**Task 38
Solar Air-Conditioning
and Refrigeration**

Monitoring Procedure for Solar Cooling Systems

A joint technical report of subtask A and B (D-A3a / D-B3b)

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1. Introduction

Monitoring of installed solar assisted cooling systems represents a fundamental tool in order not only to optimize the monitored system itself, but as well to draw conclusions for a suited selection of design and control for future installations.

This is especially true for a technology in an early stage of market penetration, as it is the case for Solar Heating and Cooling (SHC) systems. In fact to the date, only around 300 SHC are documented worldwide.

Within the documented plants, 14 small scale (< 20 kW cooling capacity) and 12 large scale systems have been monitored.

In order to enable a structured collection of monitoring data and to define common performance figures for comparisons of SHC plants, a unified monitoring procedure has been developed.

The procedure aims at:

- evaluating a set of performance figures of monitored SHC systems;

- estimating the primary energy savings of monitored SHC systems with the respect to a conventional system;

- enabling the comparison between different monitored SHC systems.

On the basis of such output, the procedure could lead to the identification of best practices hence of best design solutions in relationship with the climate, the building features and use, occupation conditions and so on.

Furthermore the procedure defines the minimum monitoring equipment required to evaluate the energy performance of the existing systems. So it is not restricted to the IEA activities and the mentioned systems but can support the development of further monitoring campaigns.

Finally, the procedure should permit as well to draw (with the results) a learning curve over the coming years on the cost development of installed solar assisted heating and cooling systems.

The procedure can be applied for both Solar Heat Driven Chiller (SHDC) and Desiccant Evaporative Cooling (DEC) systems, even if for the latter case an additional tool has been developed.

This report describes the developed monitoring procedure which includes:

- one standard tool for the graphical representation of monitored systems (ppt-file);

- one standard tool for the visual representation of a conventional system as term of comparison with SHC systems (ppt-file);

- one excel file which enables the calculation of key figures such as primary energy ratio, electrical coefficient of performance, solar heat management efficiency and fractional savings with respect to a conventional (non solar) heating and cooling system;

- one more excel file to be applied in case of DEC systems with the aim at collecting very detailed monitoring data and derive intermediate figures useful for the evaluation of relevant energy performance with respect to a conventional system.

2. Selection of graphical representations

The monitoring procedure aims at evaluating monitored systems and comparing them with a selected conventional system. Actually, depending on whether the monitored system is based on SHDC or DEC, the conventional system to be taken as reference is different.

To enable a clear and homogeneous representation of monitored systems and of the conventional system to be taken as reference for comparisons, two standard diagrams have been drawn which are below described.

2.1 Selection of a standard graphical scheme for the representation of real monitored installations

A diagram (Figure 2-1) for the representation of monitored systems has been developed on the basis of commonly applied layouts for SHC systems. This scheme is available as a power point file (see Appendix) and enables to represent largely different systems. In fact the scheme can be adapted mainly by deleting those parts which do not exist in the system under investigation (see Figure 2-2 as an example).
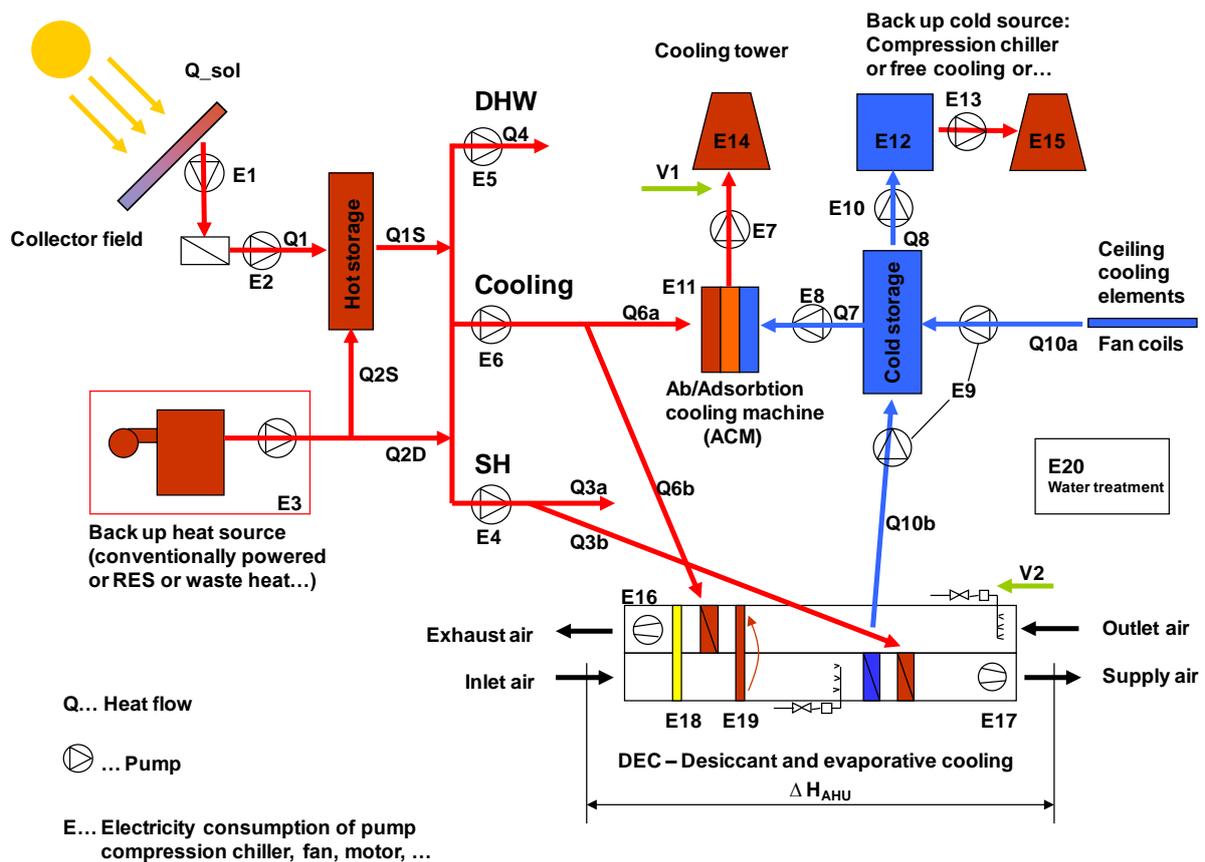
Figure 2-1 Reference solar heating and cooling system including the single energy fluxes (SHC Max System)

Electricity and thermal flows involved in a SHC system are shown in the figure. For a detailed explanation of each flow, refer to Table 1, Table 2 and Table 3.

Table 1 List of electrical flows involved in a SHC system

Electricity consumer [kWh]	Label
Heating System	
pump collector field (primary loop)	E1
pump collector field (secondary loop)	E2
pump boiler hot-storage (including internal boiler consumption)	E3
pump hot-storage to space heating (SH)	E4
pump hot-storage to domestic hot water (DHW)	E5
Cooling System	
pump hot-storage to cooling machine	E6
pump cooling machine (ACM) to cooling tower	E7
pump cooling machine (ACM) to cold-storage	E8
pump cold storage to cold distribution	E9
pump back up source - cold storage	E10
absorption/adsorption cooling machine (ACM)	E11
compression chiller (back-up system)	E12
pump compression chiller to fan (back-up system)	E13
fan, cooling tower	E14
fan of compression chiller (back-up system)	E15
Desiccant cooling/ dehumidification System	
fan exhaust air	E16
fan supply air	E17
motor for desiccant wheel	E18
motor for heat recovery wheel	E19
Water treatment System	
water treatment for wet cooling tower and humidifier for DEC	E20

Table 2 List of thermal flows involved in a SHC system

Thermal Energies [kWh]	Label
solar irradiation on total collector aperture area	Q_sol
solar thermal output to hot storage	Q1
heat output from hot storage	Q1S
boiler thermal output (fossil) into storage	Q2S_fossil
renewable energy source (RES) thermal output into storage	Q2S_RES
fossil boiler thermal input (fossil) bypassing hot storage (directly used)	Q2D_fossil
renewable heat source (RES) thermal input bypassing hot storage (directly used)	Q2D_RES
space heating (SH) consumption (conventional)	Q3a
space heating (SH) consumption (ventilation system)	Q3b
domestic hot water (DHW) consumption	Q4
hot storage input to cooling machine (ACM)	Q6a
hot storage input to DEC-system (sorption regeneration)	Q6b
cold output ACM to cold-storage	Q7
cold output back-up chiller or free cooling to cold-storage	Q8
cold storage output to cold-distribution	Q10a
cold storage to Air Handling Unit (AHU)	Q10b
Enthalpy difference - Air Handling Unit (Inlet Air => Supply Air)	ΔH_{AHU}

