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A SIMPLE PREDESIGN TOOL FOR SOLAR COOLING, HEATING AND DOMESTIC HOT WATER PRODUCTION SYSTEMS

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ABSTRACT

In the framework of the MEGAPICS project "method toward guarantee of solar cooling and heating system", a simplified pre-design tool for designer and planner has been elaborated.

The method is applied to a selected set of configuration schemes for solar cooling, heating and domestic hot water (DHW) production systems using absorption or adsorption chillers, assisted or not by hot and/or cold conventional back-up systems. The tool provides theoretical but realistic values of system performance indicators. Its main advantages compared to other tools are:

- a few parameters are required ; most of them are pre-sized ones with automatic functions,
- the calculation time is reduced (about ten seconds), therefore the user can easily run several simulations so as to find the most suitable solution between component size and best performances.

The paper presents the tool, focusing on simplified component models and pre-design function. Validation results are provided, showing both experimental and theoretical results and their comparison.

INTRODUCTION

The MeGaPICS project aims at finding a method to guarantee the performance of the solar cooling, heating and DHW production installations. The project focuses on a better knowledge of solar cooling and heating systems, on the development of tools to compare theoretical performances and real ones, and on setting up best practice cases and guidelines [Le denn, 2012].

For this purpose and in order to evaluate the feasibility of the installations, a simplified modelling tool has been developed for designers, planners and professional community.

SIMPLIFIED MODEL DESCRIPTION

The tool aims to realize easy and quick calculation of solar installation for cooling, heating and DHW production. It helps the user to pre-size the installation and provides energy balance and annual performance indicators.
The tool is composed of a user interface to upload an input file, to fill the parameter and to choose the main component characteristics. The tool also includes the calculation tables, the material databases and a step by step help file. All of them are briefly described in the following paragraphs.

General information, application selection and inputs user interface

After describing the project with general information (name of the project, date of the study …), the location of the system is defined. An automatic function (using Google map) can be used in order to define the coordinates (longitude and latitude).

An overview of the general information, parameters and input user interface is presented in Figure 1.

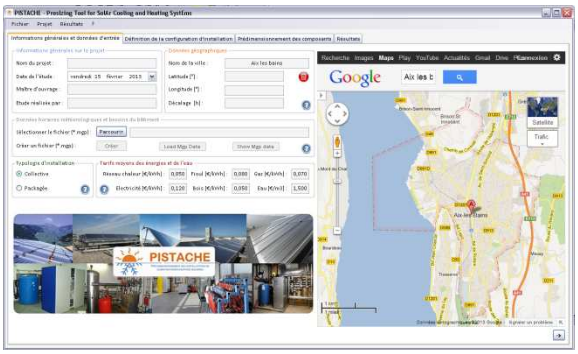

Figure 1 Input user interface

The tool is based on a one hour time step energy balance approach at system level. It uses an input file composed of meteorological data and building loads. The required input values are detailed in Table 1 They are compatible with the data provided by the standardised building simulation tools. The file is a tab text format with 8760 lines registered with specific extension (*.mgp).

Table 1 Meteorological and load input file (.mgp)*

NAME	UNIT	DESCRIPTION	VALUE
Time	-	Hour of the year	[1 - 8760]
Month	-	Month number of the year	[1 - 12]
Day	-	Day number of the month	[1 - 31]
Hour	-	Hour of the day	[1 - 24]
Text	°C	Ambiant dry bulb temperature	$[-\infty - +\infty]$
G_{HZ}	W/m^2	Global horizontal radiation	$[0 - +\infty]$
HR	%	Ambiant relative humidity	[0 - 100]
Tef	°C	Fresh water temperature for DHW	$[-\infty - +\infty]$
Bchau	kWh	Heating demand	$[0-+\infty]$
Bclim	kWh	Cooling demand	$[0 - +\infty]$
Becs	kWh	DHW demand	$[0 - +\infty]$

The tool proposes two layouts as defined by [Nowag, 2012] :

- Application n°1: small scale system for family houses, small multi-dwellings, using a small size packaged sorption solar system (Figure 2). This configuration is an adaptation of the solar combisystem concept including a cooling function, also called SSC+ or Solar Combi +.

