger
DC.CS	District cooling to Cold storage
DC.System	Total district cooling to System
DC.C1/2	District cooling to Primary (1) / Secondary (2) cold source
DCT	Dry cooling tower
DE	Double Effect chiller
DH	District heating
DHW	Domestic Hot Water
EC	Energy carrier
EC.H1/2	Energy carrier to hot backup ½
EC.System	Total purchased energy to system
EC_{an}	Annualized energy carrier costs (€/a)
El.Aux.System	Total switch board to Auxiliaries
el	electrical
El.CD	Switch Board Electricity to Cold Distribution Pump
El.Com.System	Total switch board to System
El.C1/2	Switch board electricity to Primary (1) / Secondary (2) cold source
El.CX	Switch Board Electricity to Heat Exchange for Cooling (incl. MT)
El.DC	Switch Board Electricity to District Cooling
El.DE	Switch Board Electricity to Domestic Electricity
El.DE.System	Total Switch Board to Domestic Electricity
El.DH	Switch Board Electricity to District Heating
El.Distr.System	Total Switch Board to Distribution Pumps
El.GD	Switch board electricity to Grid
El.GD.System	Total switch board to Grid
El.H1/2	Switch board electricity to Primary (1) / Secondary (2) heat source
El.HC1/2	Switch board electricity to Primary (1) / Secondary (2) cold source hot temperature pump
El.HD	Switch Board Electricity to Heat Distribution Pump
El.HS	Switch board electricity to Hot storage
El.HH1/2	Switch board electricity to Primary (1) / Secondary (2) heat source hot temperature pump
El.HX	Switch Board Electricity to Heat Exchange for Heating
El.In.System	Total electricity to Switch board
El.LC1/2	Switch board electricity to Primary (1) / Secondary (2) cold source low temperature pump

El.LH1/2	Switch board electricity to Primary (1) / Secondary (2) heat source low temperature pump
El.MC1/2	Switch board electricity to Primary (1) / Secondary (2) cold source medium temperature pump
El.MH1/2	Switch board electricity to Primary (1) / Secondary (2) heat source medium temperature pump
El.SP	Switch board electricity to Solar pump
El.sys	Total electricity consumers within the system
El.WD	Switch Board Electricity to DHW Distribution Pump
EL_{an}	Annualized electricity cost (€/a)
EER	Energy Efficiency Ratio (-)
equ	equivalent
f_l	Equity ratio (-)
f_{sav}	Fractional savings (-)
$f_{SAV.NRE.PER.C}$	Fractional savings for cooling (-)
$f_{SAV.NRE.PER.Csol}$	Fractional savings for solar cooling (-)
$f_{SAV.NRE.PER.CG}$	Fractional savings for cooling grid (-)
$f_{SAV.NRE.PER.CGsol}$	Fractional savings for solar cooling grid (-)
$f_{SAV.NRE.PER.DHW}$	Fractional savings for DHW (-)
$f_{SAV.NRE.PER.DHWsol}$	Fractional savings for solar DHW (-)
$f_{SAV.NRE.PER.HG}$	Fractional savings for district heating (-)
$f_{SAV.NRE.PER.HGsol}$	Fractional savings for solar district heating (-)
$f_{SAV.NRE.PER.SH}$	Fractional savings for space heating (-)
$f_{SAV.NRE.PER.SHsol}$	Fractional savings for solar space heating (-)
$f_{sav.NRE.PER.sys}$	Fractional savings of the system (-)
f_1	Adjustment factor depending on hot backup power and losses (-)
