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A simplified design tool for solar DHW systems in multi-family houses with decentralized storages

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Abstract

Solar DHW systems in multi-family houses is gaining more and more interest in France, where 50% of the solar collectors area installed in 2012 is dedicated to such applications. Among the various designs, systems with decentralized storages installed in each apartment offer significant advantages, such as no DHW loop requirement. Nevertheless, up to now, no simplified design tool was available on the market to calculate the solar gains. Within Scheff project, such a tool has been developed. A general overview of the software as well as the result of the validation procedure is presented within this paper.

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Keywords: Design tool; DHW systems; Multi-family houses; simulation

1. Introduction

Market share of solar DHW systems in multi-family houses (SDHW-MFH) is growing in France, where 50% of the solar collector area installed in 2012 is dedicated to such applications. Among the various designs, systems with decentralized storages (also called CESCO in France) installed in each apartment offer significant advantages.

As this system technology is relatively new, a research project was set-up in 2010 in order to optimize and to disseminate this technology. Among the various objectives, it was decided to develop a simplified design tool for engineering offices that allows a quick and easy design procedure, and provides the main valuable indicators as outputs.

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In the following sections, a more detailed description of the CESCO will be provided, the choices realized for the design of the tool will be explained, and finally a general overview of the results as well as the validation procedure will be presented.

2. Solar DHW systems for multi-family houses (SDHW-MFH) with decentralized storage

In 2012, more than 50% of the collector area was installed in multi-family buildings in France. Depending on the building typology (new or refurbishment), on the auxiliary energy used, on the owners of the building (social housing or private), three main systems design are used.

The main differences between the systems are related to the location and the numbers of storage, and on the auxiliary system used as summarized in Table 1, and illustrated in Fig 1.

Table 1. Overview of the various SDHW-MFH systems

System design	Solar DHW storage	Auxiliary DHW storage	DHW loop
CESC	One per building	One per building	Yes
CESCAI	One per building	One per flat	Yes
CESCI	One per flat (bivalent storage)	One per flat (bivalent storage)	No

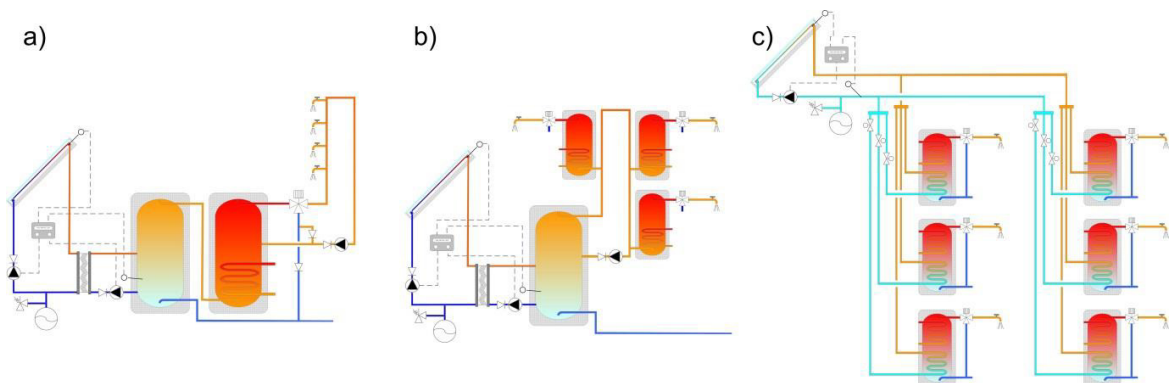


Fig 1. (a) CESC, (b) CESCAI and (c) CESCI design

The main advantage of CESCI system design is that there is no DHW loop: as a consequence, legionella risks are reduced, specific regulation on the maximum and minimum temperature of the DHW loop is suppressed and there is no thermal losses of the DHW loop which can be as high as 50% to 100% of the DHW loads. Another advantage is that the storage volume for DHW is significantly increased thus limiting the overheating risks in summer period.

For building owners, this system also provides advantages as the auxiliary energy is directly paid by the flat occupant to the utility, which avoid having additional energy meters and/or rental charges.