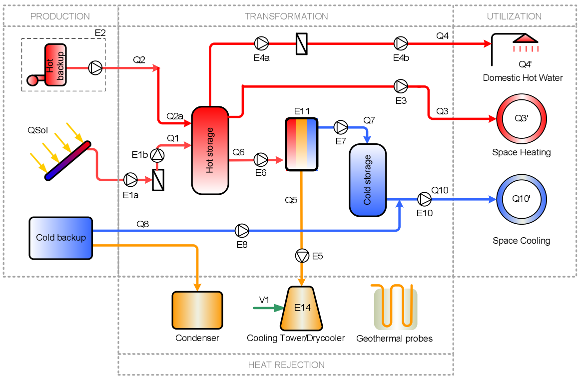

Figure 2 Schematic diagram of a SSC+

- Application n°2: large scale system for multi-dwellings, offices and commercial applications, using customized systems (Figure 3). This layout represents the main configuration of the current market.

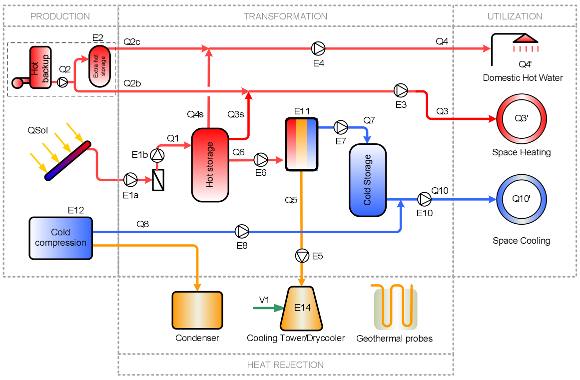

Figure 3 Schematic diagram of a large scale system

System configuration selection user interface

At this step, the cooling, heating and DHW demands are analysed and the user specifies the system configuration. Figure 4 presents an overview of the configuration page of the tool. The configuration parameters are :

- Functions of the solar system : the solar installation is at least used for cooling, but can also be used for heating and/or DHW production;
- Priority of the solar system : if heating and DHW preparation functions are selected, the user must indicate the demand that solar energy has to firstly feed;
- Backup systems : finally, solar energy can be sustained by a cold and/or a hot backup.

The cooling period is fixed by the user or defined automatically according to the cooling demand period.

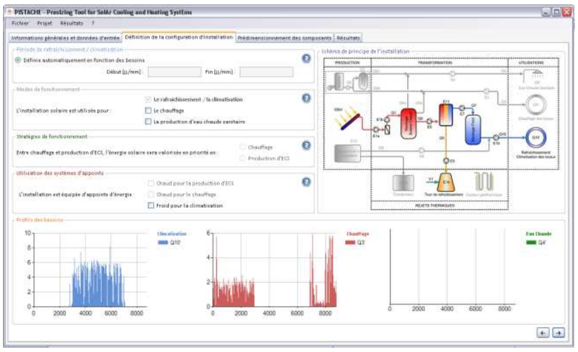

Figure 4 Simulation parameter user interface

Component parameter user interface

At this step, the user specifies the main sizing characteristics of each component of the installation: chiller cooling capacity, number and position of the solar collectors, hot and cold storage capacities, etc... Figure 5 presents an overview of the component user interface.

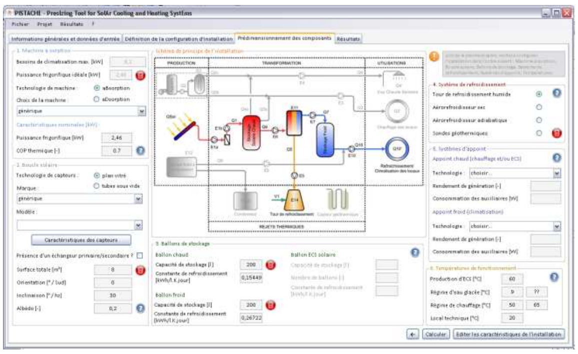

Figure 5 Component user interface

To help this specification step, several automatic functions to pre-size some components can be used. The automatic pre-sizing concerns: the sorption chiller nominal capacity, the solar thermal collector area, the hot and cold storage volumes and their heat loss time constants, as described in the following paragraphs.