f_2	Adjustment factor depending on hot backup mass (-)
GD.El	Grid to Switch board electricity
HB	Hot backup
HC	Cold distribution
HCT	Hybrid cooling tower
HD	Heat distribution
HG	Heating grid
HiL	Hardware-in-the-loop
HP	Heat Pump
HP_{LT}	Low temperature (K)
HP_{MT}	Medium temperature (K)
HP_{HT}	High temperature (K)
HT	High Temperature loop
HS	Hot Storage
HS.C1/2	Hot storage to Primary (1) / Secondary (2) cold source (ACM)

HS.DH	Hot storage to District heating
HS.HD	Hot storage to Heat distribution
HS.H1/2	Hot storage to Primary (1) / Secondary (2) heat source
HS.System	Total hot storage to System
HS.WD	Hot storage to DHW distribution
HX.HS	Heat exchanger to Hot storage
HX.H1/2	Heat exchanger to Primary (1) / Secondary (2) heat source
H1/2.C1	Primary (1) / Secondary (2) heat source to Primary cold source (ACM)
H1/2.C2	Primary (1) / Secondary (2) heat source to Secondary cold source (ACM)
H1/2.DH	Primary (1) / Secondary (2) heat source to District heating
H1/2.HD	Primary (1) / Secondary (2) heat source to Heat distribution
H1/2.HS	Primary (1) / Secondary (2) heat source to Hot storage
H1/2.System	Primary (1) / Secondary (2) heat source to System
H1/2.WD	Primary (1) / Secondary (2) heat source to DHW distribution
H_2O	Water
I_{init}	Initial investment, considering the equity ratio (€)
I_{tot}	Total investment for the SHC or reference system (€)
IC_{an}	annualized cost of the investment (€/a)
IR_{an}	annualized replacement cost (€/a)
$IR_{an}(k)$	annualized replacement cost depending on the exponent k (€/a)
k_{rc}	Exponent for replacement costs (-)
k_{rv}	Exponent for residual value (-)
LT	Low Temperature loop
MC_{an}	Annualized maintenance cost (€/a)
MT	Medium Temperature loop
m	Interest rate (-)
N	period under consideration (a)
NH_3	Ammonia
NL	Credit period (a)
NRE	Non-Renewable
P	Power (W)
pr	primary
P_{HB}	Power hot backup (W)
$P_{el.C}$	Electrical power for cooling (W)
$P_{standby,loss}$	Standby-losses of hot backup (W)
PER	Primary Energy Ratio (-)
$PER_{NRE.C}$	Primary energy ratio for cooling (-)
$PER_{NRE.Csol}$	Primary energy ratio for solar cooling (-)

$PER_{NRE.ref.C}$	Primary energy ratio for cooling (-)
$PER_{NRE.ref.CG}$	Primary energy ratio for cooling grid (-)
$PER_{NRE.ref.DHW}$	Primary energy ratio for DHW (-)
$PER_{NRE.ref.HG}$	Primary energy ratio for heating grid (-)
$PER_{NRE.ref.SH}$	Primary energy ratio for space heating (-)
$PER_{NRE.ref. sys}$	Primary energy ratio for the reference system (-)
$PER_{NRE.C}$	Non-renewable primary energy ratio for cooling (-)
$PER_{NRE.Csol}$	Non-renewable primary energy ratio for solar cooling (-)
$PER_{NRE.CG}$	Non-renewable primary energy ratio for district cooling (-)
$PER_{NRE.CGsol}$	Non-renewable primary energy ratio for solar district cooling (-)
$PER_{NRE.DHW}$	Non-renewable primary energy ratio for DHW (-)
$PER_{NRE.DHWsol}$	Non-renewable primary energy ratio for solar DHW (-)
$PER_{NRE.HG}$	Non-renewable primary energy ratio for district heating (-)
