SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Task 48

Deliverable M-C4.3 – Final report Measurement and Verification Procedures

Date: 24.05.2013

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IEA Solar Heating and Cooling Programme

The *International Energy Agency* (IEA) is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD) based in Paris. Established in 1974 after the first "oil shock," the IEA is committed to carrying out a comprehensive program of energy cooperation among its members and the Commission of the European Communities.

The IEA provides a legal framework, through IEA Implementing Agreements such as the *Solar Heating and Cooling Agreement*, for international collaboration in energy technology research and development (R&D) and deployment. This IEA experience has proved that such collaboration contributes significantly to faster technological progress, while reducing costs; to eliminating technological risks and duplication of efforts; and to creating numerous other benefits, such as swifter expansion of the knowledge base and easier harmonization of standards.

The *Solar Heating and Cooling Programme* was one of the first IEA Implementing Agreements to be established. Since 1977, its members have been collaborating to advance active solar and passive solar and their application in buildings and other areas, such as agriculture and industry. Current members are:

Australia	Finland	Singapore
Austria	France	South Africa
Belgium	Italy	Spain
Canada	Mexico	Sweden
Denmark	Netherlands	Switzerland
European Commission	Norway	United States
Germany	Portugal	

A total of 49 Tasks have been initiated, 35 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition to the Task work, a number of special activities—Memorandum of Understanding with solar thermal trade organizations, statistics collection and analysis, conferences and workshops—have been undertaken.

Visit the Solar Heating and Cooling Programme website - **www.iea-shc.org** - to find more publications and to learn about the SHC Programme.

Current Tasks & Working Group:

Task 36	*Solar Resource Knowledge Management*
Task 39	*Polymeric Materials for Solar Thermal Applications*
Task 40	*Towards Net Zero Energy Solar Buildings*
Task 41	*Solar Energy and Architecture*
Task 42	*Compact Thermal Energy Storage*
Task 43	*Solar Rating and Certification Procedures*
Task 44	*Solar and Heat Pump Systems*
Task 45	*Large Systems: Solar Heating/Cooling Systems, Seasonal Storages, Heat Pumps*
Task 46	*Solar Resource Assessment and Forecasting*
Task 47	*Renovation of Non-Residential Buildings Towards Sustainable Standards*
Task 48	*Quality Assurance and Support Measures for Solar Cooling*
Task 49	*Solar Process Heat for Production and Advanced Applications*

Completed Tasks:

Task 1	*Investigation of the Performance of Solar Heating and Cooling Systems*
Task 2	*Coordination of Solar Heating and Cooling R&D*
Task 3	*Performance Testing of Solar Collectors*
Task 4	*Development of an Insolation Handbook and Instrument Package*
Task 5	*Use of Existing Meteorological Information for Solar Energy Application*
Task 6	*Performance of Solar Systems Using Evacuated Collectors*
Task 7	*Central Solar Heating Plants with Seasonal Storage*
Task 8	*Passive and Hybrid Solar Low Energy Buildings*
Task 9	*Solar Radiation and Pyranometry Studies*
Task 10	*Solar Materials R&D*
Task 11	*Passive and Hybrid Solar Commercial Buildings*
Task 12	*Building Energy Analysis and Design Tools for Solar Applications*
Task 13	*Advanced Solar Low Energy Buildings*
Task 14	*Advanced Active Solar Energy Systems*
Task 16	*Photovoltaics in Buildings*
Task 17	*Measuring and Modeling Spectral Radiation*
Task 18	*Advanced Glazing and Associated Materials for Solar and Building Applications*
Task 19	*Solar Air Systems*
Task 20	*Solar Energy in Building Renovation*
Task 21	*Daylight in Buildings*
Task 22	*Building Energy Analysis Tools*
Task 23	*Optimization of Solar Energy Use in Large Buildings*
Task 24	*Solar Procurement*
Task 25	*Solar Assisted Air Conditioning of Buildings*
Task 26	*Solar Combisystems*
Task 27	*Performance of Solar Facade Components*
Task 28	*Solar Sustainable Housing*
Task 29	*Solar Crop Drying*
Task 31	*Daylighting Buildings in the 21st Century*
Task 32	*Advanced Storage Concepts for Solar and Low Energy Buildings*
Task 33	*Solar Heat for Industrial Processes*
Task 34	*Testing and Validation of Building Energy Simulation Tools*
Task 35	*PV/Thermal Solar Systems*
Task 37	*Advanced Housing Renovation with Solar & Conservation*
Task 38	*Solar Thermal Cooling and Air Conditioning*

Completed Working Groups:

CSHPSS; ISOLDE; Materials in Solar Thermal Collectors; Evaluation of Task 13 Houses; Daylight Research

Contents

1. Executive Summary

1.1. General objectives

The global subtask C work aims to create a set of guidelines and tools that could support the introduction of policy measures that could help develop the solar cooling market. These tools will use the results of Subtasks A and B and will above all explore the possibilities to identify, rate and verify the quality and performance of solar cooling solutions.

The specific work of work-package C4 is described in the Task 48 plan by:

"Building upon the work of the previous Task 38, minimum metering requirements, processes and analysis procedures will be defined for assessment of solar performance, in a manner suitable for (i) performance based qualification and (ii) prescribed deemed energy saving certification."

In this framework, the principal goal of work package C4 is to define the procedure for in-situ verification of the solar cooling plant performances.

While Measurement & Verification (M&V) procedures (e.g. IPMVP, ASHRAE and FEMP) exist for general energy conservation measures, it is desirable to have a more specific and targeted guide for solar cooling in order to simplify procedures, improve confidence in results and to assist M&V implementation with more detailed guidance.

The resulting in-situ and ex-situ measurement procedures will be written up as a document suitable for submission as a draft standard. The final deliverable will be a monitoring procedure and a draft standard integrating the following aspects:

- Presentation of a generic scheme for solar cooling installations;
- Definition of one (or two maximum) performance indicators, with associated calculation method applied to the generic scheme;
- Prescription of the sensors required (position, technologies, …) in order to obtain the needed information for calculating the performance indicator(s);
- Definition of the analysis method for reporting the performance and quality of the installation.

1.2. Existing work and future work planned

Overall, this work will be based on:

- Task 38 results concerning Monitoring procedures for solar heating and cooling systems;
- The other T48 subtasks results:
    - C2: Methodology for performance assessment, rating and benchmarking;
    - C3: Selection and standardization of best practice solutions;
    - B1: System/Subsystem characterization & field performance assessment;
    - B7: Quantitative quality and cost competitiveness criteria for systems;
- The existing and on-going activities of the WP contributors;
- The existing standards or procedures for monitoring.

1.3. Specific objectives

1.3.1. Generic scheme for solar cooling installations

In collaboration with the other work packages, especially C3 and B1, a generic scheme will be defined for solar cooling and heating systems. This scheme will be used to identify the position of required sensors.

This work will be based on the existing and on-going works on this subject:

- The existing IEA Tasks 25 and 38 representation scheme;
- The on-going projects of the WP C4 contributors;
- The existing procedures for solar cooling systems (EMERGENCE program for example);
- The other WP activities in Task 48 (especially B1 and C3).

1.3.2. Performance indicator with the calculation method

Task 38 has defined a lot of performance indicators. Other indicators have been defined in the French MéGaPICS project (some are similar). In addition, the work packages C2, B1 and B7 may define (or use) other performance indicators.

In this work package C4, it will be necessary to select only one (or two) indicator(s) in collaboration with other work packages on this subject and to specify the calculation method according to the generic scheme.

This part of the work will be done in strong collaboration with the B1, B7 and C2 activities.

1.3.3. Prescription for the sensor positions and technologies

In the French MéGaPICS project and in the EMERGENCE program, the adapted positions and technologies for solar cooling measurements are defined. These documents can be used as a basis for Task 48. Best practice in solar thermal system measurement will also be taken into account.

According to the generic scheme and the selected performance indicator(s), the number and the position of the sensors will be defined. This part will include the technologies chosen for each kind of measurement. An economic overview of the monitoring system will be done.

1.3.4. Analysis method of the installation level of performance

Task 38 has defined 3 level of analysis with associated performance indicators. Another analysis methodology is proposed in the French MéGaPICS project. Work packages C2, B1 and B7 will also define some level of quality.

According to the selected performance indicator(s) and the other work packages, an analysis method adapted to the generic scheme will be included in the document.

1.3.5. Draft standard for measurement and verification procedure

The final objective of work package C4 is to define a draft standard for the measurement and verification procedure.

Based on the precedent work and on the existing standards on the measurement and verification procedures, the document will be adapted as a draft standard.

1.4. Planning

The work package C4 planning proposal is presented in the next table. This proposal integrates Subtask C planning concerning work package C4 (with deliverable number):

N°	DESCRIPTION	COMPLETED BY MONTH
	Presentation of the C4 work plan proposition	6 (Milano meeting)
M-C4.1	Template of measurement and verification procedures	12
M-C4.2	Draft report of measurement and verification procedures	18
M-C4.3	Final report of measurement and verification procedures	30

1.5. Involved participants entities

The involved participants are the followings:

COUNTRY	ENTITIES	NAMES	
Australia	CSIRO	Mark PERISTY	Contributor
Austria	SOLID	Moritz SCHUBERT	Contributor
France	CEA INES	François BOUDÉHENN	WP leader
Germany	INDUSTRIAL SOLAR	Christian ZAHLER	Contributor

2. Introduction

The use of renewable energy sources in buildings is a key issue when it comes to reducing the consumption of primary energy. In southern Europe, most buildings, particularly in the tertiary industry, need active air-conditioning to provide satisfactory levels of comfort during the summer season. The use of solar energy for this purpose can be a way of reducing the consumption of fossil energy. Solar air-conditioning technologies exist and have already proved their efficiency in demonstration systems.

In both refurbishments and new build constructions, there is considerable potential for reducing air-conditioning and heating energy consumption by adopting passive measures. In certain buildings however, it is impossible to eliminate the need for heating and cooling completely. For these specific applications, the use of heating and cooling systems using decentralized renewable energy sources takes on a whole new meaning, because it can lead to a reduction in the consumption of primary fossil fuels or nuclear energy whilst continuing to provide comfort requirements.

This document is intended to be used for assisting in the determination and quantification of savings obtained from the installation of solar cooling systems. This could be used to provide measurement and verification in a range of performance based policy interventions. It could also be used by Energy Service Companies (ESCOs) and other energy efficiency contractors to determine payment for avoided consumption of primary fuel. The guide provides information on the measures to be taken, equipment to be used, checks and general good practice.

Measurement and verification (M&V) aims to measure and verify energy savings from specific changes to infrastructure. M&V has a focused purpose, it is not simply traditional energy consumption monitoring. M&V is centred on quantifying the energy savings as a result of implemented energy conservation measures (ECM) within determined confidence levels. The determination of energy savings is central to the financial evaluation, quality and confidence between parties and their contractual arrangements. M&V must be disciplined, rigorous, credible and transparent.

A common and consistent approach for measurement and verification enables more reliable assessments of performance efficiency, enabling the reduction of savings risks and improving energy conservation investments.

Good M&V practice will:

- enhance confidence levels of energy saving mechanisms;
- improve project engineering for new and retrofit projects;
- monitor system performances;
- increase the understanding and management of project risks;
- improve efficiency;
- reduce maintenance problems;
- encourage further investment.

Accurate M&V determination allows greater persistence of savings and reduced variability of savings. M&V should be well defined and use generally accepted methods, this leads to greater and more reliable savings as well as improved investment and profitability.

Good monitoring methods also reduce maintenance problems. The data recording instruments used must be of sufficient quality to meet objectives for the qualification of system performance levels, whilst keeping the costs at an acceptable level for the contractor. The method should not only quantify the overall performance levels of the system being monitored but also detect any drop in performance caused by problems occurring within that system.

Industry best practices have already been developed for general M&V [1 to 4], valid for most energy efficiency conservation measures. These include procedures and protocols for project planning and engineering activities. The information within this document builds on the general M&V guides below and adapts them for the specific case of solar cooling.

The aim of this document is to define:

- the dimensions and indicators to be used to qualify system performance and the method to be adopted for analysing the values obtained;
- how to select and install the equipment needed to take measurements;
- the type and format of data to be monitored and saved;
- basic notions for analysing air-conditioning/solar heating system operation and how to detect malfunctions.

2.1. General M&V Methodology and Concepts

It is not possible to measure energy savings directly, as energy saving is the absence of energy use. Savings are instead determined by calculating the difference in consumption between what *would have* been if the ECM was not installed and *what actually is* with the ECM in place (see section 2.1.5). Calculations are therefore the difference between real measurements and estimated values. These energy savings can also be reconciled against the expected savings.

Planning and preparation is of key concern in any M&V procedure. An M&V plan should be project specific. Objectives should be specified as well as all facility characteristics, measurement boundaries, analysis techniques, computational tools, target accuracies, report formats and budget details. The plan should be practical, cost effective, consistent, repeatable and appropriate. Information on M&V planning can be found in the FEMP M&V Guidelines Version 3.0 [4].

It is essential that the:

- agreed plan is followed (this may be part of the contractual arrangements);
- accuracy and confidence is reported;
- documentation is created for all relevant M&V activities for independent verification;
- M&V options are selected and specified.

2.1.1. Baseline Energy

Estimated values of energy consumption that would have occurred if the ECM had not been installed are referred to as the ‘Baseline energy’. However, a simple comparison of the pre and post retro-fit energy use does not represent the energy savings as it does not account for the impact of variable factors such as weather and occupancy. These influencing factors must be removed from the energy savings determination.

Baseline energy values are often determined by adjusting the pre-retrofit measurements using computational methodologies (Figure 1), however, if the installation is entirely new this is not always possible. The estimation of the Baseline Energy is a central challenge to M&V, where uncertainty must be minimised in order improve confidence in the calculated energy savings. M&V results should also clearly indicate the tolerances of the measurements and savings.

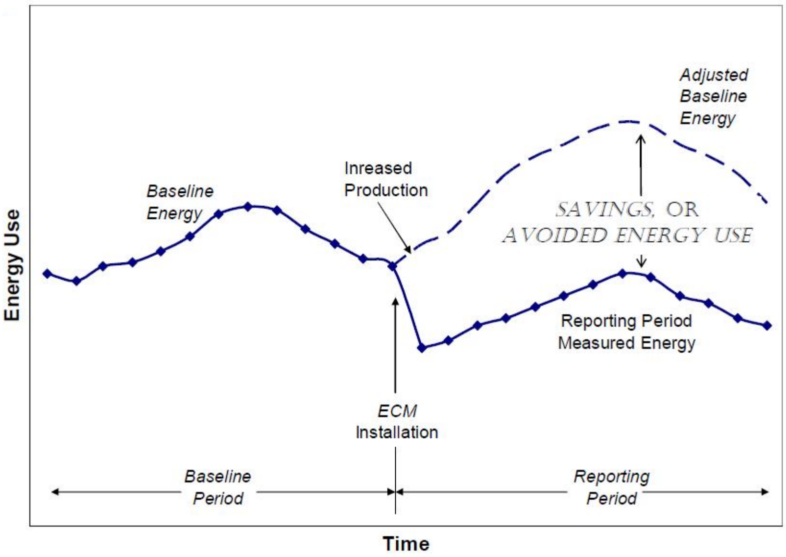


FIGURE 1 - BASELINE AND MEASURED ENERGY [1]

The period of ECM installation and measurement is often referred to as the *performance period*, this can range from 2 weeks to 12 months and is dependent on the type of ECM in place. For a solar cooling system, results will be seasonally dependant, therefore a 12 month measurement and verification period would be most appropriate.

Both performance and usage factors influence energy savings and are required to be known for accurate determination of the savings. Performance relates to the amount of energy required to perform a task, where usage is how much of the task is required. Figure 2 illustrates the effective reductions of total energy from improved efficiency and decreased usage.

The baseline energy is typically determined by applying methods associated with various M&V approaches. The International Performance Measurement and Verification Protocol (IPMVP) [1, 2] lists four M&V options:

- Option A: Retrofit/ECM isolation with key parameter measurement;
- Option B: Retrofit/ECM isolation with all parameter measurement;
- Option C: Whole building;
- Option D: Calibrated simulation.