Compared to the other solutions, the overall efficiency of CESCI is generally higher as illustrated in Fig 2. for a reference case (50 m² of flat plate collectors, climate of Chambéry, 4000 l/day as mean DHW load), with a solar fraction ranging from 38% for CESCAI, 43% for CESC and 46% for CESCI.

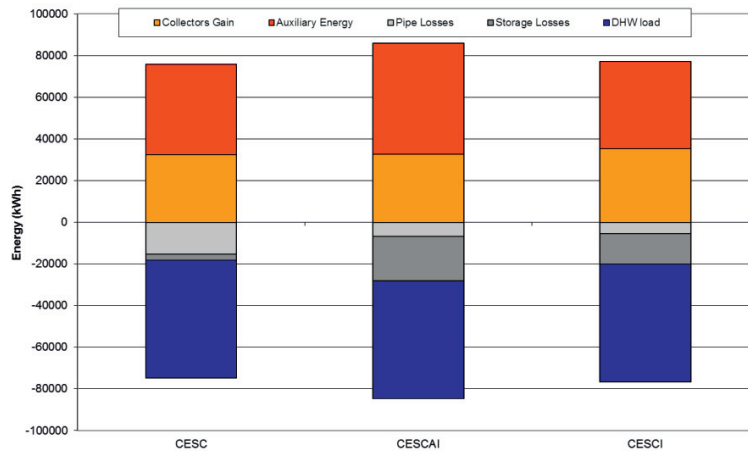


Fig 2. Energy balances for the 3 system design in a reference case

And finally, a significant advantage is the use of standard bivalent storage tanks which are well known and produced in industrial process.

However, this system design suffers of drawbacks: thermal losses of the tanks are higher and may in some case counterbalance the DHW loop thermal losses avoided, and the investment costs are up to now higher than for CESC, mainly due to the number of storage tanks for which a significant cost reduction can be expected in the near future.

These drawbacks of CESCi have been the starting point of the SCHEFF research project led by TECSOL engineering company, with Viessmann, Belenos, Cofely and CEA-INES as partners: looking further an additional objective of the SCHEFF project was the development of a software tool for engineering companies and manufacturers for a fast and reliable dimensioning of such system.

3. Specifications of the design tool

3.1. General requirements

The requirements for the tool were established on surveys among all partners involved in the SCHEFF project, ranging from educational, industrial, buildings engineering and research activities. From preliminary analysis, they are classified into two categories. On the one hand the requirements related to the use of the tool are:

- Simple and easy to use by professionals and building engineering department
- Pedagogical reports including graphics and tables
- Reliability of the results for every available configuration (no convergence issue)
- Inputs data available from manufacturers' datasheets, test reports or RT2012 database
- All the possible schemes are defined
- Computing time of the annual performance figures below 2 minutes

On the other hand the requirements related to the design of the tool are:

- Structure allowing further developments and updates
- No distribution restrictions on components library

- Distribution as a standalone software with graphical user interface for data entry
- Maximal time step 1 hour

With regard to the hydraulic distribution scheme of CESCO we derived from the list of requirements a set of functional blocks needed in the software in terms of database formats and configuration features through the user interface: the specifications of the database blocks are given in Table 2 and are used to drive the tool development.

Table 2. Database functional blocks.

Function block	Format specifications
Weather database	Station,Altitude,Latitude,Longitude,ClimateZoneRT2012, outdoor design temp. / Hour,day,dry temp., rel. humidity, total horiz. rad., diffuse horiz. rad.,cold water temp.
Waterdraw database	Hour, water draw volume
Solar Collector Database	Manufacturer, Type, aperture area for 1 module, η_0 , a_1 , a_2 , $K_{0b}(\theta_L=50^\circ)$, $K_{0b}(\theta_t=50^\circ)$, K_{0d} , C_{eff}
Water tank database	Volume,heat losses(UA),height of zones 1 to 4, rel.height solar HX in, rel.height solar HX out, rel.height aux. HX in, rel.height aux. HX out, sensor height aux. control, sensor height sol. control, elec. heat. nominal power and set point

Table 3. Outputs functional blocks.