- Sorption chiller: Two chiller technologies are available in the tool: absorption and adsorption. According to the chosen technology, the user selects an existing chiller in a market available chiller list established by [Boudéhenn, 2013], or uses a generic chiller with defined nominal cooling capacity and thermal coefficient of performance (COP_{th}). The automatic pre-sizing function consists in advising a cooling capacity according a 'chiller fraction' of the cumulated cooling loads, in a monotonic curve.
- Solar collector area: after having chosen the solar collector technology (flat plate or vacuum tubes), the user selects a market available model in a list or a generic one as defined in [Task 32]. An automatic function calculates with equation (1) the adapted collector field aperture area to feed the sorption chiller in extreme conditions i.e.: with maximal irradiation (G_{HZ} = 1000 W/m²), in nominal condition for the chiller (P_n).

$$S_{coll} = \frac{P_n}{COP_{th}} \times \frac{1}{\eta_{HS} \cdot \eta_{HX}} \times \frac{1}{G_{HZ} \cdot \cdot \eta_{coll}}. \quad (1)$$

- Hot, cold and DHW storages: the volumes of the storages are defined by the user or by using an automatic function. As an example, the hot storage capacity V_{HS} is calculated with equation (3) so as to store ten minutes of the maximum energy required as an inlet at the chiller generator that is to say in nominal conditions.

$$V_{HS} = \frac{P_n}{COP_n} \times \frac{1}{Cp \cdot dT_G} \times \frac{1}{6} \quad (2)$$

  The storage heat loss time constant CR in kWh/°C.liter.day is fixed by the user or automatically calculated according simplified equation (3) and (4) as a function of the storage tank volume V.

  DHW and hot storage : $CR = 1.43 \times V^{-0.42}$ (3)

  cold storage : $CR = 2.75 \times V^{-0.44}$ (4)

- Heat rejection system: four heat rejection technologies are available: wet cooling tower, drycooler, adiabatic drycooler and geothermal probes. Each system is automatically sized to evacuate the totality of the heat rejection energy required by the sorption chiller operation. If the geothermal probes are selected, it is necessary to complete the average depth of the probes and the thermal characteristics of the ground (thermal conductivity, specific thermal capacity and density).
- Hot and cold backup systems: they are selected in a list of common existing equipments; their efficiencies are defined according to [RT2005]. If their auxiliary electrical consumptions are unknown, 2% of the supplied energy will be considered, according to [Sparber, 2009].
- Operating temperatures: the cooling, heating and DHW required temperatures on the building side and the ambient temperature of the technical premise or substation have default values or can be specified by the user.

Hourly simplified calculation

When all the parameters are defined, the calculation can be processed. The tool uses an hourly simplified calculation in order to reduce the calculation time (less than 10 seconds for an annual calculation) while keeping a level of accuracy adapted to a pre-sizing tool (i.e lower than 10% for the annual results compared to the validation cases).

At each time step, the tool runs an energy balance, calculating all the thermal energy flux *Q1(t)* to *Q10(t)* according to the installation configuration, as defined in Figure 2 and 3 and [Nowag, 2012]. Some of the equations used in the method are given below.

At each time step, the solar energy in collectors *Q1(t)* is calculated as a function of:

- solar energy *Qsol(t)* calculated with the solar irradiation $ENS_{SL}(t)$ in the in the sloped collector field area,
- collector efficiency $\eta_{coll}(t)$ calculated with the well-known EN 12975 equation, as function of the collector performance coefficients ($\eta 0$, $a1$, $a2$), the collector average temperature T_{COLL}, the solar irradiation $ENS_{SL}(t)$ and ambient temperature $T_{EXT}(t)$.

At each time step, the chiller thermal coefficient of performance $COP_{th}(t)$ is calculated with equation (5) as a function of the Carnot efficiency η_{Carnot}, .

$$COP_{th} = A_1 \exp\frac{-\eta_{Carnot}}{B_1} + A_2 \exp\frac{-\eta_{Carnot}}{B_2} + COP_{th,0} \quad (5)$$

The A_1, B_1, A_2, B_2 coefficients are obtained with experimental values measured by CEA-INES in test bench, as described in Figure 6.