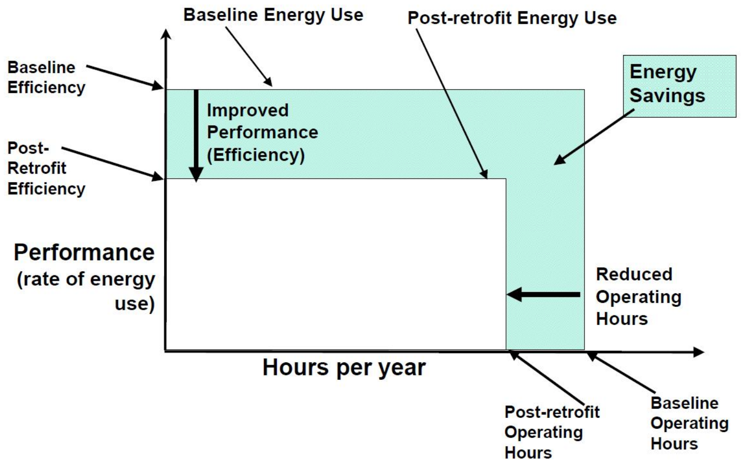


FIGURE 2 - ENERGY SAVINGS FROM PERFORMANCE AND USAGE [4]

M&V options provide a generic guide as to a method that can be used to determine the energy savings of an ECM. In the case of new builds or extensions, baseline monitoring prior to building is not possible. For some retrofits, it may not be economical or practical for installers to monitor energy consumption for a period of time prior to the installation. The baseline is therefore entirely hypothetical and must be calculated or hypothesized in some manner.

Development of the baseline is largely left to user discretion. For isolated ECMs the baseline can be equipment specific. Baselines should be consistent and be able to be readily adjusted to allow for broader performance comparisons. Energy codes and standards can provide defined and consistent means of characterisation. Standard practice or the documented performance of similar buildings may be appropriate in some circumstances. The development of the baseline is often simplified if energy analysis tools have been used as part of the building design process. Analytical tools for single ECMs are often part of the design process and are usually relatively simple in operation.

This document will focus on Option B due to the likelihood of solar air-conditioning systems being incorporated in either new or retrofit builds and the possibility that baseline monitoring over sufficient periods of time is not feasible prior to retro-fit installations. Option B focuses on the isolation of the ECM in question. Further information on the Options A, C and D can be found within IPMVP, ASHRASE Guideline 14 and FEMP [1 to 3].

2.1.2. M&V Options – The Retrofit/ECM Isolation with all parameter measurement

Option B is ideally suited where a whole building simulation is not justified and the only system that requires performance monitoring is the ECM of concern. It is also appropriate when contractual arrangements relate only to the performance of a specific system or where the projected baseline energy use is easily determined and any interactive effects are insignificant or easily accounted for. The retrofit/ECM isolation with all parameter measurement option is similar to option A, however in this case all energy quantities are measured or monitored without the use of any stipulations. The method is intended where performance factors such as power, capacity and operational dynamics relating to use are to be measured.

For an ECM isolation the savings are determined by measurement of the energy use from the specific parameters of the system. The baseline is determined by calculating the hypothetical performance of the system or equipment under the same operating conditions as the post-construction period. The characteristics of the baseline system can be specified from standards or guidelines. Typically they are developed by correlating the metered energy use to key independent variables.

A measurement boundary must be established when determining the extent of this M&V approach. Generally the boundary can be the whole facility or a single ECM. The drawing of a boundary will depend on the project. For reporting of only the equipment affected by the program then the measurement boundary will surround only that equipment. Influencing energy effects beyond the boundary are interactive effects. These should be estimated in order to determine savings. In the solar cooling special case, as described in this guide, the system boundary is illustrated by two predefined system flow schemes as described in Section 3.

Applying the retrofit/ECM isolation requires the following approach:

1. Choose independent variables for measurement and develop model for performance indicators;
2. Determine and document baseline conditions;
3. Determine duration and frequency for monitoring for baseline and performance period;
4. If applicable project baseline conditions to performance period conditions;
5. Determine savings.

More information on this approach, the classification of loads on a system, uncertainty analysis and retrofit isolation approach techniques can be found in ASHRAE Guideline 14 [3].

2.1.3. Calculations

The major challenge of M&V is to separate the energy changes that occurred due to the ECM to those that would have occurred independently of the ECM. All energy changes that are not due to the ECM must be accounted for.

Energy savings for new constructions or for a retrofit without pre-fit monitoring are determined by comparing the projected baseline energy use to the energy use post-construction. The post-construction energy use is the energy use of the building as constructed, this can be determined by monitoring of the ECM in question.

Energy Savings = Projected Baseline Energy Use – Post-Construction Energy Use

The Projected Baseline Energy Use must be generated by taking into account the same operating conditions as during the M&V period.

If in the circumstances the baseline has been monitored prior to the installation for the ECM, the estimated savings are generally calculated as follows:

Energy Savings = Baseline Energy Use – Post ECM Energy Use ± Adjustments

Adjustments account for the variations between the baseline period and the performance period. These are influencing conditions that are not due to the ECM such as differences in the weather, occupancy and operating conditions. Adjustments function to bring the baseline energy and the ECM energy to the same set of conditions.

Adjustments can fit within two categories:

- Routine adjustments: Factors that change routinely during the reporting period such as weather, operating hours and occupancy. These are factors that can be anticipated and readily documented. Routine adjustments use normalised energy use as a function of independent parameters. The assumption is made that the relationship between the normalised energy use and the performance period is a predictable relationship.

- Non-routine adjustments: Factors that are not usually expected to change such as design and facility size. Non-routine adjustments follow no expected pattern. Methods for accounting for any of these changes should be incorporated in the plan if they are a possibility.

3. System Architectures

Throughout this document, two system architectures will be taken into consideration in order to provide a system boundary for the solar cooling M&V application. These two configurations make allowance for a number of different system configurations. These systems are:

- **Large customized systems -** dimensioned and made to measure for a specific application;
- **Small productized systems** - mass produced systems generally more compact and for low power systems only.

Diagrams for each of these systems are shown in Figures 3 and 4. Though not exhaustive, they take into account a large number of potential system configurations, and are capable of producing good performance levels.

These diagrams are intended to be used to identify the energy flows to be measured, and distinguish between:

- energy production equipment: solar collector area, hot and cold back-ups;
- energy transfer and transformation equipment: hot and cold storage, auxiliaries, exchangers, pipes, etc.
- heat rejection systems: cold back-up condenser, cooling tower, vertical or horizontal geothermal probes;
- uses: production of domestic hot water, heating and air-conditioning or cooling.

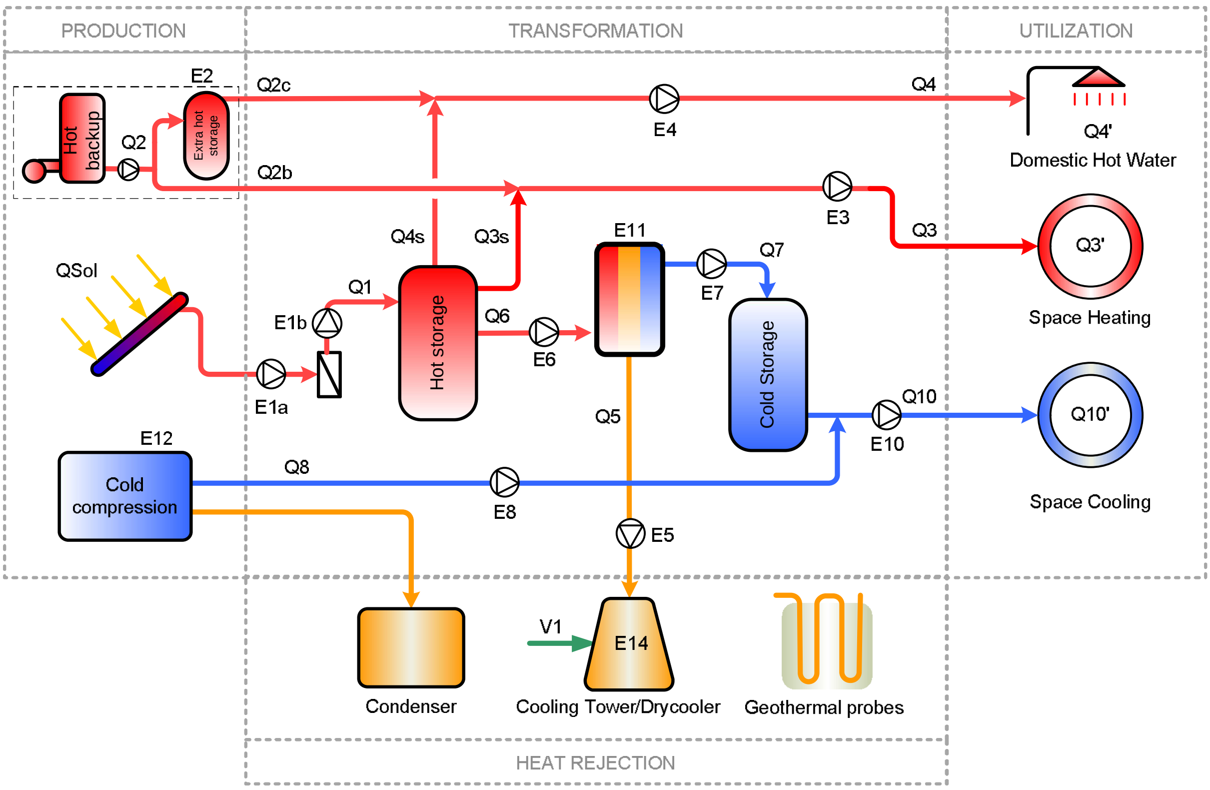


FIGURE 3 – SCHEMATIC DIAGRAM OF A LARGE CUSTOMIZED SOLAR AIR-CONDITIONING/HEATING/DOMESTIC HOT WATER SYSTEM

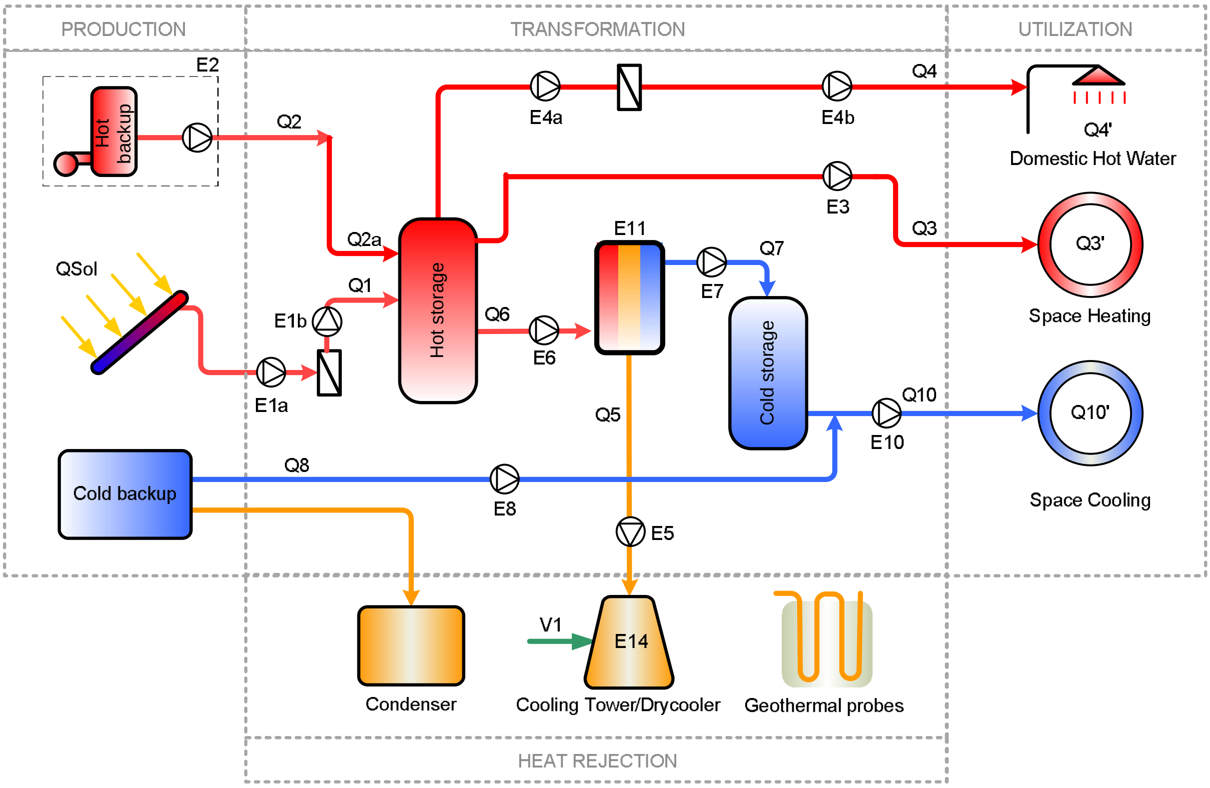


FIGURE 4 - SCHEMATIC DIAGRAM OF A SMALL PRODUCTIZED SOLAR AIR-CONDITIONING/HEATING/DOMESTIC HOT WATER SYSTEM

Depending on the configuration of the system, some components or hydraulic links may not be required and do not need to be taken into account. Further illustrations of the two generic architectures have been drawn up for different applications and are shown in Appendix 3.

4. Figures to be evaluated by monitoring

Before assessing the system performance indicators, it is essential to be familiar with the different types of energy shown in figures 3 and 4. Depending on the system diagram and in order to limit metrology investment costs, the number of meters can be limited provided that it is still possible to calculate all the performance indicators and to obtain all the information to monitor the system.

For commissioning, adjustment purposes and system monitoring, the different types of energy which needs to be measured or at the very least evaluated by calculations are set out below.

4.1. Solar energy

LABEL	DESCRIPTION	UNITS
Qsol	Total irradiation on the collector input surface	kWh
Q_{DNI}	Direct normal irradiation (for concentrating collectors)	kWh

4.2. Thermal energy

Thermal energy represents the heating or cooling quantity produced, stored and transferred within the system. This shows what has actually been produced by the system and the solar part and back-up respectively.

LABEL	DESCRIPTION	UNITS
Q1	Solar thermal heat energy supplied to the hot storage tank	kWh
Q2	Total thermal heat energy supplied by the hot back-up	kWh
Q2a	Back-up thermal heat energy supplied for storage	kWh
Q2b	Back-up thermal heat energy supplied to the building (heating)	kWh
Q2c	Back-up thermal heat energy supplied to the building (domestic hot water)	kWh
Q3s	Solar thermal heat energy supplied for heating	kWh
Q3	Solar thermal heat energy supplied to the building for heating	kWh
Q3’	Heating requirements	kWh
Q4s	Solar thermal heat energy supplied for domestic hot water production	kWh
Q4	Thermal energy supplied for domestic hot water	kWh
Q4’	Domestic hot water requirements	kWh
Q5	Thermal heat energy rejected by the ab/adsorption machine	kWh
Q6	Thermal heat energy supplied to the sorption machine	kWh
Q7	Thermal cooling energy supplied by the evaporator	kWh
Q8	Thermal cooling energy supplied by the cold back-up	kWh
Q10	Thermal cooling energy supplied to the building	kWh
Q10’	Cooling or air-conditioning requirements of the building	kWh

4.3. Electrical energy

The electricity consumptions of all the components in the system are as follows:

LABEL	DESCRIPTION	UNITS
E1a	Electricity consumption of the primary solar pump	kWh
E1b	Electricity consumption of the secondary pump	kWh
E2	Electricity consumption of the hot back-up	kWh
E3	Electricity consumption of the heating distribution pump	kWh
E4a	Electricity consumption of the primary domestic hot water distribution pump	kWh
E4b	Electricity consumption of the secondary domestic hot water distribution pump	kWh
E5	Electricity consumption of the absorber pump/condenser	kWh
E6	Electricity consumption of the generator pump	kWh
E7	Electricity consumption of the evaporator pump	kWh
E8	Electricity consumption of the refrigerating back-up pump	kWh
E10	Electricity consumption of the chilled water distribution pump	kWh
E11	Electricity consumption of the sorption machine	kWh
E12	Electrical production energy of the refrigerating back-up	kWh
E14	Electricity consumption of the cooling tower ventilator	kWh

The electricity consumption of the system is comprised as follows:

Consumption of the solar system auxiliaries ($E_{aux\ sol}$):

Customized: $$E_{aux\,sol} = E1a + E1b + E5 + E6 + E7 + E11 + E14$$

Productized: $$E_{aux\,sol} = E1a + E1b + \sum_{c\,\mathrm{lim}} (E5 + E6 + E7 + E11 + E14) \cdot \frac{Q1}{Q1 + Q2a}$$

In the productized type configuration, solar system auxiliary consumption is taken proportionally to the contribution to hot storage made by the solar system and hot back-up, during the cold production period alone.