Table 3 List of water consumptions involved in a SHC system

Water Consumption [Liter]	Label
water consumption for wet cooling tower	V1
water consumption for DEC humidifier	V2
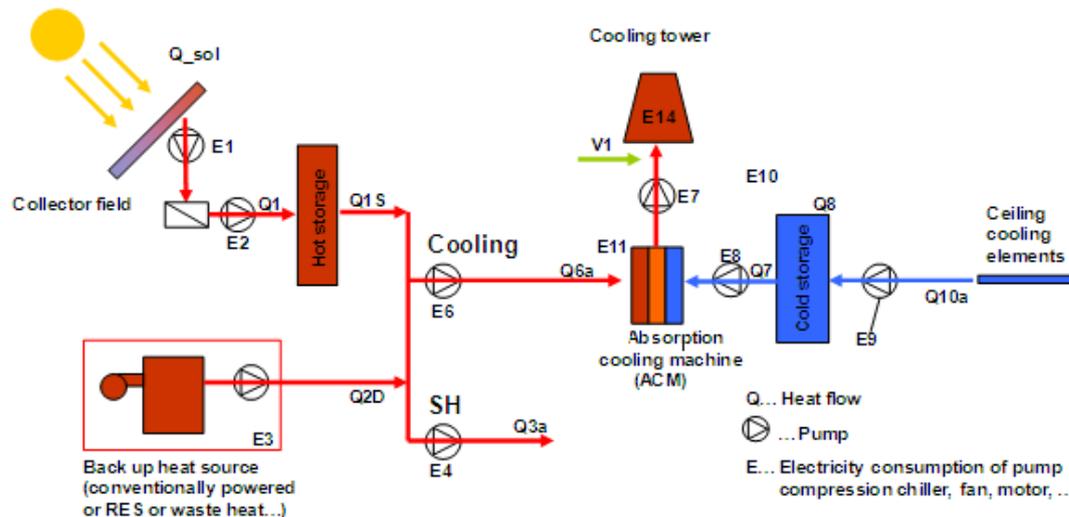
Figure 2-2 Example of a solar heating and cooling system of a specific installation based on the "SHC Max System" shown in Figure 2-1.

2.2 Selection of a standard graphical scheme for the representation of a reference system

The selected conventional system to be taken as reference for comparisons consists of a condensing natural gas boiler to match the space heating (SH) load and the domestic hot water (DHW). A small storage tank, with typical heat losses based on the measured domestic hot water consumption, is assumed to be heated by the natural gas boiler. Finally, the cooling load is supposed to be matched by a compression chiller.

The conventional system has to include an Air Handling Unit (AHU) when the monitored system is based on a DEC. In case an AHU is present in a SHDC monitored system, the conventional system includes it as well but it is not significant for the comparison as the AHU is seen as a distribution system. Figure 2-3 shows the selected conventional system and the relevant energy flows. A description of each flow is shown in the Table 1, Table 2 and Table 3.

SH DHW

Q3a↑   ↑ **Q4**

Hot water storage

Back up cold source Compression chiller

Ceiling cooling elements fan coils

E4

Q2

E5

E13

E12

Q10a

E15

E9

E3

Heat rejection

Back up heat source (conventionally powered)

Q3b

Q10b

Inlet air →

Outlet air ←

Exhaust air ←

→ **Supply air**

E16

E17

Air handling unit

Q… Heat flow

⊘**… Pump**

E… Electricity consumption of pump, fan, motor, …
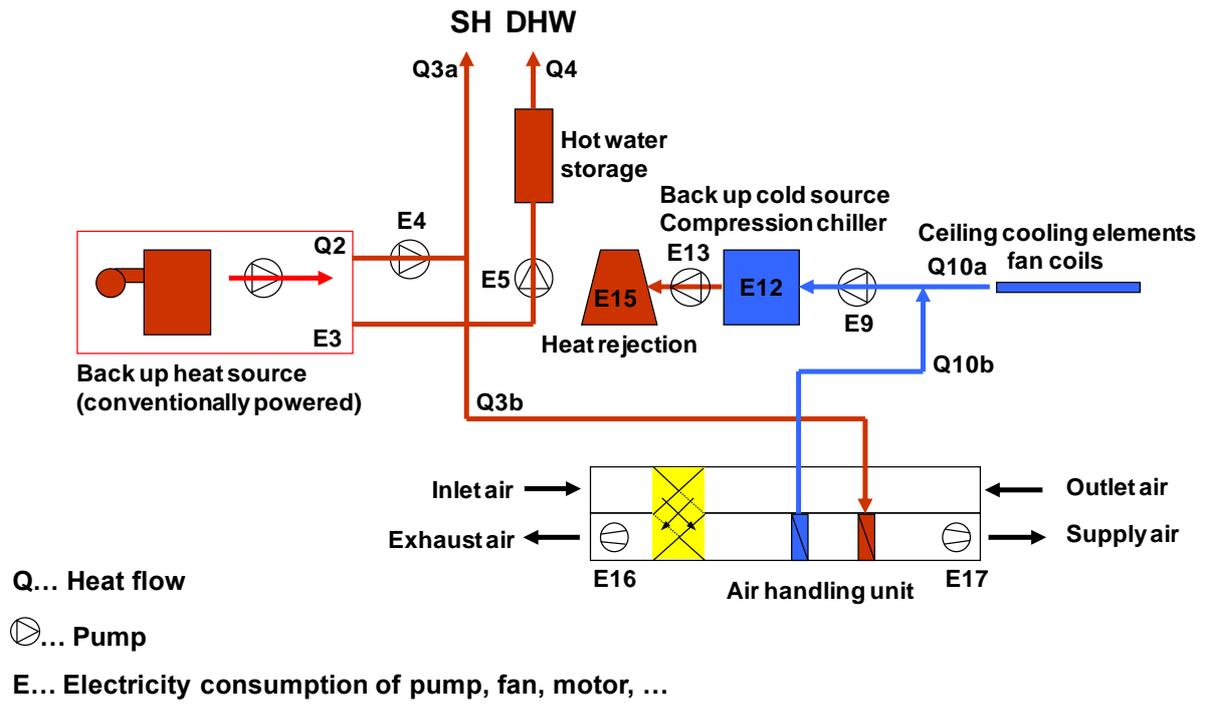
Figure 2-3 Diagram of the selected conventional reference systems including energy flows

3. Monitoring procedure

The monitoring procedure consists of an excel file where monitored data are collected and elaborated on monthly and yearly basis for both SHDC and DEC systems. For DEC systems one more excel file has been developed to collect and elaborate special data which are then integrated in the main file for a complete and correct performance evaluation.

The main excel file of the monitoring procedure consists of 3 levels:

1. First level: Basic Information on COP, Primary Energy Ratio and Costs;

2. Second level: Basic monitoring procedure mainly evaluating the solar heat management efficiency (kept simple in sense of calculation and necessary monitoring hardware);

3. Third level: Advanced monitoring procedure evaluating primary energy savings and specific COP`s of components and groups (more complex in sense of calculation and necessary monitoring hardware).

Several key figures are defined in each of the three levels and can be calculated depending on the sensors installed. In practice, each completed level of the procedure indicates a certain level of detail of the monitoring system.

3.1   Assumptions

Before going in detail with the monitoring procedure, it is necessary to list the major assumptions at the base of the monitoring data collection and elaboration.

3.1.1   <u>Accuracy of the sensors</u>

In order to enable a correct evaluation of the performance of a monitored solar heating and cooling system and a fair comparison between different systems, accuracy of measurements should be checked. Nevertheless, an estimation of the accuracy for the entire monitoring system installed is out of scope of the developed procedure. For this reason the tool only includes an estimation of the accuracy of the chilling power of the heat driven chiller (according to Eq. 1) and allows users to enter accuracies values for specific devices, such as signal conditioning devices, electricity energy counters and pyranometers.

It is highlighted that the tool does not set any benchmark for the accuracy values but only aims at informing about the reliability of the output data.

$$\frac{\Delta \dot{Q}}{\dot{Q}} = \sqrt{\left(\frac{\Delta \rho}{\rho}\right)^2 + \left(\frac{\Delta \dot{V}}{\dot{V}}\right)^2 + \left(\frac{\Delta c_p}{c_p}\right)^2 + 2 \cdot \left(\frac{\Delta \Delta T}{\Delta T}\right)} \qquad \text{Eq. 1}$$

3.1.2   <u>Efficiency of the conventional system</u>

Most key figures defined in the procedure for the evaluation of the performance of the monitored system require data on energy used for heating, cooling and DHW to be converted into primary energy.

The calculation of the energy use needs the definition of efficiency figures of the applied heating, cooling and DHW systems. In practice such efficiencies have to be defined for the heat and cold backup systems and depend of course on the technology used. Typical backup systems applied in the monitored installations are natural gas boilers and

compression chillers. In these cases the efficiencies considered for the backup system in the monitored installations are the same as in the conventional system.

The use of common values for all the monitored installations enables the comparison between their performance results. For this reason some reference values have been defined, such as:

- Natural gas boiler efficiency

$$\eta_{boiler} = 0.95 \qquad \text{Eq. 2}$$

- Seasonal Performance Factor of vapor compression chiller

$$SPF_{ref} = 2.8 \left[\frac{kWh_{th}}{kWh_{elec}} \right] \qquad \text{Eq. 3}$$

In case a boiler fired by renewable energy source (e.g. biomass) is applied, a special efficiency value can be used, labeled as:

$$\eta_{boiler\_RES} = 0.90 \qquad \text{Eq. 4}$$

All the default values listed efficiencies can also be substituted with special values in relationship with a different technology applied or according to the knowledge of the users (Refer to "3.2.1 General input data").