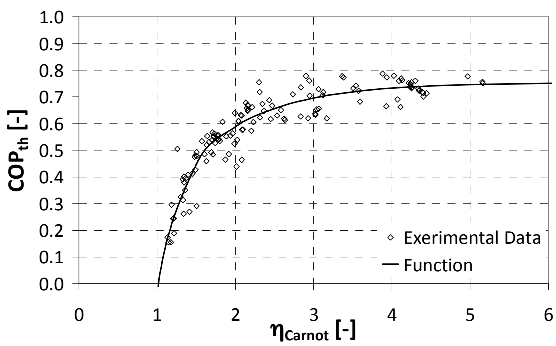

Figure 6 COP_{th} as a function of Carnot efficiency

For the storages, the output energies are calculated as a function of the storage tank capacity (in kWh) and the heat losses. For each tank and each mode (heating, cooling, DHW production) the heat loss $Qloss_{ST}$ is a constant, function of the heat loss time constant, the volume and the temperature difference between the tank (T_{ST}) and the ambiance (T_{AMB}). It is calculated with equation (6) :

$$Qloss_{ST} = \frac{V \times CR \times (T_{ST} - T_{AMB})}{24 \times 1000} \quad (6)$$

Because the tool uses a load file for the building, the performances of the installation are limited at each time step by the building needs and by the hot, cold and DHW storage capacities. If a part of the available solar energy can not be used or stored during the time step, it is considered lost and cumulated in *Q1lost(t)*. Significant energy losses prove the solar system is over-sized. In practice, oversizing solar installation leads to over-investment and risks of collector field overheating.

Results and output

At the end of the hourly calculation process, monthly and annual energy balances are built. The user gets the various energies of the system, according the installation configuration (Figure 2 and 3) i.e the incident solar energy (*Qsol*), the system thermal energies (*Q1* to *Q10*), as well as the auxiliary electrical consumptions (*Ei*) and the water consumption of the heat rejection system (*V1*). The performance indicators are calculated with annual values according to [Nowag, 2012] and briefly described bellow:

- Thermal efficiency indicators: they describe the main system thermal losses through the hot and cold storage efficiencies (η_{HS} and η_{CS}) and the thermal coefficient of performance (COP_{th});
- Global performance indicator: it represents the overall system performances and takes into account the solar energy use as well as the heating and cooling backup energy use. The defined global performance indicator is called primary energy ratio (*PER*);
- Solar performance indicators: they evaluate the system capacity to use the available solar irradiation. They are defined as the collector field thermal yield (η_{COLL}), the solar thermal efficiency (η_{SOL}), the useful solar thermal productivity (*PSU*) and the electrical coefficient of performance of the solar thermal system ($COP_{ELEC\ SOL}$);
- Ecological impact indicator: it is evaluated through the specific water consumption of the heat rejection system (WC_{SPE} in m^3/kWh of cold production) ;
- Economical indicator: it is defined as the operation cost of the system (kWh_{COST} in €/kWh of total solar production *ESU*).

In order to help the user to size the system, target values are defined for performance indicators ; they consist in minimum or maximum limits. The calculation method is also presented in [Nowag, 2012]. The tool compares immediately each indicator to its associated target values and specifies the gap in percent. In case of oversizing, automatic warning messages are sent to the user. Figure 7 provides an overview of the results user interface.

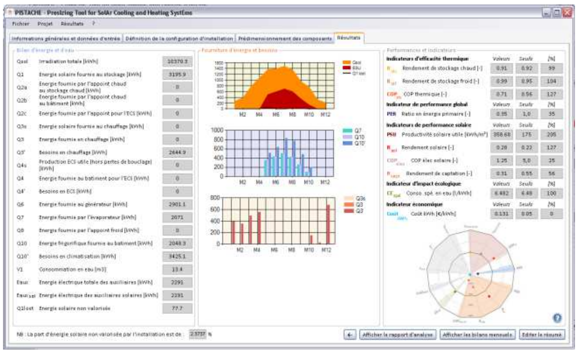

Figure 7 Results user interface

VALIDATION PROCESS

The validation process presented in this paper consists in a comparison between simulation results and monitoring data.

The set of parameters used in the tool is the same as for the real installation. It means that the simulation basically uses nominal data.

The input file is constituted with on-site irradiation, ambiant temperature and relative humidity measurements. The loads are equal to the real heat and cold production and DHW consumption.

A first run is done so as to get the initial result of the simulation ("Sim I"). Several runs are then realised to adjust simulation to reality. These adjusments will lead to identify which parameters have to be corrected in the alpha version of the tool. They also allow to correct gaps in the monitored data.