Function block	Format specifications
Energy	Monthly – energy in coll.plane, coll. Out, solar loop losses, tanks total losses, auxiliary, elec solar pump, DHW; solar fraction; dhw volume tapped
Environment	Monthly – CO_2 with and without solar, avoided CO_2 , primary energy with and without solar, saved primary energy
Temperature	Hourly – solar collector output temp. max and time above 100°C

3.2. Selection of the development environment

In order to calculate the performance of the system, two approaches have been studied at the beginning of the project while evaluating their performance against the detailed reference system built in TRNSYS environment:

- Dynamic simulation of the system,
- Performance map interpolation available from SOLO method [6], built from extensive simulation work, adapted from F-chart method [3].

While simulation was preferred with regard to flexibility and reliability of the results, interpolation was well noted with regard to guarantee a very low calculation time and to calculation robustness since there is no convergence issue in this case. However first attempts to compare a few CESCO test cases (parameter variations: 2 climates, 3 collector areas, 4 flat types distribution of 40 flats building) with the SOLO interpolation method lead to high deviations (on ref. case: 48%) for annual Usable Solar Energy (*USE*) without correction with regard to detailed reference TRNSYS simulation. A correction factor was calculated such that the *USE* deviation remains in $\pm 10\%$ interval. This might be acceptable for *USE* calculation but this method provides neither the solar collector energy output nor the used auxiliary energy: the total heat losses of the tanks can't be calculated while this is a key value for sizing such CESCO systems by buildings' engineers. Therefore the simulation approach was chosen in the end.

The use of TRNSYS environment for the design tool development was the first way of investigation since a feature of the software allows generating an executable file from a project. Whereas the free distribution of such software is not forbidden, TRNSYS license information doesn't freely allow it. Moreover the available components

models for CESCO are quite detailed and are requiring small simulation time step that lead to simulation time over the 2 minutes maximum mentioned in the specifications. Then it was decided to use Matlab®/Simulink® to develop a library of components that would be simplified enough for resulting in a low computational load.

4. Software development

4.1. Software architecture

The aim of this tool is to run dynamic “CESCI” system simulation involving control strategy for calculation of estimated temperature of the hot water draw-offs thanks to either Matlab/Simulink environment for quick design calculations or TRNSYS for detailed reference calculations. Whatever the simulation environment chosen by the user, the general architecture allow to split the software between a user interface and simulation core as illustrated in the Fig.3

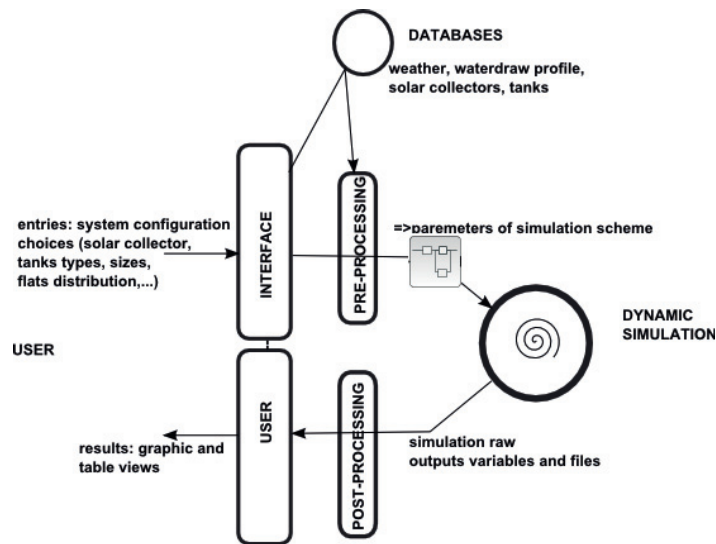


Fig.3. Outlook of the design tool software architecture

In order to build standalone software that could be distributed at the end of the project, 1 minute fixed simulation time step was required by the compiler.

4.2. Simulation scheme of the CESCO hydraulic system

To calculate the annual performance figures required for sizing any CESCO installation, a simulation diagram is set up in the Simulink simulation environment. It implements components from a library that was developed on purpose in this work. Data exchange between the components is achieved through flow rate and temperature variables for each hydraulic connection.