$PER_{NRE.HGsol}$	Non-renewable primary energy ratio for solar district heating (-)
$PER_{NRE.SH}$	Non-renewable primary energy ratio for space heating (-)
$PER_{NRE.SHsol}$	Non-renewable primary energy ratio for solar space heating (-)
$PER_{NRE.sys}$	Primary energy ratio for the system (-)
$PER_{NRE.sys\_EB}$	Primary energy ratio for the system determined with energy balance (-)
PR_{sys}	Sum of total electricity delivered by the system
PV.BS	Photovoltaic to Battery storage
PV.C1/2	Photovoltaic to Primary (1) / Secondary (2) cold source
PV.DE	Photovoltaic to Domestic electricity
PV.HS	Photovoltaic to Hot storage
PV.H1/2	Photovoltaic to Primary (1) / Secondary (2) heat source
PV.Pumps	Photovoltaic to Pumps (El.Aux and El.Distr)
PV.sys	Total photovoltaic to System
Q	Energy flow (kWh)
$\dot{Q}$	Thermal Power (W)
$Q_{C1.System}$	Total Primary Cold Source to System (kWh)
$Q_{C2.System}$	Total Secondary Cold Source to System (kWh)
$Q_{C1/2.HX}$	Primary / secondary cold source to heat exchanger (kWh)
$Q_{C1.In}$	Total input energy flow to primary cold source (kWh)
$Q_{C2.In}$	Total input energy flow to secondary cold source (kWh)
$Q_{C1.In.Sol}$	Solar energy for cooling with primary cold source (kWh)
$Q_{C2.In.Sol}$	Solar energy for cooling with secondary cold source (kWh)
$Q_{CD.System}$	Total Cold Distribution to System (kWh)
$Q_{CD.sol}$	Total Cold Distribution from Solar Collector (kWh)
$Q_{CHP1.sys}$	Total produced Power of the CHP1 unit (kWh)
$Q_{CS.IN}$	Total Cold Storage from System (input) (kWh)
$Q_{CS.OUT}$	Total Cold Storage from System (output) (kWh)
Q_{closs}	Cold Losses (kWh)
$Q_{DC.Sol}$	Total District Cooling from Solar Collector (kWh)
$Q_{DC.System}$	Total District Cooling from System (kWh)

$Q_{DH.Sol}$	Total District Heating from Solar Collector (kWh)
$Q_{DH.System}$	Total District Heating from System (kWh)
$Q_{EC.H1}$	Energy Carrier to primary Hot Backups (kWh)
$Q_{EC.H2}$	Energy Carrier to secondary Hot Backups (kWh)
$Q_{EC.ref}$	Energy carrier of reference system (kWh)
$Q_{el.BS}$	Produced Electricity to Battery Storage (kWh)
$Q_{el.C}$	Electricity for Cooling (kWh)
$Q_{el.CG}$	El. for Cooling Grid (kWh)
$Q_{el.C1}$	El. for Primary Cold Source (incl. Pumps & Re-cooling) (kWh)
$Q_{el.C2}$	El. for Secondary Cold Source (incl. Pumps & Re-cooling) (kWh)
$Q_{el.Csol}$	Electricity for solar Cooling (kWh)
$Q_{el.CGsol}$	El. for solar cooling grid (kWh)
$Q_{el.DE}$	Domestic electricity (kWh)
$Q_{el.DHW}$	El. for DHW (kWh)
$Q_{el.DHWsol}$	El. for solar DHW (kWh)
$Q_{el.GD}$	Electricity fed into the public grid (kWh)
$Q_{el.HG}$	El. for Heating Grid (kWh)
$Q_{el.HGsol}$	El. for solar Heating Grid (kWh)
$Q_{el.HP}$	Electricity demand for heat pump (kWh)
$Q_{el.HVAC}$	Total Electricity HVAC Input (kWh)
$Q_{el.H1}$	El. for Primary Heat Source (incl. Pumps) (kWh)
$Q_{el.H2}$	El. for Secondary Heat Source (incl. Pumps) (kWh)
$Q_{el.PAR}$	Total Electricity PAR Input (kWh)
$Q_{el.ref}$	Total Electricity for reference SH+DHW production (kWh)