3.1.3 **Primary energy conversion factors**

On the other hand it has been necessary to fix the primary energy factors for the main energy carriers used in the installations, i.e. electricity and fossil fuels like oil and natural gas[1]. It is the "fossil" primary energy factor, which means how much fossil energy was used in order to produce the delivered energy carrier.

$$\varepsilon_{elec} = 0.40 \left[\frac{kWh_{elec}}{kWh_{pe}} \right] \qquad \text{Eq. 5}$$

$$\varepsilon_{fossil} = 0.90 \left[\frac{kWh_{th}}{kWh_{pe}} \right] \qquad \text{Eq. 6}$$

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[1] Please note that the values selected are actually the reciprocal of the so called primary energy factors defined according to the EN 15603

Primary energy factors depend on the process beyond the delivery of the energy carriers to the building. To enable comparisons between the different monitored installations common values have been selected. However if the users are interested in making calculations according to special factors (national, local and so on), such values can also be defined as input.(Read "3.2.1 General input data").

The procedure also enables the definition of primary energy factors for renewable energy carriers, e.g. biomass. As base values the following can be considered:

$$\varepsilon\_RES = 10 \quad \left[\frac{kWh_{th}}{kWh_{pe}} \right] \qquad \text{Eq. 7}$$

One special case for the calculation of the primary energy is the utilization of cogeneration units as heat backup system.

In these cases, the calculation of the primary energy factor has to account for the electricity produced with the same fuel consumption. In practice the primary energy related with the electricity output by the prime motor is discounted from the primary energy entering the cogeneration unit, according to the formula below:

$$\varepsilon_{COG} = \frac{Q_{CHP}}{\dfrac{Q_{fuel}}{\varepsilon_{fuel}} - \dfrac{W_{el}}{\varepsilon_{elec}}} \quad \left[\frac{kWh_{th}}{kWh_{pe}} \right] \qquad \text{Eq. 8}$$

Where:

Q_{CHP} is the heat recovered from the engine or turbine

Q_{fuel} is the monitored input energy of the driving fuel

ε_{fuel} is the primary energy conversion factor for the driving fuel

W_{el} is the electricity output by the engine or turbine

ε_{elec} is the primary energy conversion factor for the electricity

Note that the calculated value represents the efficiency of the cogeneration unit but already includes the primary energy factor for the driving fuel.

3.2   Input data

3.2.1   General input data

General data on the system have to be entered: name, location and final use of the installation together with sizes, technologies and units of the major SHC components (i.e. solar collectors, TDC, tanks, back-up systems).

It is needed to adapt the standard scheme shown in Figure 2-1 to the monitored system and list the energy flows which are monitored according to Table 1. On the basis of the sensors available, different level of information can be derived which are represented by the three

different levels of the procedure. Then the major input data are basically the monthly values measured by each listed sensor.

As already mentioned in the previous subchapter, the efficiencies of the machines and the primary energy factors can be also entered by the users according to special needs. So additionally to the above Tables, the parameters listed in Table 4 can be entered.

For instance if the users know the monthly efficiency of the installed boiler, this value can be entered and used for the calculation of the monthly and yearly energy use. On the other hand, if the primary energy factor of the location where the system is installed differs from the default value, it can also be entered.

Table 4: Parameters which can be entered by the users

Parameters	Label
annual electricity generation efficiency	ε_{elec}
seasonal performance factor of the reference compression chiller	SPF_{ref}
mean annual / monthly efficiency of the auxiliary boiler	η_{boiler}
primary energy factor for fossil fuel	ε_{fossil}
mean annual / monthly efficiency of the RES device	η_{RES}
primary energy factor for RES fuel	$\varepsilon_{\_RES}$
mean annual / monthly efficiency of the reference boiler	$\eta_{boiler,ref}$

3.2.2   Special input data required for DEC systems

In the case of DEC systems further data are needed, especially for the 1° and the 3° level. Inputs for the 3° level partly have to be calculated in an extra excel file (110801_T38_MonProc_V6-0_DH-calc.xls) which has been developed to calculate the following monthly values based on high resolution monitoring data (e.g. 5 minutes):

- reference electricity consumption of the AHU (necessary for the 1° and the 3° level);

- reference enthalpy difference of the AHU supply air mass flow (3° level);

- reference enthalpy difference obtained from single components indoors the conventional AHU, such as dehumidification coil, post-cooling coil, post-heating coil (3° level).

For this reason, the following monitoring data in reasonable time steps (5 to 10 minutes are recommended) from the DEC AHU are required to be able to do the calculations in this excel tool:

1. Heating is ON or OFF   [1 or 0]

2. Cooling is ON or OFF   [1 or 0]

3. Inlet Air Temperature   [°C]

4. Inlet Air relative Humidity   [%]

5. Supply Air Temperature   [°C]

6. Supply Air relative Humidity   [%]

7. Outlet Air Temperature   [°C]

8. Supply Air Flow   [kg/h]

Additionally the following parameters need to be defined:

1. The supply air temperature of the reference AHU: "t supply max conv." [°C]; as standard 20°C is set.

2. The heat recovery ratio of the reference heat recovery wheel: "Reference Heat Recovery"; as standard 75% is set.

3. Minimum supply air flow rate [kg/h] which indicates if the AHU is in operation or not. This value is only used if in the monitoring data no status value for "Heating is ON or OFF" and "Cooling is ON or OFF" is given.

The calculated values are finally presented in the worksheet "introduction" in a light green marked field which can directly be transferred to the main excel tool by copy and paste as explained in the tool.

3.3 Monitoring data elaboration and assessment

3.3.1 General key energy performance figures in the 1st monitoring level

In the first level, an overall evaluation for the entire system is done by calculating coefficients of performances (COP) and primary energy ratios (PER) on both monthly and yearly basis.

The inputs necessary for the achievement of this level are listed in Table 5

Table 5 Monitored data necessary for the completion of the 1st monitoring level

Electricity consumer [kWh]	Label
Overall electricity consumption of the energy facility (the overall and only sensors listed in Table 1 are included)	Eelec,overall
Heating System	
pump hot-storage to space heating (SH)	E4
pump hot-storage to domestic hot water (DHW)	E5
Cooling System	

	Label
pump cold storage to cold distribution	E9
Desiccant cooling/ dehumidification System	
fan exhaust air (eventually fan regeneration air)	E16
fan supply air	E17

Thermal Energies [kWh]	Label
boiler thermal output (fossil) into storage	Q2S_fossil
renewable energy source (RES) thermal output into storage	Q2S_RES
fossil boiler thermal input (fossil) bypassing hot storage (directly used)	Q2D_fossil
renewable heat source (RES) thermal input bypassing hot storage (directly used)	Q2D_RES
space heating (SH) consumption	Q3a
domestic hot water (DHW) consumption	Q4
cold storage output to cold-distribution	Q10a
Enthalpy difference - Air Handling Unit (Inlet Air => Supply Air)	ΔH_{AHU}

The 1st monitoring level aims at comparing the useful heat and cold supply with the correspondent electricity or primary energy spent in the operation.

The *total electrical COP* (COP$_{el,tot}$) calculates the ratio of useful heat and/or cold in relation to the electricity consumption needed but excludes the electrical consumption of pumps and fans which are used to distribute heat and/or cold in the building by pumping water or blowing air (i.e. the so labelled Eelec,tot = Eelec,overall–E4-E5-E9-E16-E17).

$$COP_{el,tot} = \frac{Q3a + Q10a + Q4 + \left| \Delta H_{AHU} \right|}{Eelec, tot} \quad \left[\frac{kWh_{th}}{kWh_{elec}} \right] \qquad \text{Eq. 9}$$

The *overall electrical COP* (COPel,overall) includes also all the electrical consumers for distribution (i.e. the so labelled Eelec,overall)

$$COP_{el,overall} = \frac{Q3a + Q10a + Q4 + \left| \Delta H_{AHU} \right|}{Eelec, overall} \quad \left[\frac{kWh_{th}}{kWh_{elec}} \right] \qquad \text{Eq. 10}$$

At this monitoring level, to calculate the Eelec,overall is not needed to have all the relevant electricity meters installed, but just one meter on the overall consumption of the facility. To calculate the Eelec,tot is then needed at least one overall meter and the measurement of the electrical consumption of the distribution pumps (E4, E5 and E9). In case the monitored

system includes a conventional AHU, this is considered as a distribution system and the electricity consumed for fans (E16 and E17) should be subtracted from Eelec,overall too. If the monitored system includes a DEC AHU, only the additional electricity due to special DEC components (see chapter 3.3.2) should be considered in Eelec_overall. So further measurements are needed, or at least pressure drops of the single AHU components must be known to be able to calculate the nominal pressure drops of the DEC AHU and a Reference AHU resulting in a correction factor which is used to estimate the additional electricity consumption of the fans due to the DEC components.