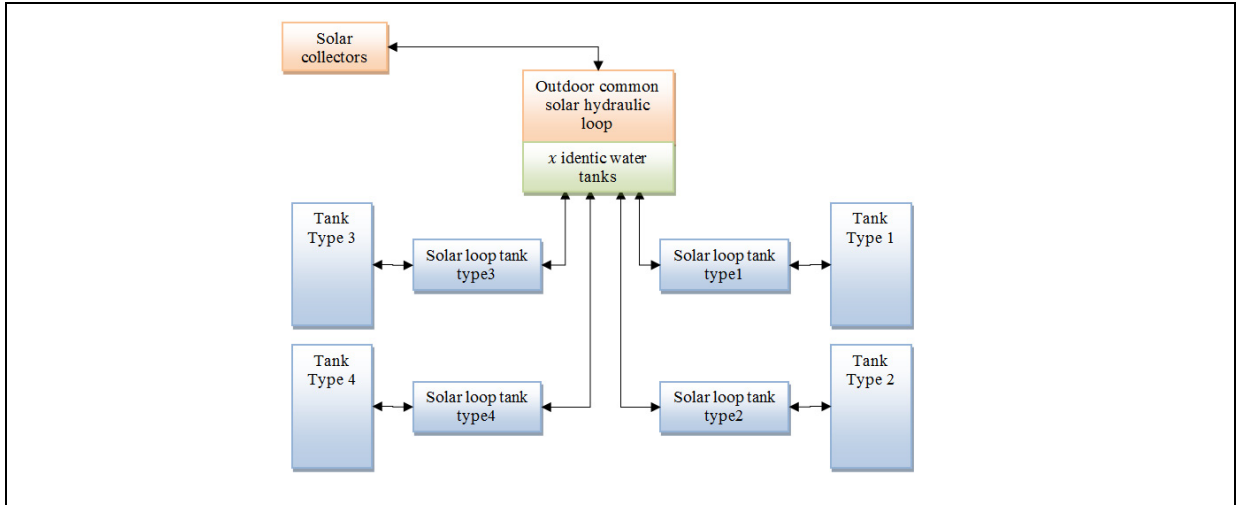


Fig. 4. Outlook of the CESCO scheme used in the simulation design tool

The multiple family house building is represented as a linear combination of four types of flat as illustrated in Fig.4. A distribution key is used for draw-off profiles, piping diameter, flowrate in the solar loop which are based on simplified ratio and assumptions calculated with the building description.

4.3. Components library for CESCO system

4.3.1. Solar collector

The component model is adapted from the 1-node solar collector model described in Standard EN 12975-2:2006 in order to match the minimal number of parameters available from solar collector testing reports. According to the usual notations used in eq. (H.2) of the Standard, solar collector mean node temperature T_m is governed by the Eq. (1).

$$C \frac{dT_m}{dt} = F'(\tau\alpha)_{en}(K_{\theta b}G_b + K_{\theta a}G_a) - a_1 \frac{T_m - T_a}{G^*} - a_2 \frac{(T_m - T_a)^2}{G^*} - 2 \frac{\dot{m}c_p(T_m - T_{in})}{A} \quad (1)$$

4.3.2. Water tank storage

This component is adapted from the domestic hot water tank model [1] described in the RT2012 standard for energy consumption calculations in new buildings in France. It defines 4 zones vertically stacked and each get a temperature node: thermal balance involving energy flows from immersed tubes heat exchangers (solar or external boiler), electric heater, thermal losses and domestic hot water draws between bottom and top of the tank, allows calculating its temperature.

Within each time step, for each node $i = \{1, \dots, 4\}$, a node i temperature variation is first computed according to Eq. (2) related to the water tapped volume V_{wt} during the time step. Within the same time step the final temperature variation of node i is then calculated by Eq.(3).

$$V_i \Delta T_i = V_{wt}(T_{i-1} - T_i) \quad (2)$$

$$c_{p,w} V_i \frac{dT_i}{dt} = Q_{sol,i} + Q_{aux,i} + Q_{EH,i} - Q_{losses,i} \quad (3)$$

Given: V_i, T_i respectively the volume and temperature of zone i ; $Q_{sol,i}, Q_{aux,i}, Q_{EH,i}, Q_{losses,i}$ respectively the energy flow from solar and auxiliary heat exchangers, electric heater and thermal losses toward the ambient temperature; $c_{p,w}$ the thermal capacity of water stored in the tank.