The energies (*Q1* to *Q10*) and the performance indicators as defined in [Nowag, 2012] and Figure 2 and 3 are compared with the relative difference explained in equation (7) :

$$\Delta X = \frac{X_{tool} - X_{monitoring}}{X_{monitoring}} \cdot 100 \quad (7)$$

Cooling mode validation in application n°2

RAFSOL [Praene, 2011] is a solar cooling installation at Saint Pierre La Réunion (France), located in tropical climate in South hemisphere. The installation is used to cool 150 m² of classrooms, using only the solar energy (no back-up system). Its main characteristics are given in Table 2 and the configuration scheme in Figure 8.

Table 2 RAFSOL main characteristics

Collector type, aperture area, nominal efficiency coeff.	Double-glazed flat plate, 90 m², η0 = 0.80, a1=3.15 W/m².K, a2=0.015 W/m².K
Chiller type, nominal power and thermal COP	Absorption, 30 kW, COPn=0.75
Heat rejection technology	Open wet cooling tower
Hot buffer tank and cold buffer tank capacities	1500 L - 1000 L

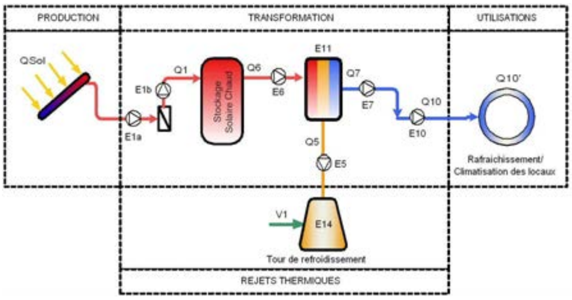

Figure 8 RAFSOL scheme

The installation is monitored by PIMENT laboratory since March 2008; data from the 16th of February to the 16th of May the year 2011 are used to validate the model. The monitoring data and some performance indicators are shown in Figure 9.

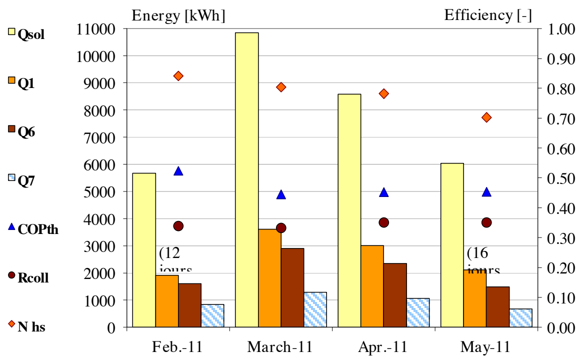

Figure 9 RAFSOL monitoring data in 2011

The results of the monitoring data and the calculated data are provided in Table 3 for two cases. "Sim I" presents the results with initial values. "Sim F" corresponds to the most optimising parameter adjustment. In this last case, the relative difference of most of the solar performance indicators is very low to nearly equal to zero for most of the solar performance indicators as shown below.

The following parameters have been adjusted:

- the maximum thermal COP ($COP_{th,0}$) used in COP_{th} hourly calculation is set to 80% of the initial value (nominal COP_n);
- the average collector temperature (T_{COLL}) used in the hourly calculation is set to 76°C rather than 70°C to match with the monitored one;
- the heat loss coefficient of the hot buffer tank (CR_{HS}) is increased so as to match the monitored one (0.25 rather than 0.07 Wh/L.°C.day).

Table 3 RAFSOL annual results and indicators

	Monit.	*Sim I*	Δx	*Sim F*	Δx
Qsol (kWh)	31 148	31 148	0%	31 148	0%
Q1 (kWh)	10 647	8 062	***-24%***	10 612	0%
Q6 (kWh)	8 350	7 241	***-13%***	8 513	2%
Q7 (kWh)	3 872	4 331	***12%***	3 947	2%
Q10 (kWh)	n.c	4 155		3 856	
Q10' (kWh)	4 155	4 155	0%	4 155	0%
ESU (kWh)	8 350	6 948	***-17%***	8 318	0%
PSU (kWh/m²)	92.8	77.2	***-17%***	92.4	0%
η_{coll}	0.34	0.26	***-24%***	0.34	0%
η_{HS}	0.78	0.90	***15%***	0.80	2%
η_{CS}	1.00	0.96	-4%	0.98	-2%
COPth	0.46	0.60	***29%***	0.46	0%
η_{sol}	0.27	0.22	***-17%***	0.27	0%
V1 (m3)	37	31	***-16%***	34	***-9%***
CEspe (L/kWh)	9.59	7.21	***-25%***	8.52	***-11%***

Only three parameters have been modified to reach the expected performances, they can be explained with real operating conditions. RAFSOL operation is worst than expected, in particular concerning the solar loop. Indeed, the initial calculated collector efficiency (η_{COLL}) is very low compared to what should be expected. Some overheating may have created some damages in the collectors. Further studies have to focus on the influence of the different parameters on this indicator.