Primary energy ratio is calculated for the monitored installation as the ratio of useful heat and/or cold in relation to the primary energy demand.

$$PER\_res = \frac{Q3a + Q10a + Q4 + |\Delta H_{AHU}|}{\dfrac{Q2\_fossil\_tot}{\varepsilon_{fossil} * \eta_{boiler}} + \dfrac{Q2\_RES\_tot}{\varepsilon\_RES * \eta_{boiler\_RES}} + \dfrac{Eelec, tot}{\varepsilon_{elec}}} \quad \left[\frac{kWh_{th}}{kWh_{pe}}\right] \qquad Eq. 11$$

Where:

$$Q2\_fossil\_tot = Q2S\_fossil + Q2D\_fossil \qquad Eq. 12$$

$$Q2\_RES\_tot = Q2S\_RES + Q2D\_RES \qquad Eq. 13$$

Note that ΔH_{AHU} has only to be included when the monitored system is based on DEC. In case the monitored system includes a conventional AHU, this is considered as a distribution system and Q3a actually includes the heat which is then transferred to all the distribution system, AHU included.

In case back up systems based on renewable energy are installed, the procedure can also evaluate the impact of such RES compared to a conventional system according to:

$$PER\_fossil = \frac{Q3a + Q10a + Q4 + |\Delta AHU|}{\dfrac{Q2\_fossil\_tot}{\varepsilon_{fossil} * \eta_{boiler}} + \dfrac{Q2\_RES\_tot}{\varepsilon_{fossil} * \eta_{boiler\_RES}} + \dfrac{Eelec, tot}{\varepsilon_{elec}}} \quad \left[\frac{kWh_{th}}{kWh_{pe}}\right] \quad Eq. 14$$

In comparison with Eq. 11, Eq. 14 considers Q2 produced from RES as produced by fossil fuel but with the same efficiency of RES technology used. In this way the influence of the much more advantageous primary energy factor for RES is eliminated and the RES-system can be compared with a fossil-system based on the same fuel type (but of course different boiler efficiency is still a weak point which should be kept in mind).

Additionally a PER is calculated also for the supposed conventional system according to:

$$PERref = \frac{Q3a + Q10a + Q4 + |\Delta AHU|}{\dfrac{Q_{boiler,ref}}{\varepsilon_{fossil} * \eta_{boiler}} + \dfrac{Q_{coolingref}}{SPF_{ref} * \varepsilon_{elec}} + \dfrac{E_{el,ref}}{\varepsilon_{elec}}} \quad \left[\frac{kWh_{th}}{kWh_{pe}}\right] \qquad \text{Eq. 15}$$

The so called Qboiler,ref not only takes into account the heat load of the monitored installation for heating and DHW purposes but of course includes also the possible heat losses of the storage for DHW in the reference system according to IEA SHC Task26: ENV 12977-1 (2000); (Weiss, Ed. 2003). So, it is defined as:

$$Q_{boiler,ref} = Q3a + Q3b + Q4 + Q_{loss\_ref} \quad \left[kWh_{th}\right] \qquad \text{Eq. 16}$$

Where:

$$Q_{loss\_ref} = 0.00016 * \sqrt{0.75 * V_D} * (T_T\_Ta) * 8760 \quad \left[kWh_{th}\right] \qquad \text{Eq. 17}$$

And:

V_D : average daily hot water consumption (liter / day)

T_T : set point temperature of the hot water tank (default 52.5 °C)

T_a : ambient temperature around the hot water tank (default 15 °C) Note that Q3b has to be entered only when the monitored system is based on DEC. In case the monitored system includes a conventional AHU, this is considered as a distribution system and Q3a actually includes the heat which is then transferred to all the distribution system, AHU included.

The so called Eel,ref, is the electrical consumption of the conventional system which includes the consumption for operating the boiler and the pump between the boiler and the storage. This is the only item which differs from the electrical consumption of a SHDC in the heating mode. The electricity consumed by a conventional system in the cooling mode is taken into account in the SPF_{ref}.

In case the monitored system is based on a DEC AHU, the Eel,ref includes the electrical consumption of the corresponding AHU as described in subchapter 3.3.4.

For conventional systems to be compared to SHDC systems:

$$E_{el\_ref} = 0.02 * (Q3a + Q3b + Q4 + Q_{loss\_ref}) \quad \left[kWh_{elec}\right] \qquad \text{Eq. 18}$$

The value 0.02 kWhel/kWhth is an assumption to be taken into consideration for small boilers and in case no real value is available (low level of detail of monitoring). In a very detailed monitoring, one more calculation procedure has been defined as described later.

The so-labeled Qcooling,ref is the cooling supplied to the load, (i.e. Q10a) and in a conventional system is entirely supplied by a compression chiller. In the 1st monitoring level it is enough to monitor Q10a and assume a proper SPF which takes into account all the relevant electrical consumption, i.e., with reference to Figure 2-3, not only E12 but also E13 and E15, e.g. the default value of SPF$_{ref}$. In a very detailed monitoring, one more calculation procedure has been defined to derive Qcooling,ref which is described later.

At the end of the 1st monitoring level one economic figure, the Cost Per kW, is calculated according to:

$$CPK = \frac{\text{Cost of total cooling system}}{\text{Cooling capacity installed}} \left[\frac{k€}{kW} \right] \qquad \text{Eq. 19}$$

3.3.2 General key energy performance figures in the 2nd monitoring level

In the second level mainly the quality of the subsystems solar thermal heat production and heat management within the system are evaluated.

The necessary measurements only concern thermal flows (Table 6).

Table 6 Necessary measurements for the completion of the second monitoring level

Thermal Energies [kWh]	Label
solar irradiation on total collector aperture area	Q_sol
solar thermal output to hot storage	Q1
heat output from hot storage	Q1S
boiler thermal output (fossil) into storage	Q2S_fossil
renewable energy source (RES) thermal output into storage	Q2S_RES
fossil boiler thermal input (fossil) bypassing hot storage (directly used)	Q2D_fossil
renewable heat source (RES) thermal input bypassing hot storage (directly used)	Q2D_RES
space heating (SH) consumption	Q3a
space heating (SH) consumption (ventilation system)	Q3b
domestic hot water (DHW) consumption	Q4
hot storage input to cooling machine (ACM)	Q6a
hot storage input to DEC-system (sorption regeneration)	Q6b

First, the _efficiency of solar collectors_ is estimated by means of:

$$\eta coll, util = \frac{Q1}{Qsol}$$ Eq. 20

Hence losses in the collectors are given by (Figure 3-1):

$$\Delta Qsol = Qsol - Q1 \ \left[kWh_{th}\right]$$ Eq. 21
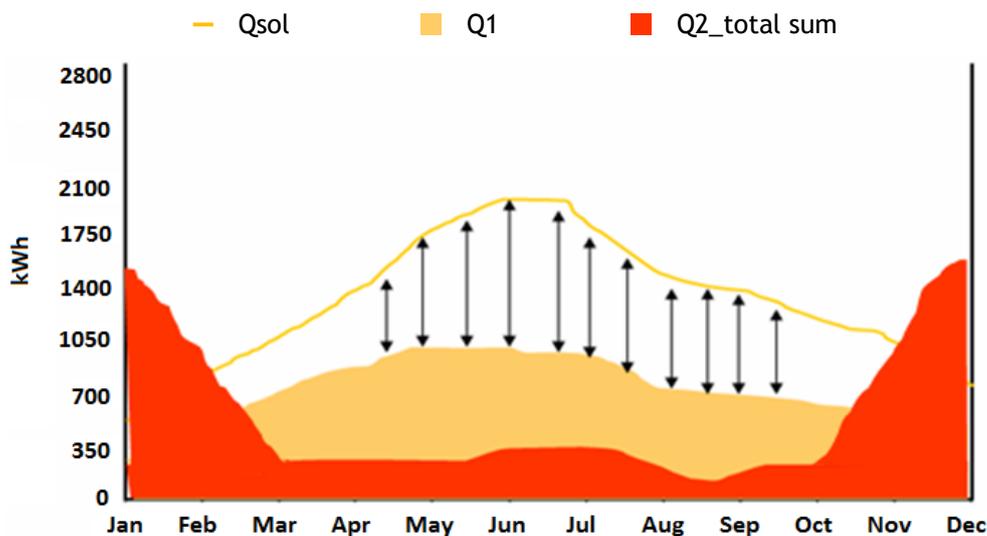
Figure 3-1 Qualitative representation of the energy gap between solar radiation, heat collected by solar collectors and heat contribution from the back up source.

The solar energy collected per square meter of the collector:

$$Qcoll\_yield = \frac{Q1}{Collector \ Aperture Area} \ \left[\frac{kWh}{m^2}\right]$$ Eq. 22

Solar cooling systems can be:

-   solar autonomous systems: the cooling load is covered only by solar energy. In these systems only solar collectors supply heat to the thermally driven chiller, and eventually to the heating and sanitary hot water systems; no back-up system is available to provide heat to the thermally driven chiller.

-   solar assisted systems: only a part of the cooling load is covered by solar energy. In these systems the solar collectors can represent an additional heat source assisting a conventional heat source for the delivery of the needed thermal energy to operate the thermally driven chiller; usually the same heat source is also used to provide heat to the

DHW and the heating system. For cooling applications also a back-up on the cold side is possible, using conventional vapor compression chillers.

As the majority of installations are solar assisted systems, it is useful to compare the solar use with the contribution from the heat back up source (Figure 3-1). In order to define suitable figures assessing the solar fraction, it is needed to distinguish three cases on the basis of the integration of the heat back up system.