Consumption of the **system auxiliaries** (E_{aux}) for air-conditioning + heating / production of domestic hot water **overall**, i.e. including back-up auxiliary consumption:

Customized: $$E_{aux} = E1a + E1b + E2 + E5 + E6 + E7 + E8 + E11 + E14$$

Productized: $$E_{aux} = E1a + E1b + E2 + E5 + E6 + E7 + E8 + E11 + E14$$

The hot or cold back-up auxiliary energy measurements (E2, E8) can be estimated as equal to 2% of the corresponding energy distributed (Q2, Q8), in accordance with IEA SHC task 38 [9]. In this case, the electrical energy of the solar auxiliaries ($E_{aux\ sol}$) is the only value which can be measured.

The latter associated with distribution (E_{dist}) is defined as follows:

$$E_{dist} = E3 + E4b + E10$$

4.4. Water

The water consumption of the cooling system must be measured. Mirror cleaning also consumes water. The amount differs for different concentrating technologies (Fresnel/Parabolic Trough).

LABEL	DESCRIPTION	UNITS
V1	Water consumption of the cooling system	m^3

5. Measuring and instrumentation

As far as possible, all magnitudes, energies and consumptions should be measured using specially designed equipment. Measuring devices must be able to communicate and should be connected to a device which can obtain and store data.

All metering is to be performed consistently and logically with an acceptable level of accuracy for the project. M&V reports must specify all equipment that was used as well as all details relating to how the measurements were conducted.

5.1. Solar energy

As far as radiative energy Q_{sol} is concerned, a sunlight probe should be set up on the same plane as the solar collectors. This sunlight probe should be connected to the data logger so that its E_{sol} value will be recorded over time. Q_{sol} is obtained from the product of E_{sol} and the surface area (A) of the installed solar collectors. The accuracy of the sunlight probe is ± 5% as an annual average.

For concentrating technologies direct irradiation can be measured using a pyroheliometer. Q_{DNI} is obtained from E_{DNI} (same as above) and the active mirror area over the time of measurement. The active mirror area must be retrievable from the PLC control output of the concentrating collector (which must know what fractions of the mirrors are in focus at any specific time).

Pyrometers are very expensive. It is therefore more cost effective to use sunlight probes which are accurate enough for in-situ monitoring. In thermal applications for the general public, sunlight probes (generally based on a calibrated photovoltaic cell) are used. The signal can be conditioned via electronics incorporated into the collector.

5.2. Thermal energy

Thermal energy (Q1 to Q10) needs to be measured either by:

- thermal energy meters, which must at the very least have an impulse output enabling connection to the data system. An energy meter which can transmit information regarding temperature/flow/energy to the data logger via bus is a real advantage as it enables measurement details to be accessed. This is vital in order to detect anomalies if the system malfunctions. Class 1 thermal energy meters should be chosen and programmed taking into account the type of fluid used (water, insulating antifreeze liquid);

- a pair of probes and a volumetric meter (for domestic hot water), or a flow meter for the other circuits. Class A Pt1000 temperature probes should be used, and each pair should have the same length of cable. Extension cables should measure 2x1mm² to limit line resistance. The probes must be set up in accordance with the recommendations given in Section 5.5, otherwise measurement errors will increase significantly. Class C volumetric meters (to measure Q4) should be used for cold water and class D volumetric meters for hot water meters[1]. The pulse load will be adapted to the flow and capacities of the data system.

Energy measured will be integrated over time.

[1] It should be pointed out that there are very few class D hot water meters available on the market. It is therefore best to position the meter on the cold water circuit and to use a class C cold water meter.

Thermal energy meters consist of 2 temperature probes, a device for measuring flow or volume and an integrator. They give direct access to the thermal energy transiting via the circuit being measured.

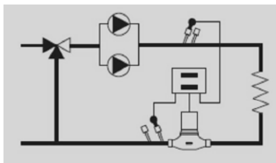
Nowadays, measuring equipment offers a range of functions due to incorporated electronics: wired or radio transmission via protocol (Mbus, Jbus etc.) to a central unit, upper and lower threshold detection, alarm management, heating and air-conditioning measurements using the same machine, etc. A thermal energy meter is an instrument designed to measure the energy absorbed (cooling) or given out (heating) by an insulating fluid in a hydraulic circuit. The meter supplies the quantity of thermal energy in commercial measuring units (kilowatt hours). A thermal energy meter is made up of the following sub-units:

- a hydraulic sensor placed at the entrance to the tank or exchanger, with insulating liquid flowing through it, emits a signal depending on the volumetric or mass flow rate. The most commonly found meters for applications in buildings are mechanical or volumetric meters (with oscillating pistons) or meters for measuring speed (Woltman, single or multiple jet meters). However, machines are now being developed which have no moving parts. This gives them a longer service life. Examples are ultrasound, vortex or fluid oscillator measuring devices. The calibre of the hydraulic sensor should be chosen according to the flow which will cross it. Flow can be calculated approximately using the following formula, if the maximum power to be supplied P_{max} and the difference in temperature $\Delta T_{estimated}$ of the circuit are known (using default values of 20°C for hot water and 70°C for superheated water):

$$Q_{n\,estimated} = (0.86 \cdot P_{\max}) / \Delta T_{estimated}$$

  with Q_n: nominal flow at which the hydraulic sensor can operate 24 hours a day in m^3/h;
- a pair of temperature probes (fitted with or without a sleeve) to measure the input and output temperatures of the insulating liquid in the heat exchange circuit;
- a calculator to receive signals from the hydraulic sensor and temperature probes and to integrate successive data measurements in order to calculate the quantity of thermal energy exchanged (product of the power produced or dissipated by the time interval (as short as possible) in between two measurements). The formula for calculating power is: $P = Q \cdot Cv \cdot \Delta T$ in kW with Cv: heating capacity, depending on the properties of the insulating liquid in relation to the corresponding temperatures and pressure.

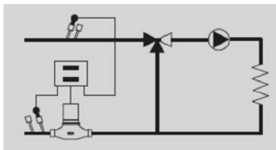
<u>Note regarding constant flow systems:</u>


► Installation à débit constant

Given a theoretical system flow, it is advisable to increase Q system x 1.25 < Q_n hydraulic sensor. The flow to be selected depends on the permanent maximum flow provided by the pump or by 2 pumps placed parallel to one another.

Recommendation: Q system < Q_n hydraulic sensor

<u>Note regarding variable flow systems:</u>


► Installation à débit variable

Given that the flow varies according to demand, the hydraulic sensor chosen must allow a wide range of measurements to be taken. This range is given by the ratio: Dy = Qmax / Qmin.

Recommendation: Qmax system < than 1.5 x Q_n hydraulic sensor

Meter accuracy depends on the metrological quality of each specific sub-unit (hydraulic sensor, temperature probe and calculator). The maximum error tolerated for a thermal energy meter will be the arithmetic sum of the maximum errors tolerated for each sub-unit.

In accordance with European standard EN 1434-1, hydraulic sensors on thermal energy meters can belong to one of the three classes of accuracy shown below:

ACCURACY OF HYDRAULIC SENSORS FOR THERMAL ENERGY METERS ACCORDING TO EN 1434-1

TOLERANCE OF CLASS ACCURACY	TOLERANCE Ef (l/s)	TOLERANCE Ef (%)
1	$\pm (1 + 0.01\ Q_n/Q)$	$< \pm 3.5$
2	$\pm (2 + 0.02\ Q_n/Q)$	$< \pm 5$
3	$\pm (3 + 0.05\ Q_n/Q)$	$< \pm 5$
Q_n nominal flow at which the hydraulic sensor can operate 24 hours a day Q real system flow		

Error Ef links the value indicated to the real conventional value of the ratio between the output signal of the hydraulic sensor and the volume or mass flow rate.

Note regarding the maximum error tolerated for the calculator:

$$Ec = \pm\left(0.5 + \Delta T_{\min} / \Delta T\right)$$

With: error Ec, which links the thermal energy value indicated to the real conventional value of this energy.

Note regarding the maximum error tolerated for the pair of temperature probes:

$$Et = \pm\left(0.5 + 3 \cdot \Delta T_{\min} / \Delta T\right)$$

With error Et, which links the value indicated to the real conventional value of the ratio between the output signal of the pair of temperature probes and the difference in temperature.

Thermal energy meters are also divided into environmental classes depending on their usage. Three classes are defined according to standard NF EN 1434:

ENVIRONMENTAL CLASS DEPENDING ON THERMAL ENERGY METER USAGE ACCORDING TO EN 1434

ENVIRONMENTAL CLASS	USAGES
A	Domestic usage, internal systems
B	Domestic usage, external systems
C	Industrial usage

The thermal energy meter must be installed in accordance with the supplier's instructions and the rules of the art. Precautions must be taken to avoid causing damage (vibrations, shocks etc.) to the thermal energy meter in unfavourable hydraulic conditions (cavitation, excess pressure, water hammer). The meter must also be installed far enough away from sources of electromagnetic disruption (switching devices, electric motors, fluorescent lights, etc.). If necessary, it must be earthed and/or protected by an external protection device against overcurrents caused by lightning.

The thermal energy meter should preferably be placed on the circuit with the lowest temperature level. The temperature measurement probe should be placed downstream from the meter to take advantage of the water movement it causes.

It is particularly important to install both plunger temperature probes in a similar way and to place them on straight pipework if possible. Paired probes must not be separated.

The wires sending measurement signals must not be placed directly next to other wires such as mains power cables, low voltage power cables or data switching cables, and must be attached separately. The distance between the two sets of wires must not be less than 50 mm. In general, all the meters currently available on the market are class 1 meters suited to the range of flows and temperatures being measured. Meters placed on hydraulic circuits will therefore be fitted with class 1 meters.

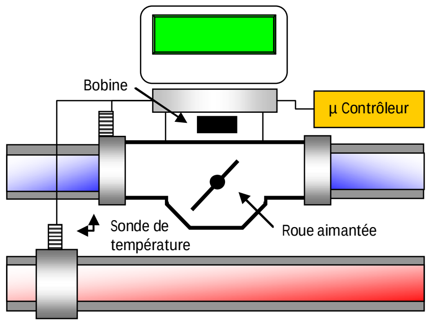


DIAGRAM OF A THERMAL ENERGY METER

It is best to choose devices with no moving parts in order to extend their service life. This is particularly advisable for continuous flow or permanent circuits (hydraulic back-up, loops).

If measurements are taken manually, meters must be fitted with monthly internal memories capable of recording a year's worth of measurements. For measurements that are taken remotely, meters must be fitted with impulse (all or nothing) or M-Bus information carriers (addressing different measurements and even error statuses, etc.).

5.3. Electrical energy

The electrical energy E1 to E15 can be:

- measured by electrical energy meters; it is advisable to set up class 1 electric meters with pulse emitters connected to the data system;
- calculated on the basis of the operating times of the devices for a given electric power absorbed, as measured on commissioning and specified in the adjustment report.

Measurements are to be given priority over calculations because this allows malfunctions to be identified.

Most thermal systems (excluding thermosiphon solar water heaters) use electrical auxiliaries (circulators, valves, regulators, compressors, etc.) or Joule effect electrical back-ups (resistance). The consumption of each of these pieces of equipment must be measured by electrical energy meters. The meters chosen need to be equipped either with pulse emitters or a transmission protocol so that they can transmit information to the central unit.

Electrical energy meters must be fitted in accordance with electrical security regulations either in the user's electric control panel or in a separate electric control panel. It is important to check in which direction the intensity transformers should be inserted depending on the chosen model.

Class 1 electrical meters must be used. Their calibre will depend on the power of electrical resistances they are supplying power to (for back-up generators) or auxiliaries (pumps, valves, etc.). Electrical energy measured must be relayed to the data system.



5.4. Water

The water consumption of the cooling system should be measured using a class C cold water volumetric meter. This should be connected to the data logger and a pulse emitter should therefore be fitted to the meter.

The main technologies used for flow sensors are:

- mechanical volumetric meters (with oscillating pistons) or speed meters (Woltman, single or multiple jets);
- meters without any moving parts: ultrasound, vortex or fluid oscillator meters.

The main characteristics to look for in this type of flow sensor are:

- the cost;
- measurement quality (accuracy, starting threshold, measurement range, etc.);
- reliability (durability, stability of data over time, etc.);
- how easy it is to connect and condition the signal;
- low loss of hydraulic charge to avoid disrupting the hydraulic circuit being measured.



Mechanical meters are still widely used in thermal applications for the general public, but meters without moving parts (which offer considerable advantages due to this absence) are also starting to become more widespread.

Consumption of domestic hot water is measured by a hydraulic sensor placed at the entrance to the tank or exchanger. It emits a signal whenever a volume or mass of insulating fluid crosses it. It also serves to measure the rate of liquid flowing in the hydraulic circuit. It must create as few losses of charge as possible, must be sufficiently accurate and, above all, reliable over time.

As far as water consumption measurements are concerned, the measurement range is particularly wide as flow can vary from a very low value (a washbasin tap open) to very high values (simultaneous use of water in several bathrooms).

The device chosen must generally have a range of operating temperatures between 10 and 100°C, depending on the maximum drawing flow (or peak flow, VPeak).

Note: For blocks of flats, the flow (in litres/10min) can be estimated using the following formulae:

$V_{pointe} = 50 \cdot N \cdot S$ with: $S = 1/\left(\sqrt{N-1} + 0.17\right)$ and $N = \sum p \cdot N_{real}$

S is the simultaneity coefficient, N the number of standard dwellings and N_{real} the number of real dwellings, p is expressed according to the type of dwelling in line with the following table:

VALUES OF COEFFICIENT P

TYPE	EQUIPMENT	COEFFIENT p
1 room	1 shower	0.6
2 rooms	1 bathtub	1
3 rooms	1 bathtub	1
4 rooms	1 bathtub + 1 shower	1.3
5 rooms	2 bathtubs	1.5

As far as cold water meters are concerned, their accuracy depends on the metrological quality of each device. There are 3 classes of accuracy A, B and C.

CLASS OF ACCURACY OF COLD WATER METERS

CLASS OF TOLERANCE OR ACCURARY	TOLERANCE q_{min} (l/s)	TOLERANCE q_t (l/s)
A	$0.04.q_n$	$0.100.q_n$
B	$0.02.q_n$	$0.080.q_n$
C	$0.01.q_n$	$0.015.q_n$
q_{min} minimum operating flow of the meter and q_t transition flow		

For hot water meters, there are 4 classes of accuracy A, B, C and D.

CLASS OF PRECISION OF HOT WATER METERS

CLASS OF TOLERANCE OR ACCURARY	TOLERANCE q_{min} (l/s)	TOLERANCE q_t (l/s)
A	$0.04.q_n$	$0.100.q_n$
B	$0.02.q_n$	$0.080.q_n$
C	$0.001.q_n$	$0.060.q_n$
D	$0.01.q_n$	$0.015.q_n$
q_{min} minimum operating flow of the meter and q_t transition flow		

For a flow of q_{min} to q_t inclusive, meter accuracy is greater than 5 %. For flows exceeding transition flow q_t, meter accuracy is greater than 2 %.

The meters generally supplied by manufacturers are volumetric meters with oscillating pistons. They do not need to be fitted on a straight line and can be placed in any position.