Other indicators are not shown in the results because convenient results have not yet been achieved.

Monthly energy balance for "Sim F" case is not published here. Whenever, the relative difference between monitoring data and simulation results is less than 10% per month for energies *Q1*, *Q6* and *Q7*. It can be concluded that the cooling mode is validated.

Cooling and heating modes in application n°2

SOLACLIM [Siré, 2011] is a solar cooling installation at Perpignan (France), located in Mediterranean climate. The installation is used to cool and heat 180 m² of offices, using only the solar energy (no back-up systems). Its main characteristics are given in Table 4 and the configuration scheme in Figure 10.

The comparison process is the same than for RAFSOL case. The results are presented in Table 5. *Q10'* and *Q3'* are respectively the space cooling and heating demands. The exploited monitoring period is eleven month from November 2008 to October 2009. April 2009 month have been removed because of chiller vacuum leackages.

Table 4 SOLACLIM main characteristics

Collector type, aperture area, nominal efficiency coeff.	Double-glazed flat plate, 25m², η0=0.80, a1=3.15 W/m².K, a2=0.015 W/m².K²
Chiller type, nominal power and thermal COP	Adsorption, 7,5 kW, COPn=0.60
Heat rejection technology	Adiabatic drycooler
Hot buffer tank and cold buffer tank capacities	300 L – 300 L

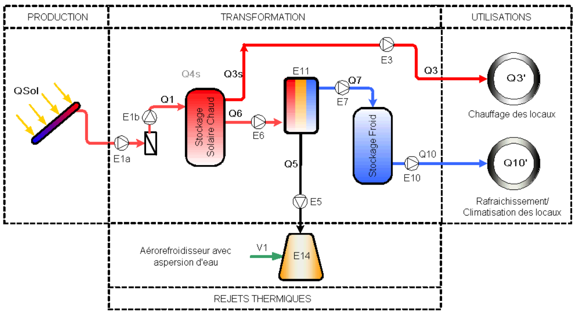

Figure 10 SOLACLIM scheme

Table 5 SOLACLIM annual results and indicators

	Monit.	*Sim I*	*∆x*	*Sim F*	*∆x*
Qsol (kWh)	35 336	35 188	0%	35 188	0%
Q1 (kWh)	10 705	9 474	***-12%***	10 860	1%
Q3s (kWh)	3 533	3 510	-1%	3 503	-1%
Q3 (kWh)	3 533	3 510	-1%	3 503	-1%
Q3' (kWh)	3 533	3 513	-1%	3 513	-1%
Q6 (kWh)	5 682	5 032	***-11%***	5 893	4%
Q7 (kWh)	1 762	1 913	***9%***	1 821	3%
Q10 (kWh)	1 753	1 769	1%	1 759	0%
Q10' (kWh)	1 753	1 770	1%	1 770	1%
ESU (kWh)	9 186	8 164	***-11%***	9 196	0%
PSU (kWh/m²)	367	327	***-11%***	368	0%
η_{COLL}	0.30	0.27	***-11%***	0.31	2%
η_{HS}	86%	90%	5%	87%	1%
η_{CS}	100%	92%	***-7%***	97%	-3%
COPth	0.310	0.380	***23%***	0.309	0%
η_{sol}	0.26	0.23	***-11%***	0.26	1%

The following parameters have been adjusted:

- $COP_{th,0} = 0.85 \times COP_n$
- $CR_{HS} = 0.25$ rather than 0.13 Wh/L.°C.24h
- $CR_{CS} = 0.10$ rather than 0.22 Wh/L.°C.24h

The initial collector efficiency (η_{COLL}) is, as in RAFSOL case, lower than the real one in the initial simulation case. Other results are coherent, the low COP_{th} value is due to some vacuum leackages which have been repared but have some influence on the operation performances.