Usually the heat acquired by the solar collectors is stored in buffer tanks before being used.Back-up systems can be connected to the same storage as the solar collectors (Figure 3-2) or supply the load directly, or allowing for both the types of connection (Figure 3-3).
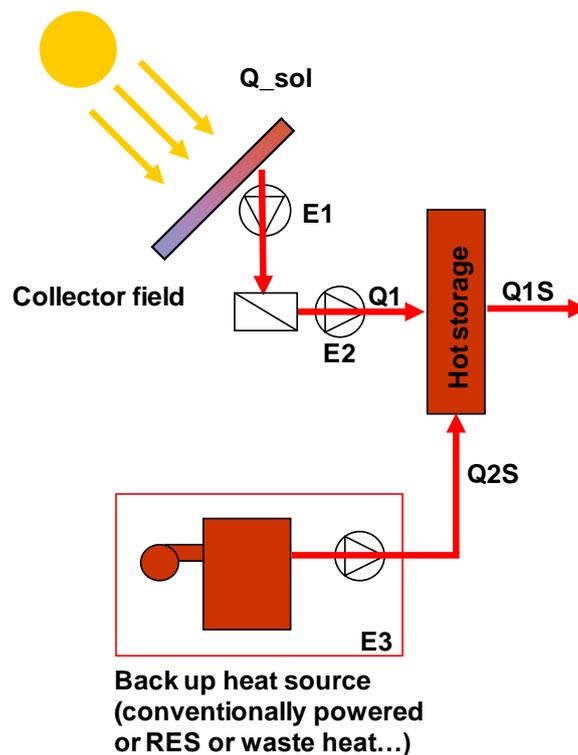
Figure 3-2 Connection between the heat back-up system and the solar collectors: shared hot storage

When the solar heat buffer is shared with the heat backup system, only Q2S is available as shown in Figure 3-2. Thereby::

$$Q2D\_fossil = 0 \ \left[kWh_{th}\right] \qquad \text{Eq. 23}$$

$$Q2D\_RES = 0 \ \left[kWh_{th}\right] \qquad \text{Eq. 24}$$

$$\begin{aligned}Q2\_totalsum &= Q2S\_fossil + Q2D\_fossil + Q2S\_RES + Q2D\_RES \\ &= Q2S\_fossil + Q2S\_RES = Q2S\end{aligned} \qquad \text{Eq. 25}$$

In these cases, as the output of the storage includes both the input from solar and back-up system, the _storage solar fraction_, defined as the ratio between the heat collected by the solar collectors and the heat produced by the backup system, is calculated according to:

$$SF_{hotstorage} = \frac{Q1}{Q1 + Q2S}$$
Eq. 26
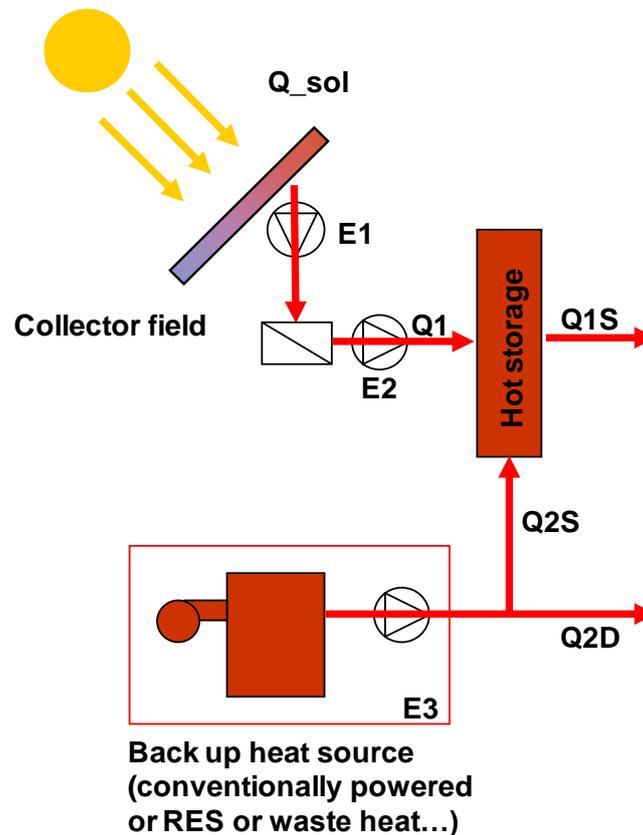
Figure 3-3 Connection between the heat back-up system and the solar collectors: direct use of the heat supplied by the back-up system

If the heat delivered by the back-up system is also directly used like in Figure 3-3, i.e. Q2D is not null, the output from the storage due to the solar collectors is given by:

$$Q1S * \left(\frac{Q1}{Q1 + Q2S} \right) \; \left[kWh_{th} \right]$$
Eq. 27

Hence the storage solar fraction amounts to:

$$SF_{hotstorage} = \frac{Q1s * \left(\dfrac{Q1}{Q1 + Q2S} \right)}{Q1 + Q2\_totalsum} \qquad \text{Eq. 28}$$

Note that in cases such as Figure 3-3 :

$$Q2\_totalsum = Q2S\_fossil + Q2D\_fossil + Q2S\_RES + Q2D\_RES$$
$$= Q2\_fossil + Q2\_RES = Q2S + Q2D \qquad \text{Eq. 29}$$

One special application of the Eq. 28 is when the heat from the back up source is only directly used, i.e.

$$Q2S\_fossil + Q2S\_RES = Q2S = 0 \quad \left[kWh_{th} \right] \qquad \text{Eq. 30}$$

Under Eq. 30, Eq. 28 becomes:

$$SF_{hotstorage} = \frac{Q1s}{Q1 + Q2D} \qquad \text{Eq. 31}$$

The losses through the buffer tank are calculated as the difference between the input and the output, if the latter is known.

$$Q\_loss\_stge = (Q1 + Q2S\_fossil + Q2S\_RES) - (Q1S) \quad \left[kWh_{th} \right] \qquad \text{Eq. 32}$$

In case, the output of the storage tanks is not known and the buffer tank is shared with the heat back-up system, the _efficiency of the storage_ can be estimated as follows:

$$Q\_loss\_stge = (Q1 + Q2S\_fossil + Q2S\_RES) - (Q3a + Q4 + Q3b + Q6) \quad \left[kWh_{th} \right] \quad \text{Eq. 33}$$

In the considered case, Q_loss_stge coincides with the overall losses in the system, which are given by:

$$Q\_loss\_sys = (Q1 + Q2\_totalsum) - (Q3a + Q4 + Q3b + Q6) \; \left[kWh_{th}\right] \quad \text{Eq. 34}$$

On the basis of the losses calculated in Eq. 33 and Eq. 34, the efficiency of the storage and the *efficiency of the system* are calculated according to:

$$\eta stge = \frac{(Q1 + Q2S\_fossil + Q2S\_RES) - Q\_loss\_stge}{(Q1 + Q2S\_fossil + Q2S\_RES)} \qquad \text{Eq. 35}$$

$$\eta sys = \frac{(Q1 + Q2\_totalsum) - Q\_loss\_sys}{(Q1 + Q2S\_fossil + Q2S\_RES)} \qquad \text{Eq. 36}$$

The *solar heat management efficiency* is defined as the rate between the "solar load contribution" and the solar availability (Eq. 41).

The *solar load contribution* refers to the amount of load energy which is fully covered by solar energy. I.e. the *solar space heating contribution* is given by:

$$Q3^{*} = SF_{hotstorage} * (Q3a + Q3b) \; \left[kWh_{th}\right] \qquad \text{Eq. 37}$$

The *solar DHW contribution* is:

$$Q4^{*} = SF_{hotstorage} * Q4 \; \left[kWh_{th}\right] \qquad \text{Eq. 38}$$

The *solar cooling contribution* is:

$$Q6^{*} = SF_{hotstorage} * Q6 \; \left[kWh_{th}\right] \qquad \text{Eq. 39}$$

On the basis of Eq. 37, Eq. 38 Eq. 39, the *total solar load contribution* is given by:

$$Qtot^{*} = Q3^{*} + Q4^{*} + Q6^{*} \; \left[kWh_{th}\right] \qquad \text{Eq. 40}$$

Refer to Figure 3-4 for a qualitative example of total solar load contribution.
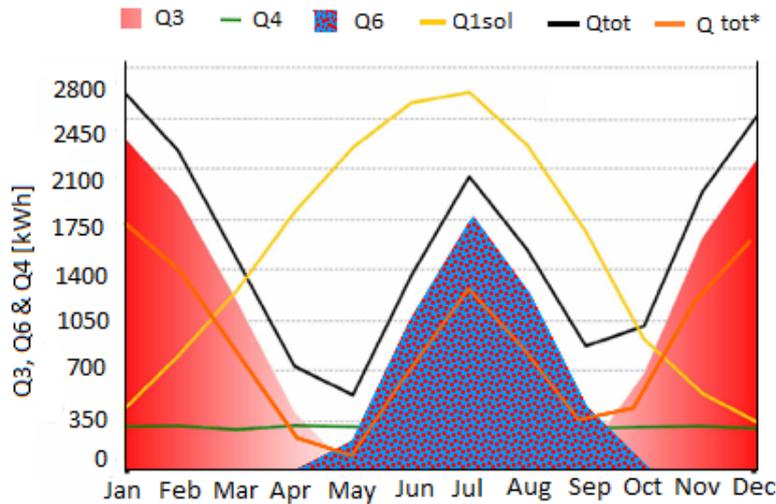
Figure 3-4 Qualitative representation of heat needs, solar radiation and solar load contribution

Hence the *solar heat management efficiency* is calculated according to:

$$\eta\text{heat}\_\text{solrad} = \frac{\text{Qtot}^*}{\text{Qsol}}$$

Eq. 41

This means that the *solar energy unexploited* is:

$$Q\_\text{solunex} = \text{Qsol} - \text{Qtot}^*$$

Eq. 42

3.3.3 General key energy performance figures in the 3rd monitoring level

In the third level all the flows listed in Table 1, Table 2 and Table 3 are required to carry out deep analysis.