$Q_{el.ref.DHW}$	Parasitic electricity consumption of reference system for DHW (kWh)
$Q_{el.ref.SH}$	Parasitic electricity consumption of reference system for SH (kWh)
$Q_{el.SH}$	El. for Space Heating (kWh)
$Q_{el.SHsol}$	El. for solar Space Heating (kWh)
$Q_{el.sys}$	Total Electricity Input (kWh)
$Q_{GD.el}$	Electricity from the public grid (kWh)
$Q_{GD.Pumps}$	Pre-calculation for electricity from grid for pumps (kWh)
$Q_{H1/2}$	Distributed energy flow from CHP (kWh)
Q_{HB}	Hot backup energy (kWh)
$Q_{HD.Sol}$	Total Space Heating from Solar Collector (kWh)
$Q_{HD.System}$	Total Space Heating from System (kWh)
$Q_{HS.IN}$	Total Hot Storage from System (input) (kWh)
$Q_{HS.OUT}$	Total Hot Storage from System (output) (kWh)
Q_{H1} / $Q_{H1.sys}$	Heat source 1 (kWh) / Total Primary Heat Source to System (kWh)
Q_{H2} / $Q_{H2.sys}$	Heat source 2 (kWh) / Total Secondary Heat Source to System (kWh)
$Q_{HX.IN}$	Total Heat Exchanger to System (input) (kWh)
$Q_{HX.OUT}$	Total Heat Exchanger to System (output) (kWh)
$Q_{H1.In}$	Total input energy flow to primary heat source (kWh)
$Q_{H2.In}$	Total input energy flow to secondary heat source (kWh)
$Q_{H1.In.Sol}$	Solar energy for heating with primary cold source (kWh)

$Q_{H2.In.Sol}$	Solar energy for heating with secondary cold source (kWh)
Q_{hloss}	Heat losses (kWh)
$Q_{loss.ref}$	Reference loss for SH+DHW (kWh)
$Q_{PE.CHP}$	Primary energy demand for CHP (kWh)
$Q_{PE.CHP\_th}$	Primary energy for heating (kWh)
$Q_{PE.CHP\_el}$	Primary energy for electricity (kWh)
Q_{PV}	Distributed energy flow from PV (kWh)
$Q_{ref.sys}$	Thermal energy (kWh)
$Q_{SC.System}$	Total Solar Collectors to System (kWh)
Q_{source}	Total energy flows of all heat and cold source to the system (kWh)
Q_{system}	Total to/from System (kWh)
$Q_{WD.Sol}$	Total DHW from Solar Collector (kWh)
$Q_{WD.System}$	Total DHW from System (kWh)
Ref	Reference (System)
REH.System	Total renewable energy harvest to System
Res.System	Total renewable energy to System
SC	Solar Collector
SC.C1/2	Solar collectors to Cold source (ACM)
SC.DH	Solar collectors to District heating
SC.HD	Solar collectors to Heat distribution
SC.HS	Solar collectors to Hot storage
SC.H1/2	Solar collectors to Heat source ½
SC.WD	Solar collectors to DHW distribution
SCOP	Seasonal COP (-)
SE	Single Effect chiller
sec	secondary
SEER	Seasonal EER (-)
SH	Space Heating
SHC	Solar Heating and Cooling
sol	solar
SPF	Seasonal Performance Factor (-)
$SPF_{C.ref}$	Seasonal performance factor of the reference VCC (-)
$SPF_{equ.C}$	Seasonal performance factor equivalent for cooling (-)
$SPF_{equ.Csol}$	Seasonal performance factor equivalent for solar cooling (-)
$SPF_{equ.CG}$	Seasonal performance factor equivalent for cooling grid (-)
$SPF_{equ.CGsol}$	Seasonal performance factor equivalent for solar cooling grid (-)
$SPF_{equ.DHW}$	Seasonal performance factor equivalent for DHW (-)
$SPF_{equ.DHWsol}$	Seasonal performance factor equivalent for solar DHW (-)
$SPF_{equ..HG}$	Seasonal performance factor equivalent for district heating (-)