Turbine or propeller meters must always be fitted horizontally (unless the manufacturer gives specific instructions to the contrary) and straight lines must be kept up and downstream as recommended by the manufacturer (although they can sometimes be replaced by honeycomb or grid meshing).

When fitted, a certain number of accessories are required:

- an upstream filter which is compulsory for turbine or propeller meters. The filter must be easy to disassemble;
- isolation valves to make disassembly easier for maintenance purposes or if a malfunction occurs;

- reduction cones: the connection diameter may be different to that of the pipes;
- a drain valve positioned between the two isolating valves;
- venting equipment, non-return valve (downstream from the meter), etc.;
- shielded cable connection (taking care to connect the meter the right way round).

For remote readings, meters need to be fitted with an impulse emission device. The impulse load is directly linked to nominal flow qn and meter technology. For low nominal flows, frequent impulse loads are 0.1, 0.25, 0.5, or 1 l/impulse. Frequencies are factory set. The number of impulses is proportional to the flow. The number of impulses emitted is counted in a register and the meter index reconstituted.

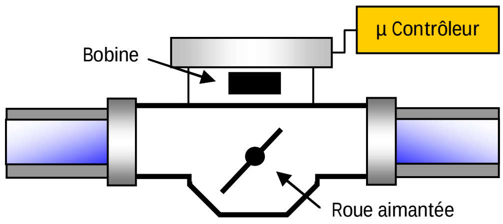


DIAGRAM OF AN IMPULSE METER

The domestic hot water meters used will be extremely accurate class C volumetric meters capable of detecting low flow rates.

5.5. Temperature Probes

Many different types of temperature probe exist:

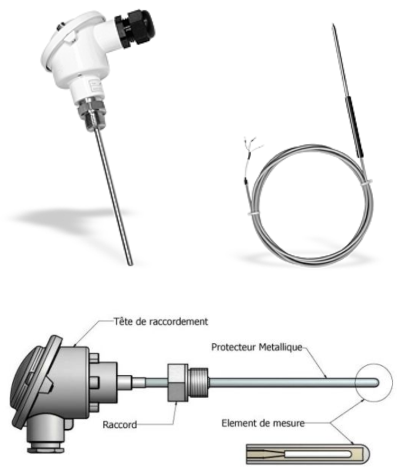
- thermocouple probes, which generate a variable voltage depending on the temperature;
- thermistance probes, based on the use of a metal whose electrical resistance varies according to temperature.

The main characteristics to look for in temperature probes are:

- their cost;
- measurement quality (temperature coefficient, response time, accuracy, self-heating, etc.);
- reliability (durability, stability of responses over time, etc.);
- how easy it is to connect and condition them (sensitivity to electrical implementation, signal linearity, type of excitation signal, etc.).

Thermistance is the main technology used in thermal applications for the general public. Thermistances using platinum (Pt1000) or nickel (Ni500) are generally used for monitoring purposes.

Water temperature must be measured using a probe adapted to the range of temperature being measured, and in particular to the maximum temperatures which could be reached by the system, depending on their location. The temperature probe used on the collector must be able to withstand the collector's stagnation temperature without its accuracy being altered by more than 1K. The probe on the storage tank must be able to withstand 0°C to 100°C without varying by more than 1K.



Temperature is usually measured using thermistances whose resistance decreases as temperature increases (Pt100 or Pt1000 platinum probes). They transmit an electrical signal proportional to the temperature. Standard NF EN 60751 defines two classes of accuracy (A and B) for temperature probes.

CLASS OF ACCURACY FOR THERMISTANCES ACCORDING TO STANDARD EN 60751

CLASS OF TOLERANCE OR ACCURARY	TOLERANCE (°C)
A	0.15 + 0.002 |T|
B	0.30 + 0.005 |T|

|T| represents the absolute value of temperature (°C)

Connection wires are responsible for a degree of measurement error which depends on their length and cross-section. The connection wire between the probe and the acquisition unit must have a cross-section of 0.9 mm². The connection used is type 2 wire connection. This is a cheaper method of maintaining measurement accuracy even over long connection distances.

The following table shows measurement errors caused by connection wires:

ERRORS CAUSED BY CONNECTION WIRES

CONDUCTOR CROSS-SECTION (mm^2)	CABLE RESISTANCE FOR 20m OF CONDUCTOR (Ω)	DIFFERENCE IN TEMPERATURE FOR A PT100 (°C)	DIFFERENCE IN TEMPERATURE FOR A PT1000 (°C)
1.5	0.227	0.58	0.038
0.9	0.378	0.967	0.063
0.6	0.567	1.45	0.094
0.3	1.133	2.90	0.189

The probes connection wires must resist the maximum temperatures which can be reached by the system so that they can be placed alongside piping. Silicone wires are best, as these can withstand temperatures of up to 180 °C.

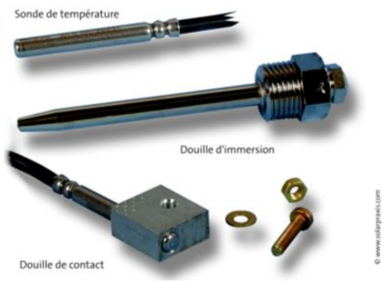
Since the principal magnitude being monitored is the difference in temperature of a liquid up and downstream from a heat exchanger, a pair of temperature probes should be chosen and the same length of connection wire kept for the two probes in question. Any extra length needs to be rolled up and attached to make sure that the length is identical on all the probes. If the wire needs to be lengthened, 2 x 1 mm² wiring should be used, connected by welded splicing and fully insulated (using shrink tubing or adhesive tape especially designed for electric usage).

The temperature probes need to be easily accessible for servicing and maintenance purposes. They must be positioned using sleeves. The advantage of using a sleeve is that the probe can be replaced without having to empty all or part of the system. The sleeve first needs to be filled with heat-conductive paste or high-thermal conductivity silicone oil. The length of the probe must be suited to the pipe diameter so that the sensitive part (the end of the plunger piston) is in the centre of the pipe. Probes can be positioned:

- either on a straight length of piping, in which case the plunger piston needs to be at an angle of 45° and positioned against the current;

- or on a bend, which is the best position, because the turbulence of the curve gives a more homogeneous temperature. In addition, the curve simplifies the integration of low diameters, no matter how long the plunger.

The probes used must be thermally insulated and protected against water infiltration. The level of protection for the temperature probes must be at least IP33.



The position chosen for the temperature probes and the way in which they are fitted must allow sufficient measuring accuracy. To ensure maximum precision, Pt1000 class A probes should be used.

5.6. Recommendations for Data Systems

The acquisition/processing/storage/transmission system is a key part of the monitoring system. A data logger/controller needs to be installed to obtain and store measurements, to carry out basic calculations and to transfer information to a remote site. Its configuration should be adapted to suit the number of measurement channels required.

This equipment will:

- liaise with all the measurement sensors and transform the electrical measurement signal into a physical value;
- carry out all the necessary energy calculations to display useful data whenever possible (energy, efficiency, productivity, economy rates, etc.);
- archive the data measured and figures calculated;
- transmit the information outside the system.

As a result, there are many different types of input/output which the data logger/controller may need to process:

- analogical (voltage or electric currents);
- digital (all or nothing signals, TOR);
- numerical (industrial buses).

The functions of the data system should include the ability to:

- record measurements;
- carry out a series of calculations to integrate values measured at 1 minute intervals;
- carry out a series of simple calculations to allow access to indicators (see relevant section);
- save 3 history files locally as rolling files:
    - o 1 10 minutes time step data file containing 1 full week of system data (# 1008 recordings x quantity of data) with status data (temperature) and metering data (operating time, volume, energy) retrieved at least once a week, archived locally for at least 2 months (# 2 Mo) and allowing system operation to be analysed;

  - o 1 daily data file containing 1 month + 10 days of data (between 38 and 41 recordings x quantity of data) with reports on energy and indicators + extremes of temperature retrieved at least once a fortnight to be used to draw up monthly energy reports and to calculate indicators;
  - o 1 monthly data file containing 1 year + 1 month of data (# 13 recordings x quantity of data) with reports on energy and indicators retrieved at least once a year;
- send history files to a central unit via an outbound means of communication such as PSTN telephone network, ADSL internet connection, GPRS, electronic messaging etc. or to be accessed remotely from a central unit via an inbound means of communication such as GPRS, internet, telephone network etc.

In some cases, supervision equipment actually consists of automatons equipped with inputs/outputs and that can use programming language enabling the user to program all the required calculation formulae. In other cases, supervision equipment will be limited in terms of on-board software, but will include a catalogue of applications that can be adapted to suit different situations.


In addition, another important point concerns human–computer interaction (HCI). The interfaces for programming and managing this type of equipment used to be restricted to providing instructions in the form of lines of commands, but significant progress has been made which makes them accessible to non-specialists. These interfaces can either be software to be installed on a computer connected to the automaton locally or a web interface mounted on the automaton itself.

The ability to manage the automaton and the system it controls from a distance has become standard practice. Automatons with specific communication modules for different networks are available.

Given the complex nature of the systems and expectations placed on the data system, it is necessary to draw up specifications before choosing supervision equipment. The specifications will dictate the choice of monitoring products or products designed specifically according to the ability to program the equipment.

The main qualities to look for in this type of equipment are:

- its cost;
- measurement quality (conversion precision, etc.);
- reliability (durability, risk of computer “crashing”, etc.);
- ease of connection;
- programming and measuring flexibility;
- extension possibilities;
- adaptability to different systems;
- openness to the outside world (GSM, on-board web interface, MBUS or JBUS protocols, etc.).

5.7. Communication Standards and Protocols

5.7.1. Wired technology

RS485: Electrical standard for twisted pairs. The signal is transmitted by variations in voltage (differential link), on a bidirectional data bus.

RS422: Cousin to RS485, the signal is transmitted on 2 unidirectional buses.

RS232: Generally called “serial port” or “COM port” this type of link is commonly used in industry to connect different electronic devices and also on personal computers, on which it now tends to be more and more widely replaced by the USB port.

BACnet: Communication protocol for building automation and for controlling CVC or lighting systems, etc. It is an ASHRAE and ISO standard. Communication takes place via wired network.

TCP/IP: Initials of Transmission Control Protocol and Internet Protocol, this is the Internet protocol used on computer networks.

5.7.2. Wireless technology

ZigBee: Communication protocol and wireless network for residential, commercial and industrial buildings. From a technical point of view, ZigBee is a WPAN (IEEE standard 802.15.4) with a secure link using ISM and S bands. Flow is quite low (< 250 Kbits/s) corresponding to sensor networks and machine to machine communication, with particularly low emitter and collector energy consumption. ZigBee is not always sufficient to cover an entire building, with repeaters often required. ZigBee is considerably widespread and is an accepted protocol in medical control (bio-telemetry), logistics, industrial control and home automation applications.

KNX (or Konnex): This communication standard for intelligent buildings is the convergence of Batibus, EHS and EIB and has existed since 2000. It is based on a communication protocol network which enables all the different aspects of building management and supervision building to dialogue with one another (sensors, actuators, system modules). It is particularly well suited to home automation. Information can be transmitted by wire, radiofrequency (860 MHz), infrarouge, carrier current (CPL) or TCP/IP. KNX is completely separate from any specific hardware or software platform. It is a shared intelligence system (multi-master) without a control computer or centralising automaton.

GSM, GPRS, EDGE, 3G: mobile telephone standard (WAN network), GSM corresponds to the 2nd generation, 3G to the 3rd generation, whilst GPRS and EDGE are improvements to GSM (generation 2.5). The difference between all these generations is the flow (exchange frequency, quantity of data sent). These standards can be used to provide a mobile station with IP connectivity which is constantly available. It is used in monitoring applications for the remote acquisition of data from the site being monitored to a distant location for analysis.

6. Monitoring daily data

Performing and inspecting measurements of the system ensures that the system is functioning correctly. The procedure involves:

- collecting and archiving monitoring data every day;
- automatically formatting monitoring data (1 file per day recommended) in the form of a daily report and graphs;
- taking note of automatic alarms, evaluating and analysing the reason for malfunctions, informing the contractor, operator and maintenance company;
- analysing reports once a week and examining detailed daily data if necessary.

6.1. Prerequisite: the system control panel

The "system control panel" summarises all the system's characteristics as well as the adjustment settings and values obtained on commissioning together with detailed adjustment regulations. For the purposes of this chapter, we will assume that the adjustment and optimisation stage is part of commissioning. The system's detailed hydraulic diagram must be attached to the control panel. Appendix 4 gives an example of a control panel.

6.2. First stage: calculating daily indicators

Daily indicators are calculated from cumulated energy over one day. Indicators should **not** be calculated from averages at specific time intervals. It is recommended that the following indicators should be calculated:

- performance coefficient of the ab/adsorption machine (COP_{th});
- solar electric performance coefficient of the system (COP_{elec}, COP_{sol});
- solar collector thermal yield (R_{coll});
- solar thermal efficiency of the system (R_{sol}).

The definitions and formulae for calculating the indicators are given in Appendix 1.

6.3. Second stage: formatting daily data

6.3.1. In cooling / air-conditioning mode:

The following parameters and graphs are relevant in cold production mode:

- Graph(T): changes in temperature and sunshine during the day, Figure 5;
- Graph(Q): changes in different heat flows during the day, Figure 6;
- Graph(P): changes in instantaneous power during the day, Figure 7;
- Graph(COP_{th}): change in COP_{th} and input temperatures at the generator, absorber-condenser and output temperatures from the evaporator, Figure 8.

LABEL	DESCRIPTION	UNITS
Qsol	Total sunshine on the collector input surface	kWh
Q1	Solar thermal heat energy supplied to the hot storage tank	kWh
Q6	Thermal heat energy supplied to the sorption machine	kWh
Q7	Thermal cooling energy supplied by the evaporator	kWh
Q8	Thermal cooling energy supplied by the cold back-up	kWh
Q10	Thermal cooling energy supplied to the building	kWh
V1	Volume of water consumed during the day	l
COP_{th}	Performance coefficient of the ab/adsorption machine	-
$COP_{elec, sol}$	Solar electric performance coefficient of the system	-
R_{coll}	Solar collector thermal yield	-
R_{sol}	Solar thermal efficiency of the system	-

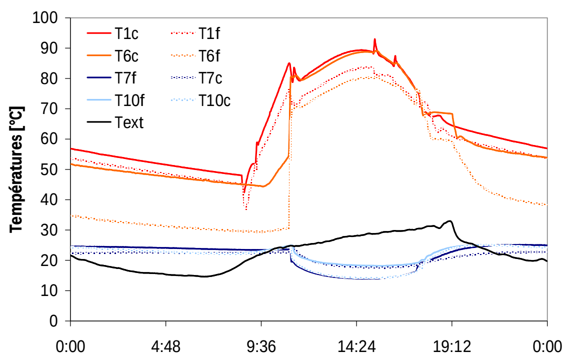


FIGURE 5 – TYPICAL GRAPH (T) OF A SOLAR AIR-CONDITIONING/HEATING SYSTEM IN AIR-CONDITIONING MODE, [15]

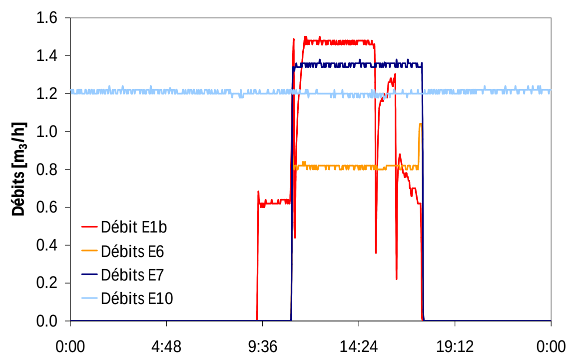


FIGURE 6 - TYPICAL GRAPH (Q) OF A SOLAR AIR-CONDITIONING/HEATING SYSTEM IN AIR-CONDITIONING MODE, [15]

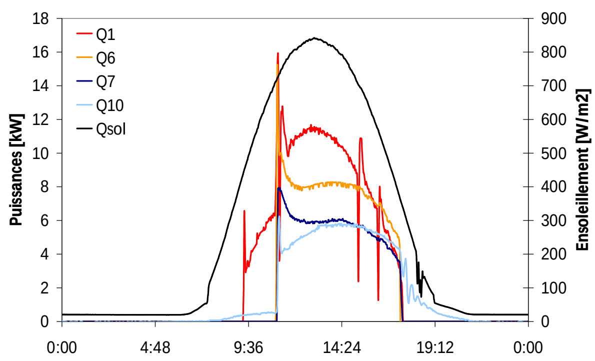


FIGURE 7 – TYPICAL GRAPH (P) TYPE OF A SOLAR AIR-CONDITIONING/HEATING SYSTEM IN AIR-CONDITIONING MODE, [15]

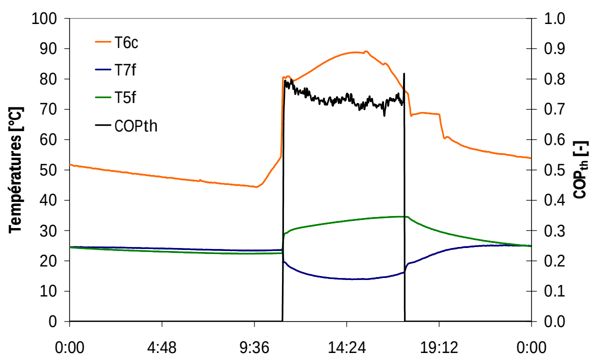


FIGURE 8 – TYPICAL GRAPH (COP_{TH}) OF A SOLAR AIR-CONDITIONING/HEATING SYSTEM IN AIR-CONDITIONING MODE, [15]

6.3.2. In heating mode:

The following parameters and graphs can be relevant in heating mode:

- Graph(T): changes in temperature and sunshine during the day;
- Graph(Q): changes in different flows during the day;
- Graph(P): changes in instantaneous power during the day.