First of all, the *fractional energy saving* (Fsav) is calculated according to the method which was elaborated in the IEA SHC Task 26 for solar combisystems and extended in the IEA SHC Task 32 for solar heating and cooling systems.

This method requires the PER of a conventional system to be calculated according to the formula already presented in the 1st level:

$$PERref = \frac{Q3a + Q10a + Q4 + |\Delta AHU|}{\dfrac{Q_{boiler,ref}}{\varepsilon_{fossil} * \eta_{boiler}} + \dfrac{Q_{coolingref}}{SPF_{ref} * \varepsilon_{elec}} + \dfrac{E_{el,ref}}{\varepsilon_{elec}}} \quad \left[\frac{kWh_{th}}{kWh_{pe}}\right] \qquad \text{Eq. 43}$$

In comparison with the 1st level, in the 3rd level the calculation of some items included in the PERref is enabled in different ways thanks to the presence of many sensors.

For instance, the calculation of Eel,ref can be more accurate thanks to the presence of the sensors E3. In fact, with reference to the Eq. 18 below repeated, the assumed 0.02 kWhel/kWhth can be substituted with a real measurements of the electrical consumption for operating the boiler and the pump between the boiler and the storage. Such real value is given by the ratio between E3 and the overall production of the boiler.

$$E_{el\_ref} = 0.02 * (Q3a + Q3b + Q4 + Q_{loss\_ref}) \quad \left[kWh_{elec}\right] \qquad \text{Eq. 44}$$

In case of DEC-AHU, it must be considered the additional pressure drops of DEC-components compared to a conventional AHU.

$$E_{ref}^{vent,el} = E_{SHC}^{DEC,el} \cdot \frac{\left(\Delta P_{supply}^{REF} \cdot \dot{V}_{supply} + \Delta P_{return}^{REF} \cdot \dot{V}_{return}\right)}{\left(\Delta P_{supply}^{DEC} \cdot \dot{V}_{supply} + \Delta P_{return}^{DEC} \cdot \dot{V}_{return}\right)} = E_{SHC}^{DEC,el} \cdot f\left(\Delta P^{REF}, \Delta P^{DEC}\right)\left[kWh_{elec}\right] \qquad \text{Eq. 45}$$

One more instance is the calculation of the so-labeled Qcooling,ref. It can be calculated in a as follows:

$$Q_{coolingref} = Qcooling, missed + Q7 \quad \left[kWh_{th}\right] \qquad \text{Eq. 46}$$

 "Qcooling,missed" refers to the cold production of the back-up system of the monitored system, i.e. Q8. This procedure enables to consider in the conventional system the real cold produced by the monitored installation, including losses in the cold tank. If the electricity consumption of the complete back-up system is not measured, the reference SPF (=2.8) is used to calculate the electricity consumption accordingly.

On the other hand, the electrical consumption due to Qcooling,missed can be directly calculated by summing up all the electrical consumptions of the back-up system (pumps and fan included), i.e. E10, E12, E13 and E15 if monitored directly. This enables to have the real electrical consumption of the back up system without assuming for it any SPF.

For DEC systems the calculation of Qcooling,missed is based on a different concept, that will be explained in the paragraph 3.3.4.

Once the PER,ref is calculated, the fractional saving which evaluates the consumption of the monitored system compared to a conventional system is given by:

$$\text{fsav.shc} = 1 - \frac{\dfrac{Q_{boiler}}{\varepsilon_{fossil} \cdot \eta_{boiler}} + \dfrac{Q_{RES}}{\varepsilon_{RES} \cdot \eta_{RES}} + \dfrac{E_{el}}{\varepsilon_{elec}} + \dfrac{Q_{coolingmissed}}{SPF \cdot \varepsilon_{elec}}}{\dfrac{Q_{boiler,ref}}{\varepsilon_{fossil} \cdot \eta_{boiler,ref}} + \dfrac{E_{el,ref}}{\varepsilon_{elec}} + \dfrac{Q_{coolingref}}{SPF_{ref} \cdot \varepsilon_{elec}}} \qquad \text{Eq. 47}$$

Which is equivalent to:

$$\text{fsav.shc} = 1 - \frac{PER_{ref}}{PER_{RES}} \qquad \text{Eq. 48}$$

If it is meant to exclude the effect of the RES, the fractional saving can be also calculated considering the PERfossil of the monitored installation.

$$\text{fsav.shc} = 1 - \frac{\dfrac{Q_{boiler}}{\varepsilon_{fossil} \cdot \eta_{boiler}} + \dfrac{Q_{RES}}{\varepsilon_{fossil} \cdot \eta_{RES}} + \dfrac{E_{el}}{\varepsilon_{elec}} + \dfrac{Q_{coolingmissed}}{SPF \cdot \varepsilon_{elec}}}{\dfrac{Q_{boiler,ref}}{\varepsilon_{fossil} \cdot \eta_{boiler,ref}} + \dfrac{E_{el,ref}}{\varepsilon_{elec}} + \dfrac{Q_{coolingref}}{SPF_{ref} \cdot \varepsilon_{elec}}} = 1 - \frac{PER_{ref}}{PER_{fossil}} \qquad \text{Eq. 49}$$

The _fractional solar consumption_ is defined as the ratio between the available and useful solar radiation (I [kW/m^2]) on the aperture area (A [m^2]) of the collector under investigation (Qsol = I x A [kWh]) and the reference heat necessary to match the space heating, DHW and cooling demand on a monthly basis and summed up for a year:

$$\text{FSC\_SHC} = \sum_{m=1}^{12} \left(\frac{Min(Q_{ref}, Q_{sol})}{Q_{ref}} \right)_m \qquad \text{Eq. 50}$$

Where Q_{ref} the monthly sum of the heat needed for different purposes. Please note that to calculate the heat needed by a thermally driven chiller is calculated with a $COP_{th,ref}$ of 0.6 as default.

$$Q_{ref} = \frac{Q_{SH} + Q_{DHW} + Q_{loss,ref}}{\eta_{boiler,ref}} + \frac{Q_{cooling,ref}}{COP_{th,ref}} \quad [kWh_{th}] \qquad \text{Eq. 51}$$

The 3rd level is also focusing on the water consumption for cold production. The water consumption of the wet cooling tower and the DEC system is evaluated in terms of:

- Cooling tower water consumption per kWh dissipated heat

$$ACM\_water = \frac{V1}{Q6a + Q7} \left[\frac{1}{kWh_{th}}\right] \qquad \text{Eq. 52}$$

- DEC humidifier water consumption per kWh COLD production

$$DEC\_water = \frac{V2}{\Delta H_{AHU\_cool}} \left[\frac{1}{kWh_{th}}\right] \qquad \text{Eq. 53}$$

On the other hand the electrical consumption related to the treatment of the water is calculated in terms of:

- Electricity consumption for water treatment per liter treated water in SHDC systems

$$El\_treat\_water = \frac{E20}{V1 + V2} \left[\frac{kWh_{el}}{1}\right] \qquad \text{Eq. 54}$$

- Electricity consumption for water treatment per kWh cold production in SHDC and DEC systems:

$$El\_treat\_water = \frac{E20}{\Delta H_{AHU\_cool} + Q7} \left[\frac{kWh_{el}}{kWh_{cold}}\right] \qquad \text{Eq. 55}$$

Several specific defined COP's evaluating the thermal and the electric performance of the subsystems sorption chiller and DEC unit are calculated.