$SPF_{equ.HGsol}$	Seasonal performance factor equivalent for solar district heating (-)
$SPF_{equ.SH}$	Seasonal performance factor equivalent for space heating (-)
$SPF_{equ.SHsol}$	Seasonal performance factor equivalent for solar space heating (-)

$SPF_{equ.sys}$	Seasonal performance factor equivalent for the system (-)
Su	Sun
Su.PV	Sun to Photovoltaic collector
Su.SC	Sun to Solar thermal collector
sys	system
TH1CHP	Type heat source 1 for CHP unit (-)
TH2CHP	Type heat source 2 for CHP unit (-)
TPV	Type photovoltaic (-)
T_a	Ambient temperature of hot water tank (°C)
T_t	Set point of hot water tank (°C)
t_{CAP}	Reference for max. performance time (CAP_{solar}) (h)
t_{BOT}	Boiler operating time (s)
VCC	Vapour Compression Chiller
V_D	Volume flow (liter/day)
$V_{HR.1/2/ref}$	Water consumption of a wet and hybrid heat rejection unit of C1 / C2 / ref
WC_{an}	Annualized water costs (€/a)
WCT	Wet cooling tower

ε	Primary energy factor (-)
ε_{CHP}	Electrical primary energy factor of CHP (-)
ε_{BG}	Primary energy factor for biogas (-)
ε_{EC}	Thermal primary energy factor of CHP (-)
$\varepsilon_{EC.CHP}$	Primary energy factor for CHP energy carrier (-)
$\varepsilon_{EC.ref}$	Primary energy factor for specific reference energy carrier (-)
ε_{el}	Primary energy factor for electricity (-)
$\varepsilon_{el.CHP}$	Primary energy factor for CHP electrical production (-)
ε_{EC1}	Primary energy factor for specific energy carrier (primary) (-)
ε_{EC2}	Primary energy factor for specific energy carrier (secondary) (-)
$\varepsilon_{CHP1.el}$	Electrical conversion factor for CHP unit 1 (-)
$\varepsilon_{CHP2.el}$	Electrical conversion factor for CHP unit 2 (-)
ε_{HP}	COP for heat pump (-)
ε_{KM}	EER of chiller (-)
ε_{NG}	Primary energy factor for Natural gas (-)
$\varepsilon_{PV.el}$	Electrical conversion factor for photovoltaic (-)
ε_{WP}	Performance factor of hot backup (-)
$\eta_{CHP.EC}$	Electrical efficiency of CHP (-)
η_{BS}	Electrical efficiency of the battery (-)
$\eta_{H.EC}$	Heat efficiency of CHP (-)
η_{HB}	Boiler efficiency of hot backup (-)
$\eta_{HB.ref}$	Efficiency of the reference boiler (-)

η_{prop}	Losses of CHP (-)
η_{sum}	Efficiency ratio sum (-)
$\Sigma_{H1/2}$	Sum of energy flow provided by the CHP unit (kWh)
Σ_{PV}	Sum of energy flow provided by the PV system (kWh)

%BG	Fraction of Percentage of biogas (-)
%C.CS	Fraction of Cooling from Cold Storage (-)
%C.C1	Fraction of Cooling from Primary Cold Source (incl. CS) (-)
%C.C2	Fraction of Cooling from Secondary Cold Source (incl. CS) (-)
%CD.C1	Fraction of Cold Distribution from Primary Cold Source (incl. CS) (-)
%CD.C2	Fraction of Cold Distribution from Secondary Cold Source (incl. CS) (-)
%CD.HX	Fraction of Cold Distribution from Heat Exchanger (incl. CS) (-)
%CD.HXC	Fraction of Heat Exchanger from Cold Distribution (-)
%CD.H1	Fraction of Cold Distribution from Primary Heat Source (incl. CS) (-)
%CD.H2	Fraction of Cold Distribution from Secondary Heat Source (incl. CS) (-)