LABEL	DESCRIPTION	UNITS
Qsol	Total sunshine on the collector input surface	kWh
Q1	Solar thermal heat energy supplied to the hot storage tank	kWh
Q2	Total thermal heat energy supplied by the hot –backup	kWh
Q3s	Solar thermal heat energy supplied for heating	kWh
Q3	Thermal heat energy supplied to the building for heating	kWh
$E_{aux\ sol}$ and/or E_{aux}	Electrical energy from the solar auxiliaries and system consumed during the day	kWh
$COP_{elec,\ sol}$	Solar electric performance coefficient of the system	-
R_{coll}	Solar collector thermal yield	-
R_{sol}	Solar thermal efficiency of the system	-

6.3.3. In domestic hot water production mode:

The following parameters and graphs can be relevant in domestic hot water production mode:

- Graph(T): changes in temperature and sunshine during the day;
- Graph(Q): changes in different flows during the day;
- Graph(P): changes in instantaneous power during the day.

LABEL	DESCRIPTION	UNITS
Qsol	Total sunshine on the collector input surface	kWh
Q1	Solar thermal heat energy supplied to the hot storage tank	kWh
Q2	Total thermal heat energy supplied by the hot –backup	kWh
Q4s	Solar thermal heat energy supplied for domestic hot water production	kWh
Q4	Thermal energy supplied for domestic hot water	kWh
Q4’	Domestic hot water requirements	
$E_{aux\ sol}$ and/or E_{aux}	Electrical energy from the solar auxiliaries and system consumed during the day	kWh
$COP_{elec,\ sol}$	Solar electric performance coefficient of the system	-
R_{coll}	Solar collector thermal yield	-
R_{sol}	Solar thermal efficiency of the system	-

6.4. Third stage: alarms and operating analysis

6.4.1. Reminders

Before being able to carry out a remote operating analysis, it is necessary to establish:

- the general operating principles of the solar cooling system with heating and production of domestic hot water;
- the system characteristics (power, surfaces, etc.) exactly as they have been implemented;
- the operating conditions and rules exactly as they have been implemented (expected flows, flow control etc.);
- which problems may be encountered on this type of system.

As far as the final point is concerned, the 2007 ADEME guide regarding the design, acceptance and monitoring of solar cooling demonstration operations lists the anomalies found on various demonstration systems. It can be used in complement to but not to replace knowledge that has already been obtained or that will be obtained from experience.

6.4.2. Setting up automatic alarms

Given the precision of measurement instruments, time constants of different elements within the circuit and transitional conditions, it is often difficult to set up automatic alarms and safeguards for instant indicators.

Basic automatic alarms can nonetheless be implemented on the various hydraulic loops, in particular:

- flow measured as zero but state of pump = 1 (pump working);
- negative energy measurement.

When an alarm is triggered, checks must be made to ensure that the system has been operating correctly during the day in progress.

6.4.3. Remote verification at time t of correct operation during the day in progress

Figure 9 gives an overview of how to monitor a solar air-conditioning/heating system working in air-conditioning mode.

In order to check that the system is functioning correctly, the following points must first be verified:

- Temperature: the temperature levels must comply with the corresponding energy loop application, for example in air-conditioning mode:

  T solar circuit > T generator circuit > T cooling circuit > T evaporator circuit

  As an indication, traditional temperature conditions in steady states (circulation pump working) are as follows:

  - solar (primary and secondary) and generator circuits: between 55°C and 100°C;
  - cooling circuit / heat rejected: between 23 and 40°C;
  - evaporator circuit: between 5 and 20°C and consistent with distribution temperature conditions.
- Flows: depending on the trigger thresholds defined for starting up the circulators, it is necessary to check for flow in each circuit. In addition, flow values must be constant if

the pump is working at constant flow (as is currently recommended for hydraulic circuits of sorption machines) and close to the set values.

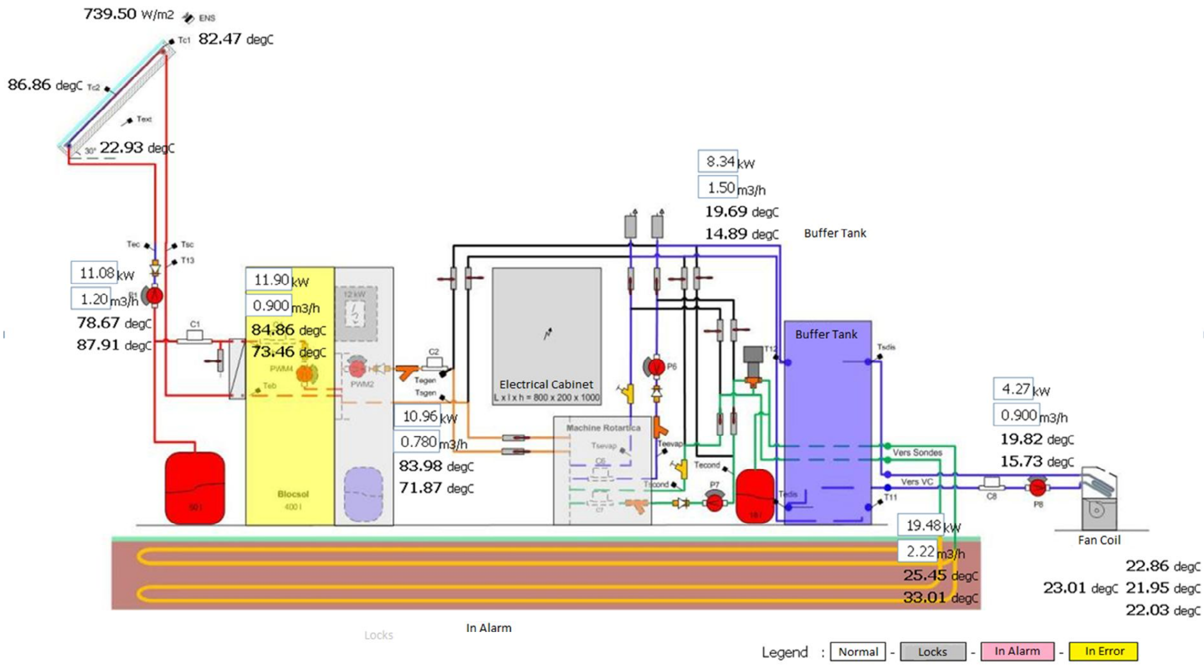


FIGURE 9 – OVERVIEW OF HOW TO SUPERVISE A SOLAR AIR-CONDITIONING/HEATING SYSTEM FUNCTIONING IN AIR-CONDITIONING MODE [15]

Important note: The aim of these simple checks is to analyse whether the alarm has merely been sent by a measuring "sound", which can cause non-representative errors. This often occurs if values correspond to the average values for too short an interval of time. In this case, the average values need to be checked over a longer period of time.

If anomalies or abnormal values are found, it is necessary to check whether the adjustment regulations have been followed correctly. To do this, it is necessary to consult the control panel and to check if the sunlight values and different temperature values and differentials are consistent with pump operation.

To identify the origin of a problem or malfunction, it may be necessary to look at data from the previous few days. In addition, verifications can be carried out in-situ to compare the value measured with the data system, the value measured on an adjustment device (for instance a compensation valve) and the volume registered on a volumetric meter for 10 minutes.

6.4.4. Verification of correct operation the previous day

Two types of checks can be made to ensure that the system was working properly the previous day:

- In general: by using the indicators defined in the second stage. The values obtained must be within the ranges defined for correct operation (Appendix 5).
- In detail: by precisely analysing the 10 minutes time step measurement file. In this case, graphs showing daily changes in temperature (Figure 5), flow (Figure 6) and power (Figure 7) are analysed. This type of analysis can have many different aims. In particular, it is necessary to check:
    - o pump operating consistency in relation to the settings;

- that temperature levels are coherent and that the maximum operating values have not been exceeded (overheating for example);
- that no inappropriate short cycles occurred (sorption machine, pumps, etc.);
- operating power value consistency.

For example, in Figure 6 we can see that the cold distribution flow (Flow E10) is not being checked by the system and that the pump is working all the time.

6.4.5. Verification of correct operation in-situ

Remote analysis can result in the need to carry out checks in-situ, in which case the technical staff on site need to be involved or the contractor should be advised to request an intervention.

Checking procedures are given in the maintenance recommendation guide written as part of the MeGaPICS project and available on the SOCOL website[2].

[2] MéGaPICS project, SOCOL site: http://www.solaire-collective.fr/index.php?pid=21

7. Monthly and annual reports

7.1. Calculating performance indicators

Performance and quality indicators are used to quantify different aspects of the solar air-conditioning/heating system:

- Thermal efficiency indicators: these indicators express the thermal efficiency (losses) of the system components that have greatest impact (sorption machine and storage);
- Solar performance indicators: these indicators combine all the different indicators which evaluate the system's ability to exploit solar energy;
- Overall system performance indicators: these indicators combine all of these factors, taking into account the system's solar and auxiliary energy to evaluate its performance in relation to the building's energy requirements;
- Ecological impact indicator: this indicator reflects the system's water consumption;
- Economic indicator: this indicator aims to define the system's (operating and investment) cost and profitability;
- Comfort indicator: this indicator reflects the difference in terms of usage between the service expected by the user and the service provided by the system;
- Proper operation indicators: these indicators are for evaluating system reliability by taking into account breakdowns and maintenance operations.

The definitions and formulae for calculating these indicators are given in Appendix 1. Most of the indicators must be calculated at monthly or annual time intervals. Otherwise their values are **not significant**. The different types of indicator can be applied at various stages when implementing a solar air-conditioning/heating system (feasibility study, dimensioning, completion and monitoring) as follows:

FIELD OF APPLICATION FOR PERFORMANCE INDICATORS

FEASIBILITY STUDY	DIMENSIONING	COMPLETION	REMOTE MONITORING
	Thermal Efficiency Indicators		
η_s (hot and cold)			η_s (hot and cold)
COP_{th}	COP_{th}		COP_{th}
	Overall Performance Indicator		
PER	PER		PER
	Solar Performance Indicators		
PSU	PSU		PSU
	R_{sol}		R_{sol}
R_{coll}	R_{coll}		R_{coll}
$COP_{elec\ sol}$	$COP_{elec\ sol}$		$COP_{elec\ sol}$
	Ecological Impact Indicator		
CE_{spe}			CE_{spe}
	Economic Indicator		
kWh_{cost}			kWh_{cost}
	Proper Operation Indicators		
			I_{op}
			I_{Data}
	Comfort Indicator		
			$I_{Comfort}$

Note: All the indicators defined do not take into account distribution pumps to the building (chilled water E10, heating water E3 and secondary domestic hot water E4b).

7.2. Performance and quality indicator thresholds

Target values have been set for each different category (thermal efficiency, overall performance, solar performance, ecological, economic and quality indicators).

It is particularly important to define target values or thresholds because the absolute value of an indicator alone is not sufficient to demonstrate system quality or performance. The latter can greatly depend on external conditions (climate, requirements) or on the technology used (adsorption or absorption machine, type of back-ups, solar collector technologies etc.).

The definitions and formulae for calculating indicator thresholds are given in Appendix 2.

7.3. Verification of overall performances

The system's overall performances must be verified over a sufficient period of time: monthly, seasonal or annual. The overall performance of a system is established by calculating the performance indicators and comparing them with the corresponding target values to be reached.

In addition, given that it is difficult to identify just one indicator which is representative of the quality and performance of a solar air-conditioning/heating/domestic hot water production system, it is suggested that a graph should be used to illustrate the differences between the defined indicators and the associated target values. However different indicators may be more meaningful for different purposes.

Two methods have been established to calculate indicator values compared with their corresponding target values (as a percentage), depending on the type of target value:

If the target value is a minimum value (I_{min}):

$$I_{\%} = 100 \cdot \left[1 + \left(I - I_{\min}\right) / I_{\min}\right]$$

If the target value is a maximum value (I_{max}):

$$I_{\%} = 100 \cdot \left[1 + \left(I_{\max} - I\right) / I_{\max}\right]$$

By using this method, each indicator can be compared to its target value. A good indicator value is a value equal to or greater than 100%. In order to produce a representative picture, the values obtained are limited to 0% for negative values and 200% for positive values. The limited values are displayed as such in figure 10 which illustrates four different solar air-conditioning systems during different years of operation.

The methodology given here allows us:

- to establish a full, synthetic cartography of the performances of a solar air-conditioning/heating/domestic hot water production system;
- to identify the strengths of a system as well as any areas for improvement/ optimisation;
- to observe changes in a system's performances year by year.