The *thermal and electrical COP* of the chiller itself is evaluated according to:

$$COP\_el\_chill = \frac{Q7}{E11} \left[\frac{kWh_{th}}{kWh_{elec}} \right]$$
                                                                                Eq. 56

$$COP\_th\_chill = \frac{Q7}{Q6a}$$
                                                                                Eq. 57

Then the cold production is rated to the sum of all the electricity consumptions relevant with the heat driven chiller (HDC) (Eq. 58), i.e. pump hot-storage to cooling machine, pump cooling machine (ACM) to cooling tower, pump cooling machine (ACM) to cold-storage, absorption/adsorption cooling machine (ACM) and cooling tower:

$$COP\_el\_cold\_chill = \frac{Q7}{E6 + E7 + E8 + E11 + E14} \left[\frac{kWh_{th}}{kWh_{elec}} \right]$$
                                                                                Eq. 58

One more COP includes also the electricity to run the solar pumps according to:

$$COP\_el\_cold\_chill\_Sol = \frac{Q7}{E1 + E2 + E6 + E7 + E8 + E11 + E14} \left[\frac{kWh_{th}}{kWh_{elec}} \right]$$
                                                                                Eq. 59

For DEC systems following COP-values are interesting during cooling operation months:

$$COP\_el\_cold\_DEC = \frac{\Delta H_{AHU\_cool}}{(E16 + E17) \cdot (1 - f(\Delta P^{REF}; \Delta P^{DEC}) + E18 + E19} \left[\frac{kWh_{th}}{kWh_{elec}} \right]$$ Eq. 60

Where:

- ΔH_{AHU_cool} is the Cooling Energy from AHU, without auxiliary (conventional) contribution

- $(E16 + E17) \cdot (1 - f(\Delta(^{REF}; \Delta P^{DEC}))$ is the Electricity Consumption for fans (only the additional part for DEC relevant components, like: exhaust air humidifier, sorption wheel, exhaust air regeneration heat exchanger,…)

- $E18 + E19$ is the electricity consumption for motors of desiccant wheel and other additional DEC-components

To take in consideration also additional PE-consumption for solar components, further is defined:

$$\text{COP\_el\_cold\_DEC\_Sol} =$$

<div align="right">Eq. 61</div>

$$= \frac{\Delta H_{AHU\_cool}}{(E16 + E17) \cdot (1 - f(\Delta(^{REF}; \Delta P^{DEC}) + E18 + E19 + E1 + E2} \left[\frac{kWh_{th}}{kWh_{elec}} \right]$$

With:

- E1 is the electricity consumption of the pump in the primary loop of the collector field.
- E2 is the electricity consumption of the pump in the secondary loop of the collector field.

Finally the thermal COP of the DEC-AHU has to be calculated:

$$\text{COP\_th\_DEC} = \frac{\Delta H_{AHU\_DEC}}{Q6a}$$

<div align="right">Eq. 62</div>

Where Q6a is the regeneration heat for the sorption wheel coming from the solar tank.

3.3.4 Special energy performance figures for DEC systems in the 3rd monitoring level

In case the monitored system includes a DEC-AHU, the comparison to a conventional AHU requires an in-depth consideration of both the air-treatment processes.

Savings in terms of Primary Energy are obtained in a DEC-Process through:

- Avoiding the cooling of the air until below the dew-point for dehumidification
- Avoiding the necessary post-heating of the air to reach required inlet-temperature

On the other hand, inlet-temperature of supply air from the DEC-AHU can be higher than in a conventional AHU, it means the DEC-AHU delivers less cooling energy than conventional AHU

Further important advantage of a DEC AHU can be the possibility of humidity recovery during winter time. This can lead to quite high energy savings compared to conventional AHU, of course strong depending on the specific climatic zone.

In order to make easier and more comparable the results of single plants, an excel-tool has been created, where measured data can be directly inserted (in same time-step as measured), and the enthalpy differences reached in DEC-AHU and reference AHU will be calculated for a month.

For a better validation of possible scenarios, 4 cases are considered:

1. with post-heating of supply air in the Reference AHU after the cooling to the dew-point for dehumidification up to a FIXED supply temperature (to be chosen individually for every plant) (figure 3-3)
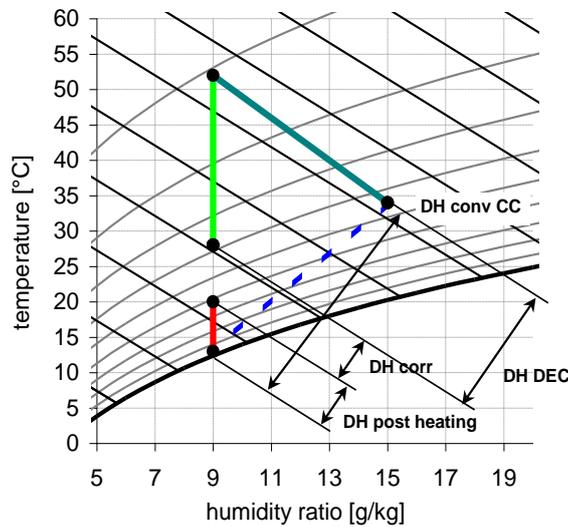
Figure 3-5 Air-treatment in DEC-AHU (green line) and in conventional AHU (blue-red line); e.g.: reference inlet temperature = 20°C

2. with post-cooling of supply air in the DEC AHU to the IDENTICAL supply temperature as FIXED for the reference AHU. (light green line down to the top end of the red line in Figure 3-5)

3. with post-heating of supply air in the Reference AHU after the cooling to the dew-point for dehumidification up to the IDENTICAL supply temperature as measured in the DEC-AHU
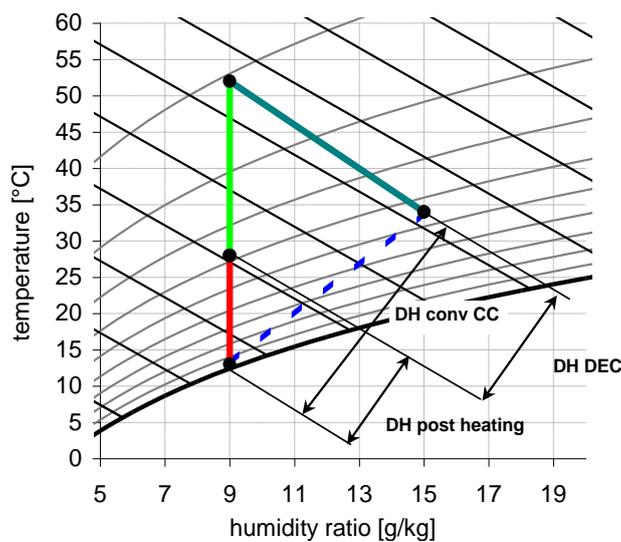
Figure 3-6 Air-treatment in DEC-AHU (green line) and in conventional AHU (blue-red line); post heating up to the identical supply temperature as measured in the DEC-AHU

27

4. without post-heating. It is assumed that in the conventional AHU the heat demand for post heating is for free because any kind of waste heat is used (e.g. from CHP plant or using an additional heat recovery wheel or using the waste heat of the vapor compression chiller).

Necessary Input-data for every time-step are shown in Table 7.

Table 7 Necessary measurements for the calculation of the enthalpy differences (DH)

Description of data input	Label
Heating mode	Heating ON/OFF
Cooling mode	Cooling ON/OFF
Temperature of inlet air in the AHU (external air)	T inlet
Relative humidity of inlet air in the AHU (external air)	rH inlet
Temperature of supply air from the AHU	T supply
relative humidity of supply air from the AHU	rH supply
Supply air flow,	Supply air flow

Besides the inputs shown in Table 7, one parameter has to be set: the supply temperature of reference AHU if it is considered as fixed.

The values output by this spreadsheet are listed inTable 8.

Table 8: Output of the spreadsheet for the calculation of enthalpy differences (DH)

Description of data output	Label
Difference between cooling energy delivered from DEC AHU and from conventional AHU with fixed supply temperature, m*DH AHU corr	ΔH_{corr}
Difference of enthalpy (cooling energy) achieved from cooling coil in conventional AHU, m*DH AHU CC	ΔH_{conv_CC}
Difference of enthalpy (heating energy) achieved from heating coil in conventional AHU, m*DH postheat	$\Delta H_{postheat}$
Difference of enthalpy between inlet (external) air and outlet (supply) air of conventional AHU, m*DH AHU conv	ΔH_{conv_AHU}

m*DH AHU DEC cooling	ΔH_{AHU_cool}
m*DH AHU DEC heating	ΔH_{AHU_heat}

These outputs are the special input on the monitoring procedure for DEC systems.

On their basis the *Primary Energy Ratio for conventional AHU (PER REF)* can be calculated as follows:

$$PER_{ref\_DEC} = \cfrac{\Delta H_{conv\_AHU}}{\cfrac{\Delta H_{conv\_CC}}{SPF \cdot \varepsilon_{el}} + \cfrac{\Delta H_{postheat}}{\eta_{boiler} \cdot \varepsilon_{fossil}} + \cfrac{E_{elec,conv\_AHU}}{\varepsilon_{elec}}} \left[\frac{kWh_{th}}{kWh_{elec}}\right] \qquad \text{Eq. 63}$$

The Primary Energy Saving factor f_{save} is calculated as for all Solar Heating and Cooling systems with PER_{RES} or PER_{fossil}:

$$f\,sav,shc = 1 - \frac{PER_{ref}}{PER_{RES/fossil}} \qquad \text{Eq. 64}$$

3.4   Summary of the output of the procedure

The monitoring procedure supports the evaluation of the performance of the monitored system and its comparison with a conventional system. To this purposes, three level of data elaboration have been defined depending on the kind of monitored energy flows. The major output of each level is summarized in the following tables.