%CD.sys	Fraction of System to Cold Distribution (-)
%CG.CS	Fraction of Cooling Grid from Cold Storage (-)
%CG.C1	Fraction of Cooling Grid from Primary Cold Source (incl. CS) (-)
%CG.C2	Fraction of Cooling Grid from Secondary Cold Source (incl. CS) (-)
%CHP1.C	Fraction of Electricity CHP unit 1 for Cooling (-)
%CHP1.CG	Fraction of El. CHP1 for Cooling Grid (-)
%CHP1.C1	Fraction of El. CHP1 for Primary Cold Source (-)
%CHP1.C2	Fraction of El. CHP1 for Secondary Cold Source (-)
%CHP1.DE	Fraction of El. CHP1 for Domestic Electricity (-)
%CHP1.DH	Fraction of El. CHP1 for District Heating (-)
%CHP1.DHW	Fraction of El. CHP1 for DHW (-)
%CHP1.el	Fraction of Electricity from CHP unit 1 (-)
%CHP1.HD	Fraction of El. CHP1 for Space Heating (-)
%CHP1.HG	Fraction of El. CHP1 for Heating Grid (-)
%CHP1.HS	Fraction of El. CHP1 for Hot Storage (-)
%CHP1.H1	Fraction of El. CHP1 for Primary Heat Source (-)
%CHP1.H2	Fraction of El. CHP1 for Secondary Heat Source (-)
%CHP1.SH	Fraction of El. CHP1 for Space Heating (-)
%CHP1.WD	Fraction of El. CHP1 for DHW (-)
%CHP2.C	Fraction of Electricity CHP unit 2 for Cooling (-)
%CHP2.CG	Fraction of El. CHP2 for Cooling Grid (-)
%CHP2.C1	Fraction of El. CHP2 for Primary Cold Source (-)
%CHP2.C2	Fraction of El. CHP2 for Secondary Cold Source (-)
%CHP2.DE	Fraction of El. CHP2 for Domestic Electricity (-)
%CHP2.DH	Fraction of El. CHP2 for District Heating (-)

%CHP2.DHW	Fraction of El. CHP2 for DHW (-)
%CHP2.el	Fraction of Electricity from CHP unit 2 (-)
%CHP2.HD	Fraction of El. CHP2 for Space Heating (-)
%CHP2.HG	Fraction of El. CHP2 for Heating Grid (-)
%CHP2.HS	Fraction of El. CHP2 for Hot Storage (-)
%CHP2.H1	Fraction of El. CHP2 for Primary Heat Source (-)
%CHP2.H2	Fraction of El. CHP2 for Secondary Heat Source (-)
%CHP2.SH	Fraction of El. CHP2 for Space Heating (-)
%CHP2.WD	Fraction of El. CHP2 for DHW (-)
%CS.C1	Fraction of Cold Storage from Primary Cold Source (-)
%CS.C2	Fraction of Cold Storage from Secondary Cold Source (-)
%CS.H1	Fraction of Cold Storage from Primary Heat Source (-)
%CS.H2	Fraction of Cold Storage from Secondary Heat Source (-)
%CS.HX	Fraction of Cold Storage from Heat Exchanger (-)
%CS.HXC	Fraction of Heat Exchanger from Secondary Cold Source (-)
%CS.LO	Fraction of Cold Storage Losses (-)
%C1.HXC	Fraction of Heat Exchanger from Primary Cold Source (-)
%C1:SC	Fraction of Input of Primary Cold Source from Solar Collector (-)
%C1.System	Fraction of Primary Cold Source to System (-)
%C2.HXC	Fraction of Heat Exchanger from Secondary Cold Source (-)
%C2:SC	Fraction of Input of Secondary Cold Source from Solar Collector (-)
%C2.System	Fraction of Secondary Cold Source to System (-)
%DC.C1	Fraction of District Cooling from Primary Cold Source (incl. CS) (-)
%DC.C2	Fraction of District Cooling from Secondary Cold Source (incl. CS) (-)
%DC.sys	Fraction of System to District Cooling (-)
%DH.sys	Fraction of System to District Heating (-)
%DH.System	Fraction of District Heating from SC to System (-)