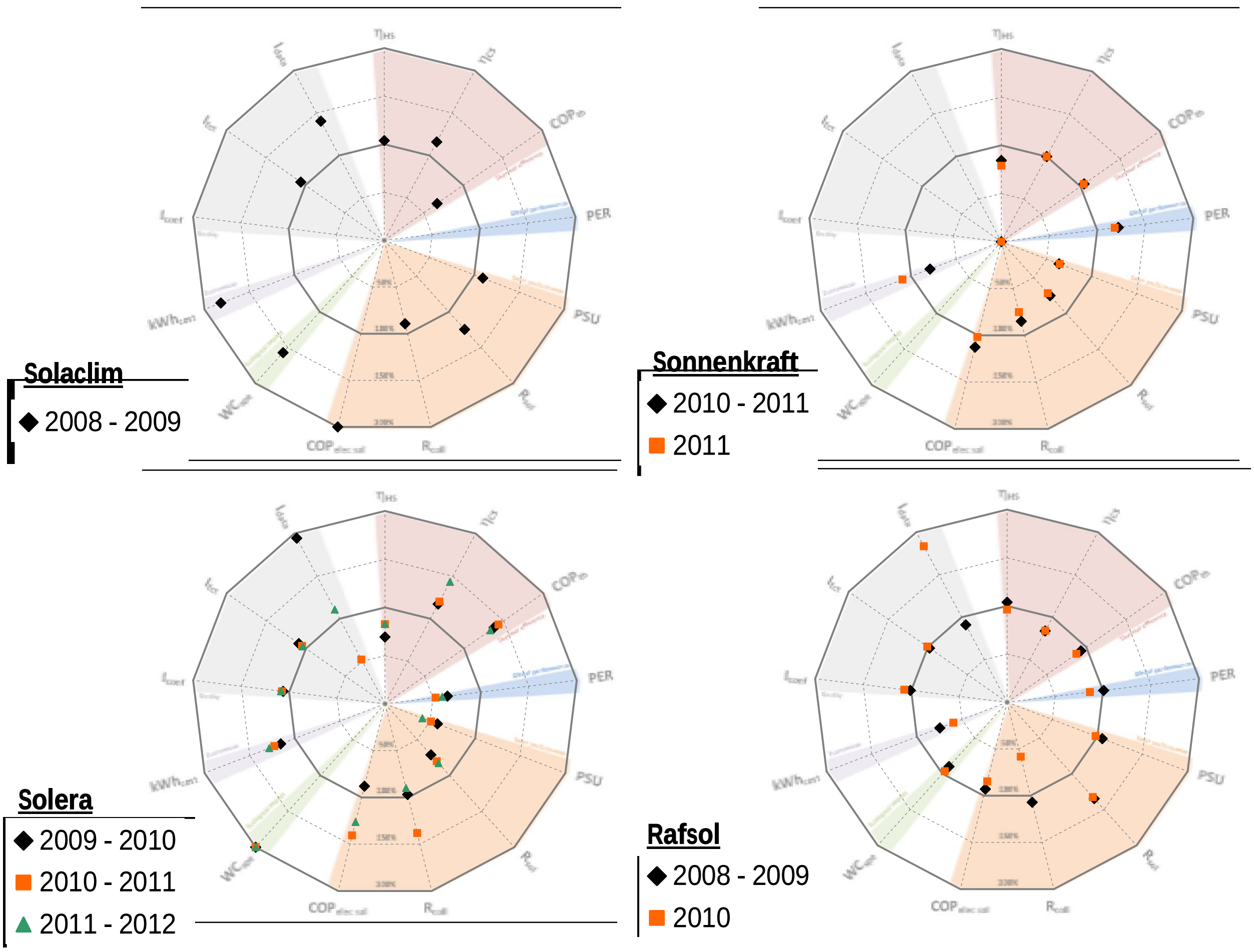


FIGURE 10 – ILLUSTRATION OF OVERALL SYSTEM PERFORMANCE OF A SOLAR HEATING/AIR-CONDITIONING/ DOMESTIC HOT WATER PRODUCTION SYSTEM (SOLERA [27], SOLACILM [24], RAFSOL [25] & SONNENKRAFT [26] SYSTEMS)

8. Conclusions

The installation of measuring equipment is one of the necessary recommendations not only to ensure that a system is functioning correctly but also to quantify its performances.

The equipment used must be of high quality in order to meet objectives for qualifying system performance whilst keeping costs at an acceptably low level for the contractor.

It should be possible to meet these objectives if measuring equipment is implemented in accordance with the rules set out in this document. The recommendations given here should also enable a common methodology to be established for implementing the data controller of solar air-conditioning systems, which should become systematic as this type of technology becomes more widespread on the market.

9. References

This monitoring procedure is based mainly on the XnA procedure for application to the heat fund [8], on the decree dated 15th September 2006 regarding the methods and procedures applicable to energy performance diagnoses for existing buildings offered for sale in metropolitan France [10], on the results of task 38 of the IEA's [9] "Solar Air-Conditioning and Refrigeration" program, on the EMERGENCE program's procedure for implementing monitoring facilities for solar air-conditioning/heating systems [11] and on work carried out as part of the ANR HABISOL 2009 MeGaPICS project.

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APPENDIX 1: Calculation of performance and quality indicators

The calculation of the performance and quality indicators is based mainly on [37].

- **Calculating important dimensional magnitudes**

  - **Thermal losses from storage**

Overall thermal losses from hot and/or cold storage are evaluated in relation to the input/output energy for each component:

- Hot storage:

  Customized: $$Q_{\text{hot loss}} = Q1 - Q3s - Q4s - Q6$$

  Productized: $$Q_{\text{hot loss}} = Q1 + Q2a - Q3 - Q4 - Q6$$

- Cold storage: $$Q_{\text{cold loss}} = Q7 - Q10 + Q8$$

  - **Thermal losses from storage due to back-ups**

Thermal losses from hot and cold storage can result from losses of thermal energy from the solar part and of thermal energy from hot and cold back-ups. Not taking into account the proportion of thermal losses due to back-ups when calculating the system's useful solar energy would be equivalent to putting such losses down to solar energy, which would thus be penalised. Losses from hot and/or cold storage due to back-ups are therefore calculated from the overall losses of hot and/or cold storage ($Q_{\text{hot loss}}$ and/or $Q_{\text{cold loss}}$) in proportion to the input of hot and/or cold back-ups (Q2a and/or Q8) as follows:

- Hot storage:

  Customized: $$Q_{loss\,hot\,b-up} = 0$$

  Productized: $$Q_{loss\,hot\,b-up} = Q_{\text{hot loss}} \cdot Q2a / (Q1 + Q2a)$$

- Cold storage: $$Q_{loss\,cold\,b-up} = Q_{\text{cold loss}} \cdot Q8 / (Q8 + Q7)$$

  If a cold back-up (Q8) is connected to the cold storage of the solar system, thermal losses from cold storage caused by the back-up ($Q_{\text{loss cold b-up}}$) are calculated based on the following formulae:

  - **Useful solar energy**

Useful solar energy (ESU) refers to thermal solar energy exploited by the system integrating thermal losses from hot and cold storage due to back-ups ($Q_{\text{cold loss}}$ and $Q_{\text{hot loss}}$). The useful solar energy defined takes into account thermal losses from hot and cold storage caused by back-ups.

Customized: $$ESU = Q3 - Q2b + Q4 - Q2c + \left(Q10 - Q8 + Q_{loss\ cold\,b-up}\right)/COP_{th}$$

Productized: $$ESU = Q3 + Q4 - Q2a + Q_{loss\ app\ hot} + \left(Q10 - Q8 + Q_{loss\,cold\,b-up}\right)/COP_{th}$$

  - **Back-up consumption**

The energy consumption of the hot and cold back-ups can be determined from:

- sub-meters on the back-ups (gas or electricity meter, etc.): in this case, the consumptions are in relation to the total requirements (including distribution losses and equipment efficiency);
- thermal energy supplied to the system (Q2a, Q2b, Q2c, Q8) and average generation efficiencies (Rg_c and Rg_f). These consumptions are in relation to useful requirements (Q3', Q4' and Q10').

The average generation effiency values of the back-ups to be taken into account are given in Appendix 5

- Hot back-up: $Conso_{hot\,b-up} = Q2/Rg_c = (Q2a + Q2b + Q2c)/Rg_c$

  Energy consumption of the hot back-up is determined from the thermal heat energy supplied by the back-up (Q2) and the average heat efficiency generated by the back-up (Rg_c)[3].

- Cold back-up: $Conso_{cold\,b-up} = Q8/Rg_f$

  Energy consumption of the cold back-up is determined from the thermal cooling energy supplied by the back-up to cold storage (Q8) and the cooling generation efficiency of the cold back-up (Rg_f).

- **<u>Thermal efficiency indicators</u>**

  - **Thermal storage efficiencies**

Hot and/or cold storage efficiencies are defined by:

- Hot storage:

  Customized : $\eta_{hs} = 1 - Q_{loss\,hot}/Q1$

  Productized : $\eta_{hs} = 1 - Q_{loss\,hot}/(Q1 + Q2a)$

- Cold storage: $\eta_{cs} = 1 - Q_{loss\,cold}/Q7$

  As shown previously for hot storage, cold storage efficiency (η_{cs}) is evaluated from the cold storage energy report in relation to its thermal losses.

  <u>Note</u>: If the cold back-up is connected to cold storage, cold storage efficiency is expressed according to the following formula:

$$\eta_{cs} = 1 - Q_{loss\,cold}/(Q7 + Q8)$$

  - **Thermal performance coefficient**

The thermal performance coefficient[4] (COP_{th}) corresponds to the ratio between the thermal cooling energy supplied by the evaporator (Q7) and the thermal heat energy supplied to the generator of the sorption machine (Q6):

---

[3] If the hot back-up uses fossil fuels (natural gas or fuel oil), the consumption values must be converted from HHV to LHV, i.e. divided by 1.11 for natural gas and by 1.07 for fuel oil.

[4] This coefficient only applies to the air-conditioning season.

$$COP_{th} = Q7/Q6$$

- **Solar performance indicators**

  - **Useful solar productivity**

Useful solar productivity (PSU) corresponds to the thermal solar energy exploited by the system (useful solar energy, ESU) in relation to a unit surface of solar collectors. This indicator is expressed in kWh/m². It can be a good indicator for sizing because the greater the solar collector surface installed, the lower the productivity of a unit surface.

$$PSU = ESU/Aa$$

Aa refers to the input surface of the solar collectors expressed in m².

  - **Solar collector thermal yield**

This indicator expresses the system's ability to recover the solar energy available and primary loop performance in particular. The solar collector thermal yield (R_{coll}) is calculated according to the following ratio:

$$R_{coll} = Q1/Qsol$$

  - **Solar thermal efficiency**

The solar thermal efficiency (R_{sol}) of the system is a dimensionless number which corresponds to the useful solar energy in relation to the total sunshine on the collector input surface. This indicator represents the system's ability to exploit sunshine.

$$R_{sol} = ESU/Qsol$$

  - **Solar electric performance coefficient**

The "solar" performance coefficient defined as $COP_{elec\ sol}$ corresponds to the ratio of the system's useful solar energy to auxiliary consumption. This indicator expresses the ratio between the energy which needs to be supplied to the system in order to exploit solar energy and the useful solar energy. This dimensionless indicator is expressed according to the following ratio:

$$COP_{elec\ sol} = ESU/E_{aux\ sol}$$

This indicator can also prove extremely relevant in seasonal applications in order to distinguish between air-conditioning/domestic hot water and heating and/or domestic hot water operating modes.

- **Overall system performance indicator**

  - **Primary energy ratio**

The PER (Primary Energy Ratio) corresponds to the ratio between the energy supplied to the building and the system's primary energy consumption. The indicator takes into account all the different forms of energy consumption (electricity, gas, wood, fuel oil, etc.) expressed in terms of primary energy.

This indicator can therefore be used to quantify system performance in terms of overall energy efficiency.

$$PER = (Q10 + Q3 + Q4)/\left(E_{aux} \cdot \varepsilon_{elec.} + Conso_{cold\ b-up} \cdot \varepsilon_X + Conso_{hot\ b-up} \cdot \varepsilon_X\right)$$

The following coefficients can be used for converting final energy into primary energy (ε_X), in accordance with RT 2012 [16]:

- Electricity: 2.58
- Wood: 1
- Gas and fuel oil: 1[5]

The PER can be used during different stages of the project. For instance during feasibility studies, the PER can be established on the basis of the calculated requirements for the building. Subsequently, during the system monitoring stage, the PER can be established based on energy measured from the system.

Note 1: This indicator can also prove relevant in seasonal applications in order to distinguish between air-conditioning/domestic hot water and heating and/or domestic hot water operating modes.

Note 2: If we consider the PER as the main overall performance indicator, this prevents penalising gas or wood back-up systems with a lower SPF than the steam compression system but nonetheless a PER of the same order of magnitude.

- **Ecological impact indicator**
  - **Specific water consumption**

The Specific Water Consumption (WC_{spe}) of the system represents the quantity of water consumed in relation to the cooling production of the absorption machine and is expressed in l/kWh. This indicator is only valid for the air-conditioning season.

$$WC_{spe} = V1/Q7$$

- **Economic indicator**
  - **kWh production cost**

The cost of kWh (kWh_{cost}) indicator corresponds to the ratio between the energy supplied and the cost of the system's consumption of final energy and water. It is expressed in €/kWh.

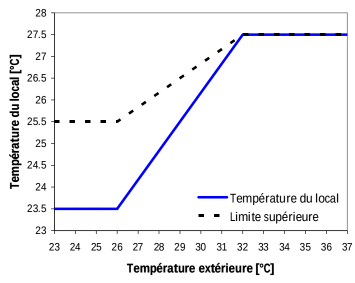
$$kWh_{cost} = \left(E_{aux} \cdot €_{elec.} + Conso_{cold\,b-up} \cdot €_X + Conso_{hot\,b-up} \cdot €_X + V1 \cdot €_{eau}\right) / \left(Q10 + Q3 + Q4\right)$$

If $€_{elec.}$ represents the price of an electric kWh in €/kWh, $€_{water}$ represents the price of a m^3 of water in €/m^3 and $€_X$ represents the price of a kWh of energy X considered in €/kWh.

- **Quality indicators**
  - **Comfort indicator**

The comfort indicator (I_{comf}) shows that the system is operating correctly from the user's point of view. It is divided into two seasons corresponding to the air-conditioning and heating seasons.

As far as the air-conditioning season is concerned, the temperature of the premises must be lower than a threshold temperature depending on the outside temperature, in accordance with the German standard DIN 1946 (see opposite)



Note: The comfort indicator shown here does not take into account compliance with the second recommendation of the DIN 1946 standard, i.e.

5 The coefficients for converting final energy into primary energy for gas and fuel oil are based on LHV.

controlled hygrometry (relative humidity constantly less than 50%). The indicator is difficult to apply given that hygrometric measurements in buildings are virtually nonexistent.

COMFORT TEMPERATURE DURING THE AIR-CONDITIONING PERIOD IN ACCORDANCE WITH STANDARD DIN 1946

As far as the heating season is concerned, the set recommended internal temperature is 19°C, in accordance with RT 2005.

For both seasons, the comfort indicator is defined in relative terms (as a %) taking the number of hours during which the internal temperature meets the recommendation in relation to the number of hours during which the recommendation should be met. The indicator therefore takes into account periods of absence.

- **Proper operating indicators**

Two proper operating indicators are defined:

- Operating indicator (I_{op}) which corresponds to the number of days the system is in operation (operating time). This indicator is expressed in relative terms (as a %) in relation to the number of days in the period in question;
- Data monitoring indicator (I_{Data}) corresponds to the number of days when system monitoring data was lost. It is expressed in relative terms (as a %) in relation to the number of days in the period in question.

Appendix 2: Definitions and formulae for calculating indicator thresholds

The definition and formulae for calculating indicator thresholds is based mainly on [37].

- **Thermal efficiency indicator thresholds**

  - **Minimum thermal storage efficiencies**

The hot and cold storage efficiencies thresholds are determined on the basis of theoretical thermal storage losses as defined in RT2005 [17]. These are minimum values.

Target hot and cold storage efficiencies can therefore be expressed as follows:

- **Hot storage:**

Customized:

$$\eta_{hs,\,\min} = 1 - Q_{loss\ hot\ ref} / Q1$$

Productized:

$$\eta_{hs,\,\min} = 1 - Q_{loss\ hot\ ref} / (Q1 + Q2a)$$

Thermal losses from the hot storage tank given as a reference ($Q_{loss\ hot\ ref}$) take into account the unit volume of the tanks used for storing the system's hot water (V_{hs}), the temperature of the storage tank location (T_{amb} presumed to be 20°C) and the number of months of system operation during the period in question (N_{months}). Losses are calculated according to the following ratio:

$$Q_{loss\ hot\ ref} = \left[N_{hs} \cdot 4.2 \cdot V_{hs}^{0.55} * (T_{hot} - T_{amb}) \cdot 365 \cdot N_{months}\right] / (12 \cdot 1000)$$

The storage temperature for hot water (T_{hot}) is calculated according to the system's operating mode (presumed to be 80°C for air-conditioning/cooling and 60°C for heating /domestic hot water) monthly proportional to usage, taking into account the number of months the system has been operating in air-conditioning mode ($N_{cold\ months}$) during the period in question (N_{months}):

$$T_{hot} = 80 \cdot N_{cold\ months} / N_{months} + 60 \cdot \left(1 - N_{cold\ months} / N_{months}\right)$$

Note 1: If there is no hot storage tank, target hot storage efficiency is 1.

Note 2: As part of a study of good practice for the combined solar system SSC [18], it has been shown that a difference (factor 2) linked to implementation (hydraulic connection and quality of insulation implementation) is often found between theoretical and real losses.