Table 9 Summary of the output of the 1st monitoring level

First monitoring level		Description
SHDC	**DEC**	
COPel, tot		Ratio between load and the electrical consumption excluding distribution
COPel, overall		Ratio between load and the electrical consumption including distribution
PER_res	PER_res with DEC postcooling, Tsupply fixed to: xx°C	Primary energy ratio for the monitored system accounting for RES contribution
PER_fossil		Primary energy ratio for the monitored system accounting RES contribution as fossil
PER_ref	PER_ref with	Primary energy ratio for the conventional

30	ref_AHU postheating, Tsupply fixed to: xx°C	system set as reference for comparisons
	PER_ref_AHU postheating, Tsupply = measured in DEC	
	PER_ref without ref_AHU postheating	

Table 10 Summary of the output of the 2nd monitoring level

Second monitoring level	**Description**
ηcoll,util	Collectors efficiency
ηstge	Storage efficiency
ηsys	System efficiency (taking into account the heat losses in all the system)
ηheat_solrad	Solar heat management efficiency
Q_solunex	Solar energy unexploited
Q_tot, heat	Total heat load

Table 11 Summary of the output of the 3rd monitoring level

Third monitoring level		Description
SHDC	**DEC**	
Fsav,fossil or Fsav,res		Fractional primary energy saving of the monitored system accounting for RES or fossil as it is existing compared with a conventional system
		For DEC systems 5 different versions are calculated.
Fsav,fossil		Fractional primary energy saving of the monitored system accounting RES as fossil compared with a conventional system; (artificial number for comparison reasons)
		For DEC systems 5 different versions are calculated as described before.
FSC_SHC		Fractional solar consumption of the available solar energy compared to the overall heat load
ACM_water, y	DEC_water, y	Water consumption
Water_treat, y		Electricity consumption for water treatment
COP_el_chill		Electrical COP of the chiller
COP_el_coldSol,y	COP_el_DEC-Sol,y	Electrical COP of the heat driven cooling system
COP_el_cold,y	COP_el_DEC,y	Electrical COP of the heat driven cooling system plus solar collectors
COP_th_chill,y	COP_th_DEC,y	Thermal COP of the heat driven cooling system

For a visual representation of the results the following graphs are used (Figure 3-7 and Figure 3-8):
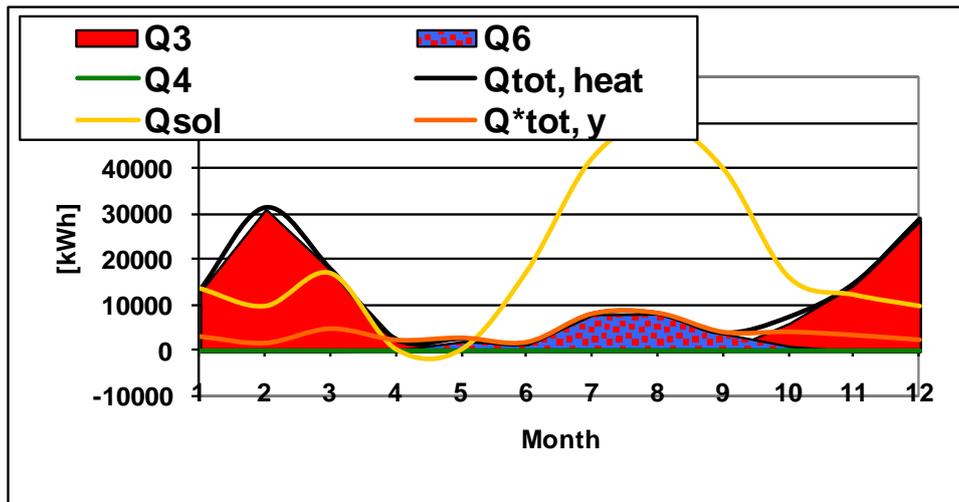
Figure 3-7 Example for the solar energy source management in a solar assisted cooling system using an absorption chiller

postheat fix: post heating up to a fixed supply temperature (to be chosen individually for every plant)	**postheat meas**: post heating up to the identical supply temperature as measured in the DEC-AHU
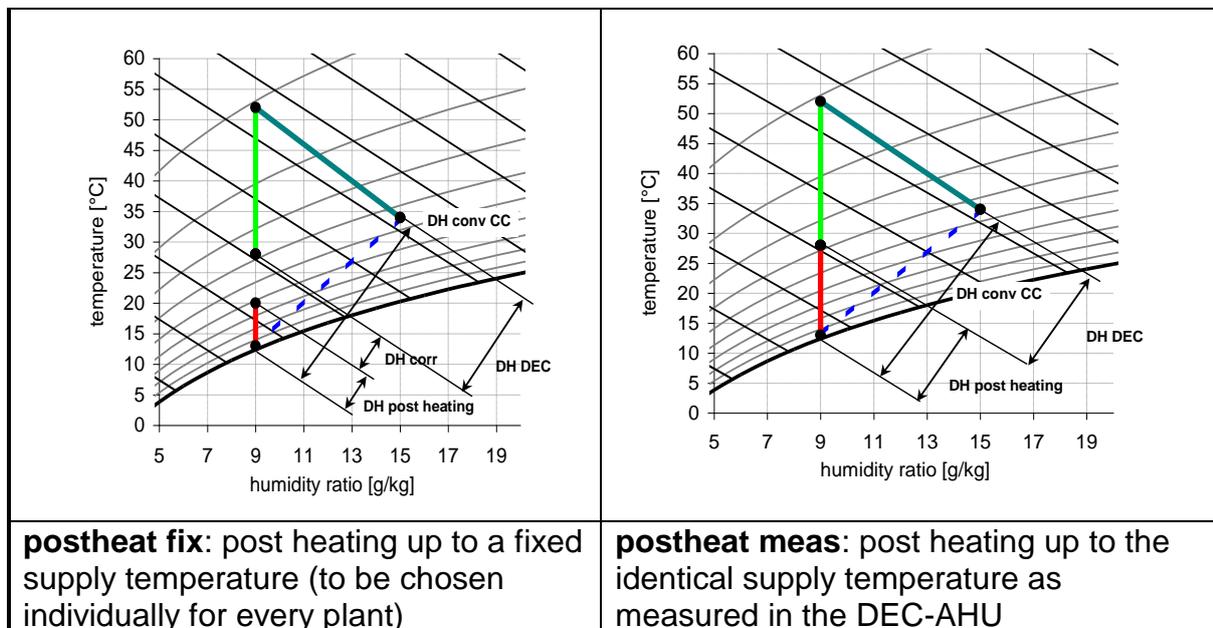
Figure 3-8 Representation of an example for cooling and de-humidification process with a solar assisted cooling system using a DEC unit DEC

4. How to fill in the monitoring procedure

The excel tool for the evaluation of monitored data is composed of six sheets.

The first sheet, named "Introduction", shortly presents the tool and its authors.

Users are then required to enter data:

- in the second sheet, named "Data", entering pieces of information on the installed SHC and monitoring system;

- in the fifth sheet, named "3rdLvl", entering the required monitoring data;

- In the sixth sheet, named "Summary" entering main key data of the installed SHC and inserting the energy flow diagram as shown in the sheet "Introduction" (see also Figure 2-1) adapted to the installed SHC.

Yellow cells require data to be entered whereas.

The sheets automatically calculate all the performance figures described in this report. Orange cells output results. All the results are summarized in the sixth sheet, named "Summary" so that the overall system and its performance are shown all at once.

5. Conclusions

This technical report describes a tool which has been developed within IEA SHC Task 38 in order to evaluate, with a common procedure, the performance of monitored solar heating and cooling installations. The tool also enables the relative evaluation of a monitored system with respect to a conventional system. Nevertheless, such comparison is based on many assumptions of the conventional system which can lead to misleading results.

The development of a standard procedure was expected to enable the comparison between the results of several systems as well. Actually, at the current state of the art, custom made systems differ so much that a comparison between many of the energy performance figures defined in the tool sometimes is not fair. Further improvement of this tool is planned within IEA SHC Task 48, starting in autumn 2011.

The tool is usually referred to as a "monitoring procedure". In fact, even if it is not explicitly giving any guidelines for carrying out monitoring campaigns for solar heating and cooling systems, it suggests the necessary measurements for the evaluation of selected energy performance figures. Depending on the kind and the number of measurements needed, three level of detail of monitoring have then been defined, which correspond to different scopes, level of efforts and thus costs of monitoring.

The procedure has been applied to more than twenty five installations, including large and small systems. Results are presented in the following documents of Task 38:

- Jähnig D. and Thür A., "Monitoring Results of fourteen small scale systems - A technical report of subtask A (Pre-engineered systems for residential and small commercial applications)", December 2010;

- Sparber W. and Napolitano A., "Monitored installations and results – A technical report of subtask B (large scale and custom made applications)", December 2010;

- Sparber, W., & Napolitano, A. (2009). State of the art on existing solar heating and cooling systems - A technical report of Task 38 - Subtask B1. http://www.iea-shc.org/task38/work.htm.

The complete package of this IEA SHC Task 38 Monitoring Procedure can be downloaded from IEA SHC Task 38 Webpage:

http://www.iea-shc.org/publications/task.aspx?Task=38

and it consists of 4 files:

1. This joint monitoring procedure report of Subtask B (D-B3b) and Subtask A (D-A3a):

    Task38-SubtaskA+B_report_D-B3b_D-A3a_monitoring procedure V6-0.doc

2. XLS-file as the master file for the monitoring procedure:

    110801_T38_MonProc_V6-0.xls

3. PPT-file with reference energy flow schemes:

    110801_T38_MonProc_V6-0_Schemes.ppt

4. XLS-file for extra calculations for DEC systems:

    110801_T38_MonProc_V6-0_DH-calc.xls

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