Cooling and heating mode in application n°1

SOLERA [Chèze, 2011] is a solar cooling and heating installation at Chambery (France), located in the French Alps under a mountain climate. The installation is used to cool and heat 54 m² in an office building. An electrical hot back-up is used during the heating period. There is no DHW demand. Its main characteristics are presented in Table 6 and the configuration scheme in Figure 11.

Table 6 SOLERA main characteristics

Collector type, aperture area, nominal efficiency coeff.	flat plate, 30 m², η0 = 0.753, a1=3.62 W/m².K, a2=0.020 W/m².k²
Chiller type, nominal power and thermal COP	Absorption, 5 kW, COP=0.6
Heat rejection technology	Geothermal horizontal probes
Hot buffer tank capacity	400 L

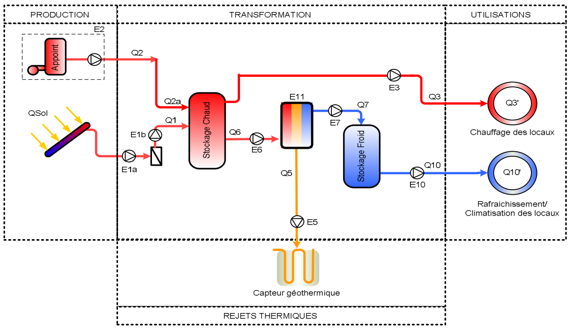

Figure 11 SOLERA scheme

The installation is monitored by the CEA INES since 2009. The comparison process is the same than RAFSOL one. The results are presented in Table 7. *Q10'* and *Q3'* are respectively space cooling and heating demand.

Table 7 SOLERA annual results and indicators

	Monit.	*Sim I*	*∆x*	*Sim F*	*∆x*
Qsol (kWh)	25 550	25 550	0%	25 550	0%
Q1 (kWh)	5 222	4 614	***-12%***	5 556	6%
Q2a (kWh)	2 913	2 112	***-28%***	2 489	***-15%***
Q3 (kWh)	4 389	4 393	0%	4 393	0%
Q3' (kWh)	4 389	4 393	0%	4 393	0%
Q6 (kWh)	1 289	1 526	***18%***	1 262	-2%
Q7 (kWh)	862	906	5%	851	-1%
Q10 (kWh)	862	851	-1%	851	-1%
Q10' (kWh)	862	865	0%	865	0%
ESU (kWh)	3 645	3 968	9%	3 906	7%
PSU (kWh/m²)	122	132	9%	130	7%
η_{COLL}	0.20	0.18	***-12%***	0.22	6%
η_{HS}	70%	88%	***26%***	70%	1%
η_{CS}	100%	94%	-6%	100%	0%
COPth	67%	59%	***-11%***	67%	1%
η_{sol}	0.14	0.16	9%	0.15	7%

In the initial monitoring data, a measurement error is done in the distributed energy, showing a cold buffer tank efficiency of 120%. To limit the influence of over-valued *Q10*, the energy balanced is has been done before the cold storage tank.

The following parameters have been changed:

- $COP_{th,0}$ = 1.13 x COP_n
- CR_{HS} = 0.4 rather than 0.12 Wh/L.°C.24h
- T_{COLL} = 61°C in cooling mode rather than 70°C
- T_{COLL} = 52° C in heating mode rather than 55°C

The collector thermal yield is a function of:

- the irradiation which is the same in both real and simulated case;
- the collector performances which are certificated by normative test lab results;
- the temperature within the collector: this parameter can be modified in order to adjust simulation results to monitoring ones.

Table 8 presents the average values of the monitored inlet and outlet collector temperatures for the two operating mode (i.e heating or cooling).

Table 8 SOLERA monitored collector temperature

(°C)	Tin	Tout	Tm	Tout max
Cooling mode	62.5	64.3	63.4	103.6
Heating mode	54.2	56.0	55.1	106.5

DISCUSSION AND RESULT ANALYSIS

By now, several configurations and uses of solar energy are validated by comparing simulation and monitoring data. The remaining work for the other configuration is still in progress.