- **Cold storage:**

$$\eta_{cs,\,\min} = 1 - Q_{loss\ cold\ ref} / Q7$$

Note: If the cold back-up is connected to cold storage, cold storage efficiency is expressed as follows:

$$\eta_{cs,\,\min} = 1 - Q_{loss\ cold\ ref} / (Q7 + Q8)$$

Thermal losses from cold storage given as a reference ($Q_{cold\ loss\ ref}$) take into account the unitary volume of tanks for storing the system's chilled water (V_{cs}), the storage location temperature (T_{amb} presumed to be 20°C), the storage temperature of the chilled water

(T_{cold} presumed to be 12°C), the number of months the system has operated during the period in question (N_{months}) and is calculated according to the following ratio:

$$Q_{loss\ cold\ ref} = \left[N_{cs} \cdot 4.2 \cdot V_{cs}^{0.55} * \left(T_{amb} - T_{cold}\right) \cdot 365 \cdot N_{months}\right] / \left(12 \cdot 1000\right)$$

Note: If there is no cold storage, the target cold storage efficiency is equal to 1.

- **Minimum thermal performance coefficient**

The performance coefficient shows that the absorption machine is working properly. Given its value below 1 (except for double or triple effect machines which are not yet commonly found on the market), it would seem important to operate the machine in conditions which are as close as possible to nominal conditions (often favourable) specified by the manufacturers. This value, called $COP_{th,\ constr.}$, is specified in the technical documentation for sorption machines available on the market.

Since the machine is part of a system operating under dynamic conditions which are different to the manufacturer's test conditions, COP_{th} is rarely equal to the nominal value. It is therefore possible to define a minimum COP_{th} as follows:

$$COPth_{\min} = 0.80 \cdot COPth_{constr.}$$

Factor 0.8 used in the equation is rather ambitious. A study conducted by CLIMESPAC-GDF Suez [28] showed that performance levels (EER) measured in-situ for a vapour compression cold unit were 32% to 78% lower than those specified by the manufacturer [20]. Extending this study to heat pumps and reversible configurations (air-conditioning and heating) shows variations between EER and COP and the SPF measured in-situ of between 23.8 and 48.1%, as shown in figure 11 below (based on a synthesis of 570 systems in Europe, including any type of cooling system).

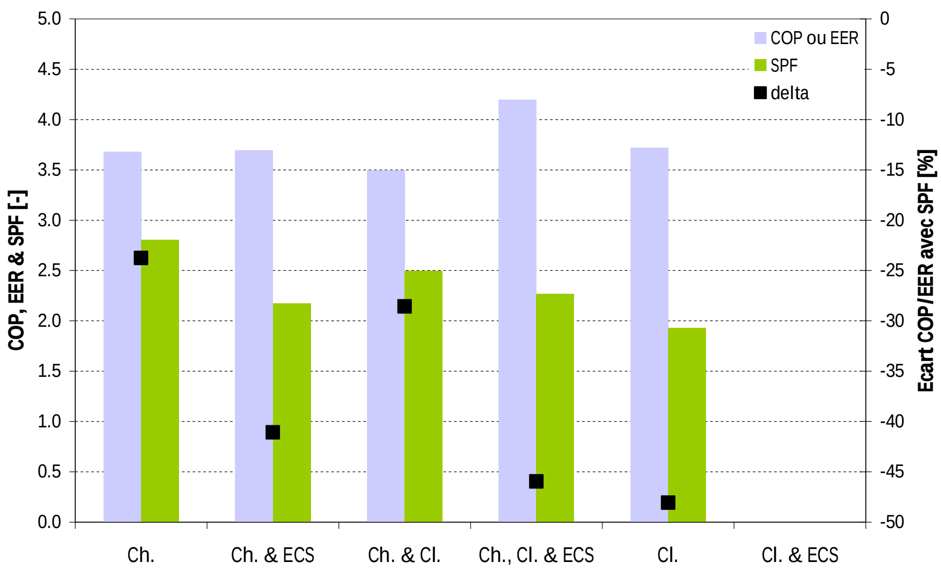


FIGURE 11 - COMPARISON OF COP AND EER WITH SPF BASED ON MONITORING DATA ON LOCATION DEPENDING ON SYSTEM CONFIGURATIONS [28 TO 36]

Note 1: In an effort to maximise machine performance, it would no doubt be better to refer to the machine's maximum performances, i.e. the maximum COP_{th}. This figure is however hardly ever given by the manufacturer.

Note 2: Ideally, it would be best to return to a “standardised” COP_{th} between different manufacturers according to the same temperature levels. The definition of this type of test is on the agenda of Task 48 of the IEA SHC [19].

- **Solar performance indicator threshold**

  - **Minimum useful solar productivity**

The minimum threshold for useful solar productivity defined in the EMERGENCE [11] program is 350 kWh/m²/year. As this is an annual value, the definition suggested below includes an adjustment value depending on the system’s operating time (N_{months}).

$$PSU_{\min} = (350 \cdot N_{months})/12$$

Note: Taking into account the system’s operating time when calculating useful solar productivity takes away the notion of profitability for each m² of collectors installed. This information should be taken into account in economic indicators.

  - **Minimum solar thermal yield**

Minimum solar collector thermal yield ($R_{coll,\ min}$) is calculated according to standardised coefficients (a_0, a_1 and a_2) from the quadratic output equation corresponding to the solar collectors installed on the system and available according to relevant technical opinions.

$$\eta_{coll,\min} = a_0 + a_1 \cdot (T_{av} - T_{ext})/ENS - a_2 \cdot (T_{av} - T_{ext})^2 / ENS$$

Note: As a result of reflections on overall efficiency, factors for modifying the angle of incidence and wind influence have been ignored.

The average temperature of the collector (T_{av}) is regarded as a typical use average (80°C if air-conditioning alone, 62.5°C (average of 80 and 45°C) for mixed usage.

Average sunshine (ENS) of the location in question is calculated on the basis of sunshine measurements carried out locally (Qsol).

$$ENS = \left(1000 \cdot \sum_{0}^{12} Qsol\right) \bigg/ \left(Nh_{ENS} \cdot Aa \cdot \sum_{0}^{12} t_{fct}\right)$$

If the operating time is unknown (t_{op}), the duration of operating months in days must be taken into account. The average external temperature is regarded as [22] according to NASA data or, even better, measured locally. The average number of hours of sunshine per day (Nh_{ENS}) is considered to be equal to 8 hours/day (with an average sunlight of 12 hours but without taking into account the system’s operating limits; start-up thresholds, objects masking the sun, etc.)

  - **Minimum solar thermal efficiency**

The system’s minimum solar thermal efficiency is based on the value of the solar collector thermal yield, the COP_{th} of the sorption machine and the operating times in air-conditioning or cooling/heating or domestic hot water as follows:

$$Rsol_{\min} = \left[(COPth \cdot N_{c\lim})/N_{months} + 1 - N_{c\lim}/N_{months}\right] \cdot R_{coll}$$

Note: For systems also working in heating mode, the criteria seem easier to reach. However, if the system has been implemented properly, the minimum performance threshold should be reached.

  - **Solar electric performance coefficient**

The solar electric performance coefficient is relative to the electricity consumption of the auxiliaries needed to exploit useful solar energy. The minimum threshold defined by the EMERGENCE [11] program for COP_{elec} is 5.

Note: For the EMERGENCE [11] program, this value was not defined using the same definition of useful solar energy and may be a little ambitious for the definition of $COP_{elec\ sol}$ as defined within the framework of the MeGaPICS project.

- **Overall system performance indicator threshold**
  - **Minimum primary energy ratio**

Reference works [21] give an appropriate range of values for PER as 1 to 1.7 inclusive for cold solar systems. In the same way, considering a comparison with reversible heat pumps the Seasonal Performance Factor given by EUROVENT [20] for class B machines less 20% to reflect their real operation, the corresponding PER is 0.95.

Consequently, the minimum threshold for PER is 1.

- **Ecological impact indicator threshold**
  - **Maximum specific water consumption**

Under "normal" operating conditions, a heat rejection system using water (cooling tower, adiabatic dry cooler, etc.) consumes approximately 2.7 to 3.3 litres of water per kWh of energy rejected [23]. In an effort to encourage the reduction of water consumption of systems, the lower threshold is taken into account here. The maximum threshold for water consumption can be expressed in kWh of cool produced via the COP_{th} by the following formula:

$$WC_{spe.\max} = 2.7 \cdot (1 + COP_{th}) / COP_{th}$$

- **Economic indicator threshold**
  - **Maximum production cost of a kWh**

The cost of a kWh at maximum production is defined in comparison to an equivalent system.

$$kWh_{cost,\max} = \lfloor 0.02 \cdot (Q4 + Q3 + Q2) \cdot €_{elec.} + (Q4 + Q3) / Rg_c \cdot €_X + Q10 / Rg_f \cdot €_X \rfloor / (Q4 + Q3 + Q10)$$

The equivalent system, i.e. which provides the same service as the system, corresponds to the system's hot and cold auxiliaries only. If the latter are unknown or inexistent, the reference system taken into consideration will be a gas boiler (Rg_c = 0.75) for the production of heating and domestic hot water, and a cold steam compression unit (Rg_f = 2.46) for the production of air-conditioning. In agreement with [9], auxiliary consumption is supposed to be 2% of the energy distributed.

- **Quality indicator threshold**
  - **Minimum comfort indicator**

The minimum value assumed for the comfort indicator ($I_{comf,\ min}$) is 90%.

  - **Proper operating indicators**

The minimum value assumed for the operating indicator ($I_{op,\ min}$) is 90% and the maximum value assumed for the data loss indicator ($I_{Data,\ max}$) is 10%.

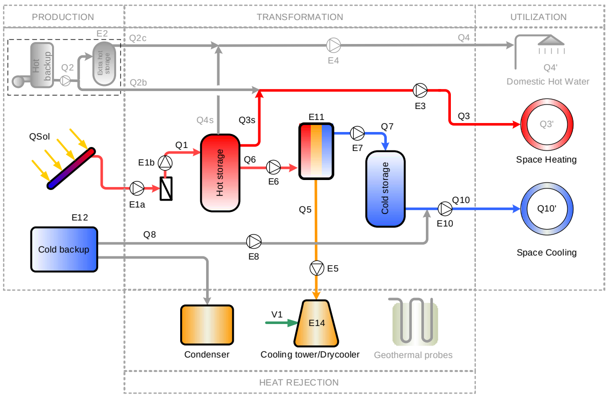
Appendix 3: Illustrations of different configurations

Illustrations of different applications are given in this appendix based on the generic diagrams set out in the Section X.

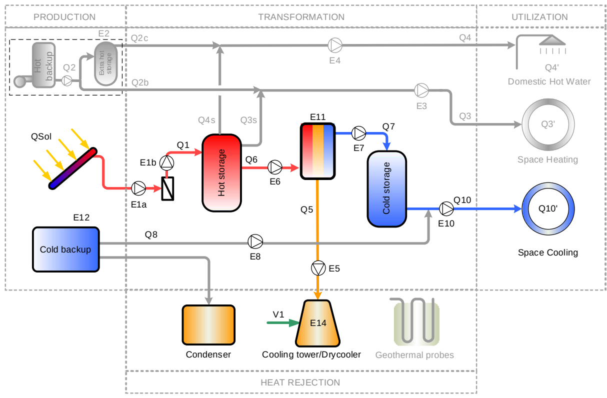
LIST OF ILLUSTRATIONS DRAWN UP FOR DIFFERENT APPLICATIONS

SERVICES COOL: COOLING AIR-CON: AIR-CONDITIONING HEAT: HEATING DHW: DOMESTIC HOT WATER	HOT BACK-UP	COLD BACK-UP	EXAMPLE OF EXISTING SYSTEMS	DIAGRAM NO.
Collective systems				
COOL	×	×	RAFSOL, GICB	A1
COOL + HEAT	×	×	SOLACLIM	A2
COOL + HEAT	✓	×	MACLAS, SONNENKRAFT	A3
COOL + DHW	✓	×	VENELLES	A4
COOL + HEAT +DHW	✓	×	GIVAUDAN	A5
AIR-CON	×	✓	Port Louis	B1
AIR-CON +HEAT	×	✓	Saint Maxime	B2
AIR-CON +HEAT	✓	✓	ISTAB	B3
AIR-CON + DHW	✓	✓		B4
AIR-CON + HEAT + DHW	✓	✓	CRES	B5
“SSC+” systems				
AIR-CON + HEAT +DHW	✓	×	SOLERA (without DHW)	C
AIR-CON + HEAT +DHW	✓	✓		D

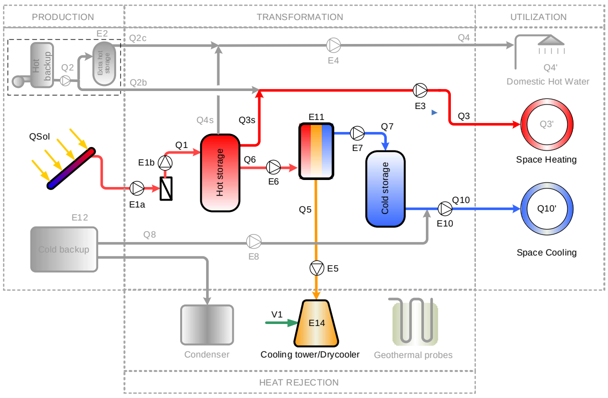
A1



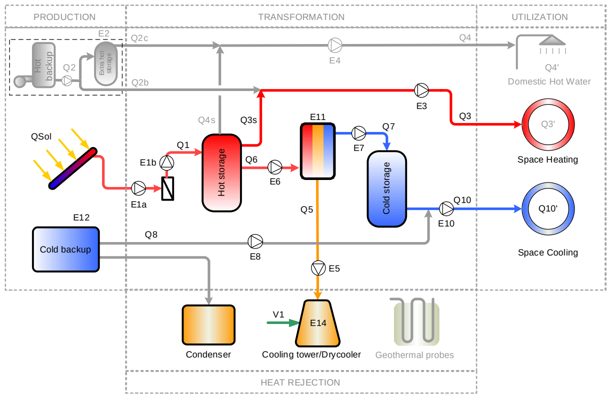
B1



A2



B2



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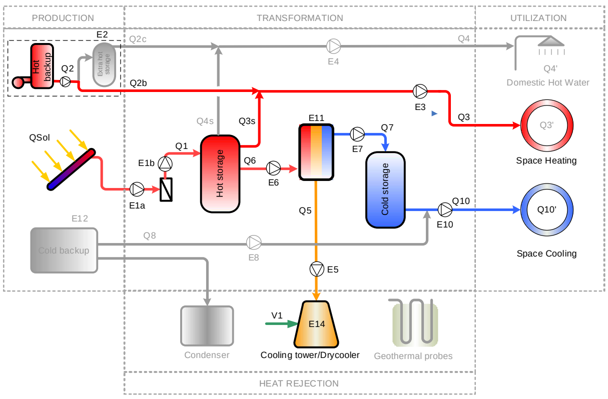

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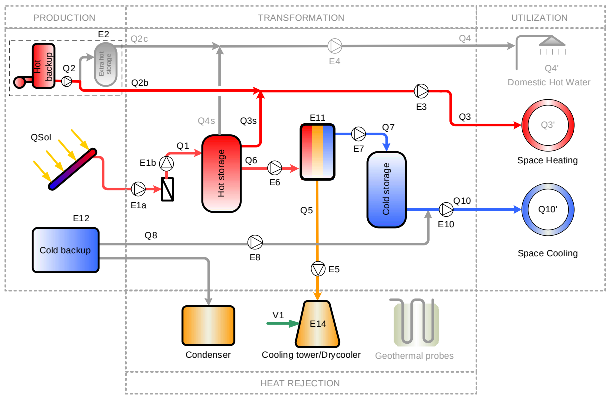