%El.C	Fraction of Electricity for Cooling (-)
%El.CG	Fraction of Electricity for Cooling Grid (-)
%El.DHW	Fraction of Electricity or DHW (-)
%El.GD	Fraction of Electricity to Grid (-)
%El.HG	Fraction of Electricity for Heating Grid (-)
%El.SH	Fraction of Electricity for Space Heating (-)
%GD.C	Fraction of Electricity Grid for Cooling (-)
%GD.CG	Fraction of El. Grid for Cooling Grid (-)
%GD.C1	Fraction of El. Grid for Primary Cold Source (-)
%GD.C2	Fraction of El. Grid for Secondary Cold Source (-)
%GD.DE	Fraction of El. Grid for Domestic Electricity (-)
%GD.DH	Fraction of El. Grid for District Heating (-)
%GD.DHW	Fraction of El. Grid for DHW (-)
%GD.el	Fraction of Electricity from Grid (-)

%GD.HD	Fraction of El. Grid for Space Heating (-)
%GD.HG	Fraction of El. Grid for Heating Grid (-)
%GD.HS	Fraction of El. Grid for Hot Storage (-)
%GD.H1	Fraction of El. Grid for Primary Heat Source (-)
%GD.H2	Fraction of El. Grid for Secondary Heat Source (-)
%GD.SH	Fraction of El. Grid for Space Heating (-)
%GD.WD	Fraction of El. Grid for DHW (-)

%HD.sys	Fraction of System to Space Heating (-)
%HS.C1	Fraction of Hot Storage to Primary Cold Source (-)
%HS.C1:H1	Fraction of Hot Storage to C1 from H1 (-)
%HS.C1:H2	Fraction of Hot Storage to C1 from H2 (-)
%HS.C2	Fraction of Hot Storage to Secondary Cold Source (-)
%HS.C2:H1	Fraction of Hot Storage to C2 from H1 (-)
%HS.C2:H2	Fraction of Hot Storage to C2 from H2 (-)
%HS.DH	Fraction of Hot Storage to District Heating (-)
%HS.HD	Fraction of Hot Storage to Space Heating (-)
%HS.LO	Fraction of Hot Storage Losses (-)
%HS.System	Fraction of Hot Storage from SC to System (-)
%HS.WD	Fraction of Hot Storage to DHW (-)
%HS.H1	Fraction of Hot Storage to Primary Heat Source (-)
%HS.H2	Fraction of Hot Storage to Secondary Heat Source (-)
%HX.H1	Fraction of Heat Exchanger to Primary Heat Source (-)
%HX.H2	Fraction of Heat Exchanger to Secondary Heat Source (-)
%HX.HS	Fraction of Heat Exchanger to Hot Storage (-)
%H1.C	Fraction of Primary Heat Source for Cooling (-)
%H1.CG	Fraction of Primary Heat Source for Cooling Grid (-)
%H1.C1	Fraction of Primary Heat Source to Primary Cold Source (-)
%H1.C2	Fraction of Primary Heat Source to Secondary Cold Source (-)
%H1.DH	Fraction of Primary Heat Source to District Heating (-)
%H1.DHW	Fraction of Primary Heat Source for DHW (-)
%H1.HD	Fraction of Primary Heat Source to Space Heating (-)
%H1.HG	Fraction of Primary Heat Source for Heating Grid (-)
%H1.HS	Fraction of Primary Heat Source to Hot Storage (-)
%H1.LO	Fraction of Primary Heat Source Losses (-)
%H1:SC	Fraction of Input of Primary Heat Source from Solar Collector (-)
%H1.SH	Fraction of Primary Heat Source for Space Heating (-)
%H1.System	Fraction of Primary Heat Source to System (-)
%H1.WD	Fraction of Primary Heat Source to DHW (-)
%H2.C	Fraction of Secondary Heat Source for Cooling (-)
%H2.CG	Fraction of Secondary Heat Source for Cooling Grid (-)
%H2.C1	Fraction of Secondary Heat Source to Primary Cold Source (-)