A limited number of parameters have been tested so as to match to the real performances. A relative difference lower than 10% between simulation and monitoring data for annual performances can be achieved with minor changes. The limits to focus are explained bellow :

- The hot storage tank heat loss time constant CR_{HS} influences *Q6* (generator energy) and *Q3s* (solar energy for heating). It has been increased at different values for the three validation cases. This can be due to the fact that equation (3) is not appropriated, or because the tank efficiency is worst in reality than in theory. It can also be explained by the fact the method does not take into account any variations of the pipe lengths between the solar collector field and the storage tank. Consequently, the thermal losses in the solar primary circuit are not precisely evaluated.
- The real COP_{th} can be different regarding the theoretical one. Indeed, it is highly influenced by the operating conditions at the generator (solar temperature), the absorber and condenser (heat rejection technology) and the evaporator (space cooling demand). Moreover, because the method is a simplified and hourly one, it does not take into account the exact transient operation chiller reaction or the short cycles. The solution consists in lowering the $COP_{th,0}$ value, because it directly influence the COP_{th}, as presented in equation (5).
- The collector temperature T_{COLL} is an important parameter so as to calculate the collector yield η_{COLL}. Because the method is a simple and non dynamic one, T_{COLL} is now program as a default and constant value, depending on the mode (heating, cooling, DHW). A detailed sensitive analysis of this value will be done in further step.

CONCLUSIONS

The presented simplified method to pre-size solar cooling, heating and DHW installation demonstrates promising results. Because the aim is a large dissemination and use of the tool, the user interface has been carefully designed; moreover, the MeGaPICS consortium focuses on a wide range of validation. The next step and the further studies are the following:

- finalization of the development and the debug of the user interface ;
- validation of the DHW mode and the multi-use mode (DHW+cooling and DHW+heating) ;
- comparison with the half-detailed model developed by PIMENT (University of La Réunin) ;
- comparison with the TRNSYS simulation ODIRSOL model [Le denn, 2009] and other performance prediction tools ;

The tool is now called PISTACHE, is will be distributed by CEA-INES and TECSOL in the framework of the MeGaPICS project.

NOMENCLATURE

η_{Carnot}	= Carnot efficiency [-]
η_{COLL}	= Collector thermal yield [-]
η_{HX}	= Heat exchanger efficiency [-]
$\eta_{CS/HS}$	= Cold / hot storage efficiency [-]
$COP_{elecSOL}$	= Solar Electrical COP [-]
COP_{th}	= Thermal COP [-]
Cp	= Water massic thermal capacity [J/kg.K]
$CR_{CS/HS}$	= Cold/hot storage heat loss coefficient [Wh/L.°C.24h]
dT_G	= Temperature lift at the generator [°C]
E1 to *E14*	= Auxiliary electrical consumptions [kWh]
ENS_{SL}	= Irradiation on collector slope area [kWh]
G_{HZ}	= Horizontal global insulation [W/m²]

kWh_{cost}	= Operation cost of the system [€/kWh]
PER	= Primary energy ratio [-]
Pn	= Nominal cooling capacity [kW]
PSU	= Useful solar thermal productivity [kWh/m²]
Qsol	= Global irradiation on collector area [kWh]
Q1	= Solar energy supplied to the hot storage [kWh]
Q2c	= Back-up energy supplied to the building for domestic hot water [kWh]
Q3s	= Solar energy supplied for heating [kWh]
Q3	= Total energy supplied to the building for heating [kWh]
Q3'	= Net heating loads (exluding distribution losses) [kWh]
Q4s	= Solar thermal heat energy supplied for domestic hot water production [kWh]
Q4	= Total thermal energy supplied for domestic hot water [kWh]
Q4'	= Net domestic hot water demand (exluding distribution losses) [kWh]
Q6	= Thermal heat energy supplied to the sorption machine [kWh]
Q7	= Thermal cooling energy supplied by the evaporator [kWh]
Q10	= Total thermal cooling energy supplied to the building [kWh]
Q10'	= Net cooling or air-conditioning loads (exluding distribution losses) [kWh]
Q1lost	= Solar not used thermal energy [kWh]
S_{COLL}	= Solar collector area [m²]
T_{COLL}	= Solar collector average temperature [°C]
T_{EF}	= Fresh water temperature for DHW [°C]
$V_{HS/CS}$	= Hot and cold storage volume [L]
V1	= Water consumption [m^3]
WC_{SPE}	= Specific water consumption [L/kWh]

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