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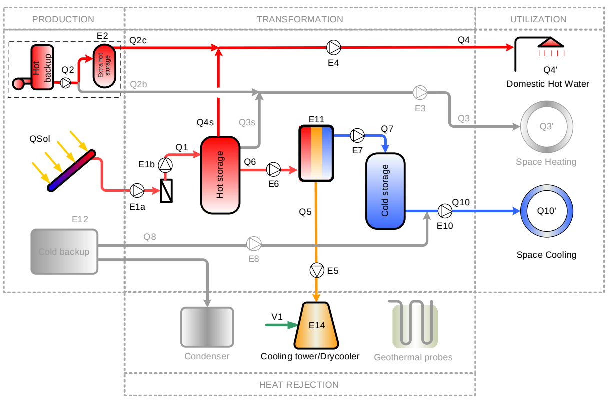
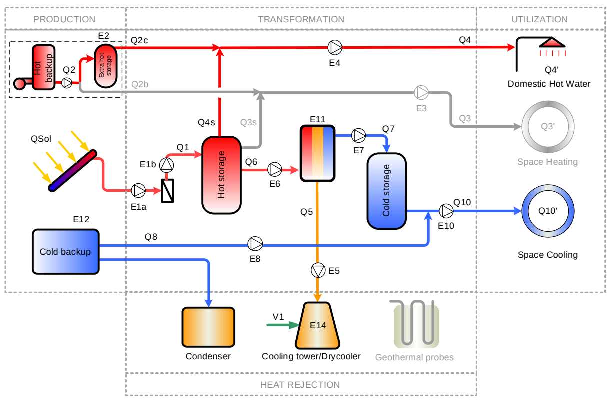
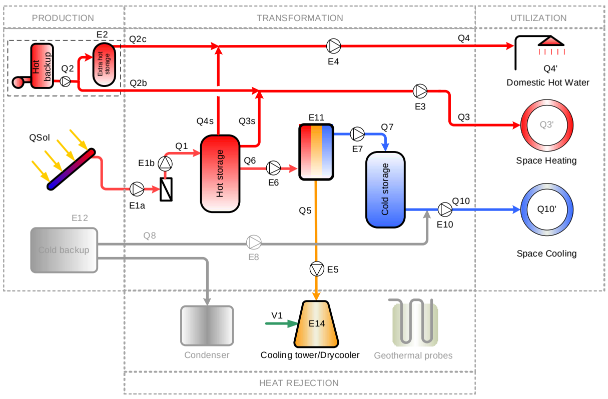


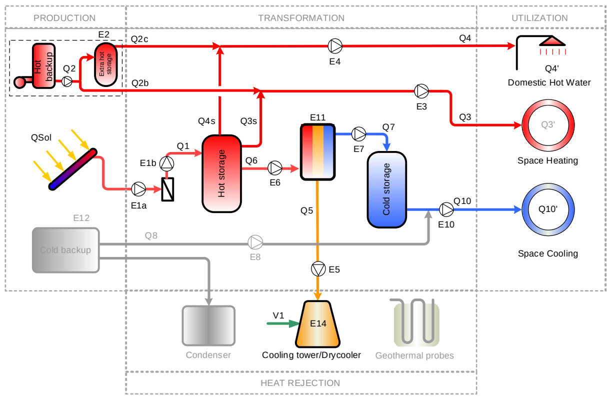
B4



A5


PRODUCTION
TRANSFORMATION
UTILIZATION
Hot backup
Extra hot storage
E2
Q2
Q2c
Q2b
Q4
E4
E3
Q4'
Domestic Hot Water
Q4s
Q3s
Q3
QSol
Q1
E1b
E1a
Hot storage
Q6
E6
E11
Q7
E7
Cold storage
Q3'
Space Heating
Q5
Q10
E10
Q10'
Space Cooling
E12
Cold backup
Q8
E8
E5
V1
E14
Condenser
Cooling tower/Drycooler
Geothermal probes
HEAT REJECTION

B5


PRODUCTION
TRANSFORMATION
UTILIZATION
Hot backup
Extra hot storage
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Q2c
Q2b
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Domestic Hot Water
Q4s
Q3s
Q3
QSol
Q1
E1b
E1a
Hot storage
Q6
E6
E11
Q7
E7
Cold storage
Q3'
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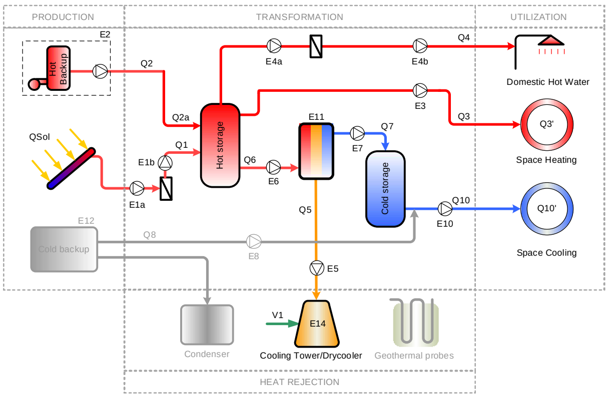
Q5
Q10
E10
Q10'
Space Cooling
E12
Cold backup
Q8
E8
E5
V1
E14
Condenser
Cooling tower/Drycooler
Geothermal probes
HEAT REJECTION

C


PRODUCTION
TRANSFORMATION
UTILIZATION
Hot Backup
E2
Q2
E4a
E4b
Q4
Domestic Hot Water
Q2a
E3
Q3
QSol
Q1
E1b
E1a
Hot storage
Q6
E6
E11
Q7
E7
Cold storage
Q3'
Space Heating
Q5
Q10
E10
Q10'
Space Cooling
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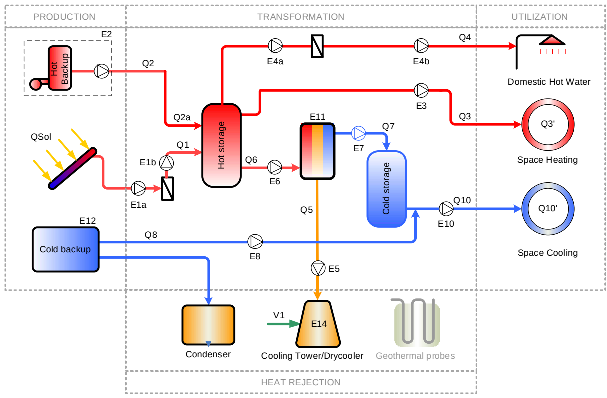
Cold backup
Q8
E8
E5
V1
E14
Condenser
Cooling Tower/Drycooler
Geothermal probes
HEAT REJECTION

D


PRODUCTION
TRANSFORMATION
UTILIZATION
Hot Backup
E2
Q2
E4a
E4b
Q4
Domestic Hot Water
Q2a
E3
Q3
QSol
Q1
E1b
E1a
Hot storage
Q6
E6
E11
Q7
E7
Cold storage
Q3'
Space Heating
Q5
Q10
E10
Q10'
Space Cooling
E12
Cold backup
Q8
E8
E5
V1
E14
Condenser
Cooling Tower/Drycooler
Geothermal probes
HEAT REJECTION

Appendix 4: Example of a system control panel

The "system control panel" summarises all the system's characteristics as well as the adjustment settings and values obtained on commissioning together with detailed adjustment regulations.

The system's detailed hydraulic diagram must be attached to the system control panel.

CONTROL PANEL **Cooling or air-conditioning solar system with solar heating /domestic hot water**		
System information		
System name		
Address		
Participants	Contractor:	
	Operators:	
	Etc.	
Schematic diagram		
Technical description		
Solar circuit (primary and secondary)		
Collectors	Brand / Model:	
	Unit input surface:	
	Coefficient a_0, a_1, a_2:	
	Total input surface:	
	Number of batteries:	
	Tilt angle:	
	Orientation:	
Adjustment valves	General:	*no. of sensors, flow +adjustment valve (brand, type, revs)*
	Battery no.1:	*no. of sensors, flow +adjustment valve (brand, type, revs)*
	Battery no.2:	*…*
	Etc.:	
Solar circuit pump	Brand / Type:	
	Flow / Hm:	
	Elec. characteristics:	
Energy or volumetric meter	Brand / Type:	
	Qn:	
	DN:	
Security	Expansion tank:	*volume, brand and type, inflation pressure*
	Security valve:	*calibration pressure*
	Filling pressure:	
Coolant liquid	Brand / Type:	
	Protection temperature:	
	Characteristics:	*density ρ, heating capacity Cp*
Secondary circuit pump	Brand / Type:	
	Flow / Hm:	

	Elec. characteristics:	
Three way valve	Brand / Type:	
	Motor:	*Brand / Type*
	Auxiliary contact:	*Brand / Type*
Exchanger	Brand / Type:	
	Efficiency:	
Sorption machine		
Sorption machine	Brand / Type:	
	Electrical characteristics:	
	Nominal characteristics:	*Power, flow, input/output temperature*
Storage tank Hot solar buffer	Brand / Type:	
	Volumetric capacity:	
	Heat insulation:	*thickness, fire protection*
Storage tank Cold buffer	Brand / Type:	
	Volumetric capacity:	
	Heat insulation:	*thickness, fire protection*
Circuit generator		
Pump	Brand / Type:	
	Flow / Hm:	
	Elec. characteristics:	
Adjustment valve	Brand / Type:	
	Flow:	
	Revs:	
Energy or volumetric meter	Brand / Type:	
	Qn:	
	DN:	
Security	Expansion tank:	*volume, brand and type, inflation pressure*
	Security valve:	*calibration pressure*
	Filling pressure:	
Evaporator circuit		
Pump	Brand / Type:	
	Flow / Hm:	
	Elec. characteristics :	
Adjustment valve	Brand / Type:	
	Flow:	
	Revs:	
Energy or volumetric meter	Brand / Type:	
	Qn:	
	DN:	
Security	Expansion tank:	*volume, brand and type, inflation pressure*
	Security valve:	*calibration pressure*
	Filling pressure:	
Cooling circuit		
Pump	Brand / Type:	
	Flow / Hm:	
	Elec. characteristics :	
Adjustment valve	Brand / Type:	
	Flow:	
	Revs:	
Energy or volumetric meter	Brand / Type:	
	Qn:	
	DN:	
Security	Expansion tank:	*volume, brand and type, inflation pressure*
	Security valve:	*calibration pressure*
	Filling pressure:	
Cooling system	Type:	*open circuit tower / dry cooler / vapour / etc…*
	Brand / Type:	
	Elec. characteristics :	
Command control		

Regulation device	Description of the regulation law	
Primary solar pump	Type:	*TOR / PI / PID*
	Principle:	
	Operating threshold values:	
	Stop threshold value:	
	Security threshold values:	
Solar three way valve	Type:	*TOR / PI / PID*
	Principle:	
	Operating threshold values:	
	Stop threshold value:	
Secondary pump	Type:	*TOR / PI / PID*
	Principle:	
	Operating threshold values:	
	Stop threshold value:	
Generator pump	Type:	*TOR / PI / PID*
	Principle:	
	Operating threshold values:	
	Stop threshold value:	
Absorption machine	Type:	*TOR / PI / PID*
	Principle:	
	Operating threshold values:	
	Stop threshold value:	
Cooling pump	Type:	*TOR / PI / PID*
	Principle:	
	Operating threshold values:	
	Stop threshold value:	
Cooling system	Type:	*TOR / PI / PID*
	Principe:	
	Operating threshold values:	
	Stop threshold value:	
Evaporator pump	Type:	*TOR / PI / PID*
	Principle:	
	Operating threshold values:	
	Stop threshold value:	
Etc.	Type:	*TOR / PI / PID*
	Principle:	
	Operating threshold values:	
	Stop threshold value:	

Appendix 5: Efficiency values for heat energy generation and cooling generation efficiency

▪ Generation efficiency of the heat production systems

The average heat energy generation efficiency (Rg_c) depending on the type of back-up, the technology and the energy used are given in the table below, obtained from DPE [6].

VALUE OF HEAT GENERATION EFFICIENCY (RG_C) DEPENDING ON THE TYPE OF GENERATOR FOR SHARED BUILDINGS

Heating system	Rg_c
No heating system, electrical convectors NF electrical performance category C, electric panel heaters or NF C electric radiators, underfloor or ceiling electric heating, electric accumulation radiator or electric underfloor accumulation heating, direct electric or other system	1
Split or multisplit	2.6
Gas suction radiators	0.73
Gas radiator on chimney	0.68
Individual gas boiler installed before 1988	0.57
Individual gas boiler installed between 1988 and 1999	0.68
Individual gas boiler installed after 2000	0.72
Individual low temperature gas boiler	0.75
Individual condensation gas boiler	0.8
Individual electric boiler	0.95
Air/air heat pump	1.9
Collective gas or fuel oil boiler installed before 1988	0.65
Collective free-standing gas or fuel oil boiler installed before 1988 with change of burner	0.7
Collective gas or fuel oil boiler installed between 1988 and 2000	0.75
Collective gas or fuel oil boiler installed after 2000	0.8
Collective gas or fuel oil condensation boiler	0.85
Collective wood boiler, class unknown	0.4
Collective wood boiler, class 1	0.45
Collective wood boiler, class 2	0.5
Collective wood boiler, class 3	0.55
Collective coal boiler	0.5
Heat network	0.9
Collective electric boiler	0.95
Bijunction convectors	1
Collective electric underfloor heating	1
Collective electric air/water heat pump	2.6
Collective electric water/water heat pump	3.2
Geothermic electric heat pump	4
Electric underfloor storage heating	1
Gas air/air or air/water heat pump	1.2 HHV
Gas brine/water or water/water heat pump (HHV)	1.3 HHV

Note 1: DPE is a tool for diagnosing the energy performances of existing buildings. The systems concerned are generally connected to existing equipment, such as radiators, and the heat requirements are considerable. This distinction is particularly important for heat pump technology, the performance of which depends greatly on combining pumps with other equipment.

Nevertheless, it does not seem relevant to consider manufacturer's indicated boiler efficiency because the figures given do not correspond to an average annual efficiency but to instant efficiency, and the use of DPE generation efficiency only considers a single unified source for different types of generator.

Note 2: As the values specified for gas heat pumps are not given in the DPE, the values suggested here are representative average annual values for the various products on the market. These values were obtained by GDF Suez according to two methods which gave identical results:

- by using the average of the nominal values for different operating conditions and by applying a corrective ratio to change the nominal value to the annual value. This ratio was validated by tests on a gas heat pump motor;
- values have been validated by a calculation tool in EXCEL (GDF SUEZ) which can be used to predict annual performance levels of different parameters;
- generation efficiency for fossil fuel generators are given as HHV values.

- **Cooling generation efficiency of cooling production systems**

Cooling generation efficiency (Rg_f) depending on the technology, is given in the following table, obtained from RT 2005 [5].

NOMINAL COOLING GENERATION EFFICIENCY (RG_F) DEPENDING ON THE TYPE OF GENERATOR

<table>
<tr><th rowspan="2">Type of product</th><th colspan="2">Nominal cooling efficiency (Rg_f)</th></tr>
<tr><th>Before 2000</th><th>After 2000</th></tr>
<tr><td>Air-conditioners 12 – 45 kW</td><td>2.4</td><td>2,5</td></tr>
<tr><td>Air-conditioners > 45 kW</td><td colspan="2">2.3</td></tr>
<tr><td>Air condensation cooling unit 20 – 80 kW</td><td colspan="2">2.5</td></tr>
<tr><td>Air condensation cooling unit > 80 kW</td><td colspan="2">2.6</td></tr>
<tr><td>Water condensation cooling unit 20 – 80 kW</td><td>4.0</td><td>3,8</td></tr>
<tr><td>Water condensation cooling unit > 80 kW</td><td>3.7</td><td>4,2</td></tr>
<tr><td>Gas air/air heat pump motor</td><td colspan="2">1.5</td></tr>
<tr><td>Gas air/water heat pump motor</td><td colspan="2">1.3</td></tr>
<tr><td>Absorption heat pump</td><td colspan="2">0.7</td></tr>
</table>

The values used for cooling generation efficiency correspond to nominal values and will be used as default values as no official average values are available.

As the values given for gas heat pumps are not included in the DPE, the values suggested here are nominal values (identical to those taken into account for other equipment) representative of different products on the market and supplied by GDF Suez. Values for gas back-ups are given in LHV.