%H2.C2	Fraction of Secondary Heat Source to Secondary Cold Source (-)
%H2.DH	Fraction of Secondary Heat Source to District Heating (-)

%H2.DHW	Fraction of Secondary Heat Source for DHW (-)
%H2.HD	Fraction of Secondary Heat Source to Space Heating (-)
%H2.HG	Fraction of Secondary Heat Source for Heating Grid (-)
%H2.HS	Fraction of Secondary Heat Source to Hot Storage (-)
%H2:SC	Fraction of Input of Secondary Heat Source from Solar Collector (-)
%H2.SH	Fraction of Secondary Heat Source for Space Heating (-)
%H2.System	Fraction of Secondary Heat Source to System (-)
%H2.LO	Fraction of Secondary Heat Source Losses (-)
%H2.WD	Fraction of Secondary Heat Source to DHW (-)
%Pumps.C1	Fraction of Pumps Electricity for Primary Cold Source (-)
%Pumps.C2	Fraction of Pumps Electricity for Secondary Cold Source (-)
%Pumps.DH	Fraction of Pumps Electricity for District Heating (-)
%Pumps.HD	Fraction of Pumps Electricity for Space Heating (-)
%Pumps.HS	Fraction of Pumps Electricity for Hot Storage (-)
%Pumps.H1	Fraction of Pumps Electricity for Primary Heat Source (-)
%Pumps.H2	Fraction of Pumps Electricity for Secondary Heat Source (-)
%Pumps.WD	Fraction of Pumps Electricity for DHW (-)
%PV.C	Fraction of Electricity Photovoltaic for Cooling (-)
%PV.CG	Fraction of El. Photovoltaic for Cooling Grid (-)
%PV.C1	Fraction of El. Photovoltaic for Primary Cold Source (-)
%PV.C2	Fraction of El. Photovoltaic for Secondary Cold Source (-)
%PV.DE	Fraction of El. Photovoltaic for Domestic Electricity (-)
%PV.DH	Fraction of El. Photovoltaic for District Heating (-)
%PV.DHW	Fraction of El. Photovoltaic for DHW (-)
%PV.el	Fraction of Electricity from Photovoltaic (-)
%PV.HD	Fraction of El. Photovoltaic for Space Heating (-)
%PV.HG	Fraction of El. Photovoltaic for Heating Grid (-)
%PV.HS	Fraction of El. Photovoltaic for Hot Storage (-)
%PV.H1	Fraction of El. Photovoltaic for Primary Heat Source (-)
%PV.H2	Fraction of El. Photovoltaic for Secondary Heat Source (-)
%PV.SH	Fraction of El. Photovoltaic for Space Heating (-)
%PV.WD	Fraction of El. Photovoltaic for DHW (-)
%SC.C	Fraction of Solar Collectors for Cooling (-)
%SC.CG	Fraction of Solar Collectors for Cooling Grid (-)
%SC.C1	Fraction of Solar Collectors to Primary Cold Source (ACM) (-)
%SC.C2	Fraction of Solar Collectors to Secondary Cold Source (ACM) (-)
%SC.DH	Fraction of Solar Collectors to District Heating (-)
%SC.DHW	Fraction of Solar Collectors for DHW (-)
%SC.HD	Fraction of Solar Collectors to Space Heating (-)
%SC.HG	Fraction of Solar Collectors for Heating Grid (-)
%SC.HS	Fraction of Solar Collectors to Hot Storage (-)

%SC.H1	Fraction of Solar Collectors to Primary Heat Source (HP) (-)
%SC.H2	Fraction of Solar Collectors to Secondary Heat Source (HP) (-)
%SC.LO	Fraction of Solar Collectors Losses (-)
%SC.SH	Fraction of Solar Collectors for Space Heating (-)
%SC.WD	Fraction of Solar Collectors to DHW (-)
%WD.sys	Fraction of System to DHW (-)
%WD.System	Fraction of DHW from SC to System (-)