As stated in [2] we assumed that this “lightweight” nodes number approach would performed satisfactory since we were not so much interested in accurate real-time behavior representation of components than in overall yearly yield for the whole system.

Parameters allow to set the size of each zone in the tank, the heat losses coefficient according to the storage tank database and to distribute power from heat exchangers or electric heater among each node.

4.3.3. Pipes – capacitive hydraulic connections

Since in [5] dynamic behaviors and standby losses have shown a first rank influence on overall annual performance for the hydraulic distribution through pipes in CESCO, a 1-node model was used to take into account those effects in the simulations while giving up the effect of transport time.

Given an insulated pipe section in the loop, R_{ext} and R_{int} , the external and internal radius of insulation (λ_{ins} the thermal conductivity of the insulation material), A_{int} the internal area, h_{ext} the external heat transfer coefficient to the environment temperature T_{env} , C_{pipe} the thermal capacity of the whole fluid contained in the pipe (C_{pf} the specific thermal capacity of the fluid), Eq.(4) calculates the temperature variation of the node’s pipe owing to a flow rate \dot{m} .

$$C_{pipe} \frac{dT_{pipe}}{dt} = - 2 \dot{m} c_{pf} (T_{pipe} - T_{in}) - U_{int} A_{int} (T_{pipe} - T_{env}) \quad (4)$$

$$\text{With } U_{int} = \frac{1}{\frac{R_{int}}{R_{ext}} h_{ext} + \frac{R_{int}}{\lambda_{ins}} \ln\left(\frac{R_{int}}{R_{ext}}\right)} \text{ and } T_{pipe} = \frac{T_{in} + T_{out}}{2}$$

Special attention was paid to high flow rates resulting in volume flow during one time step higher than the volume of the pipe. In that case, the pipe’s output temperature is given in Eq.(5).

$$T_{out} = \frac{T_{in} (\dot{m} c_{pf} - U_{int} \frac{A_{int}}{2}) + U_{int} A_{int} T_{env}}{U_{int} \frac{A_{int}}{2} + \dot{m} c_{pf}} \quad (5)$$

4.3.4. Mixing valve

The role of the mixing valve is to control the water output temperature to prevent user scalding during draw-offs by mixing hot water from the tank storage with cold water at temperature T_{cw} from the mains. The hot water output temperature T_{dhw} is governed by Eq.(6) provided that the temperature T_{store} is above the delivery set temperature T_{set} .

$$T_{dhw} = \gamma T_{store} + (1 - \gamma) T_{cw} \text{ with } \gamma = \frac{T_{set} - T_{cw}}{T_{store} - T_{cw}} \quad (6)$$

4.4. Input data

Monthly averaged weather data for more than 40 locations in France have been used. These data (global horizontal irradiation, outdoor temperature, humidity ratio and mains water temperature) have been processed to derive realistic hourly data with the same overall characteristics (mean and cumulative values) as the monthly original data. These values are linearly interpolated to match the simulation time step smaller than one hour, except for the radiation values: algorithms have been adapted from [3] to interpolate irradiation on the collector aperture especially around sunrise or sunset.

Up to now, only one 4000L/day water draw-off profile is used originally described in [4] and used in IEA Task 26 /32 work. Once the user choosed the standard profile T1,T2,...T5 for a type of flat, the daily mean volume is proportionally adjusted from the base 4000L/day profiles.

The current solar collector database is based on Viessmann products, and the parameters of the collectors are the certified values published on the Solar Keymark website, and the water tank database is established from the manufacturer's datasheets.

4.5. User Interface

As previously stated, the user interface should allow a quick and reliable description of the system. The numbers of parameters should thus be limited for the climate, components (collectors and storage tanks) characteristics as well as building description (Fig. 5). Additionally; the user interface should be as user friendly as possible. Microsoft Visual Basic has been selected for this software development.

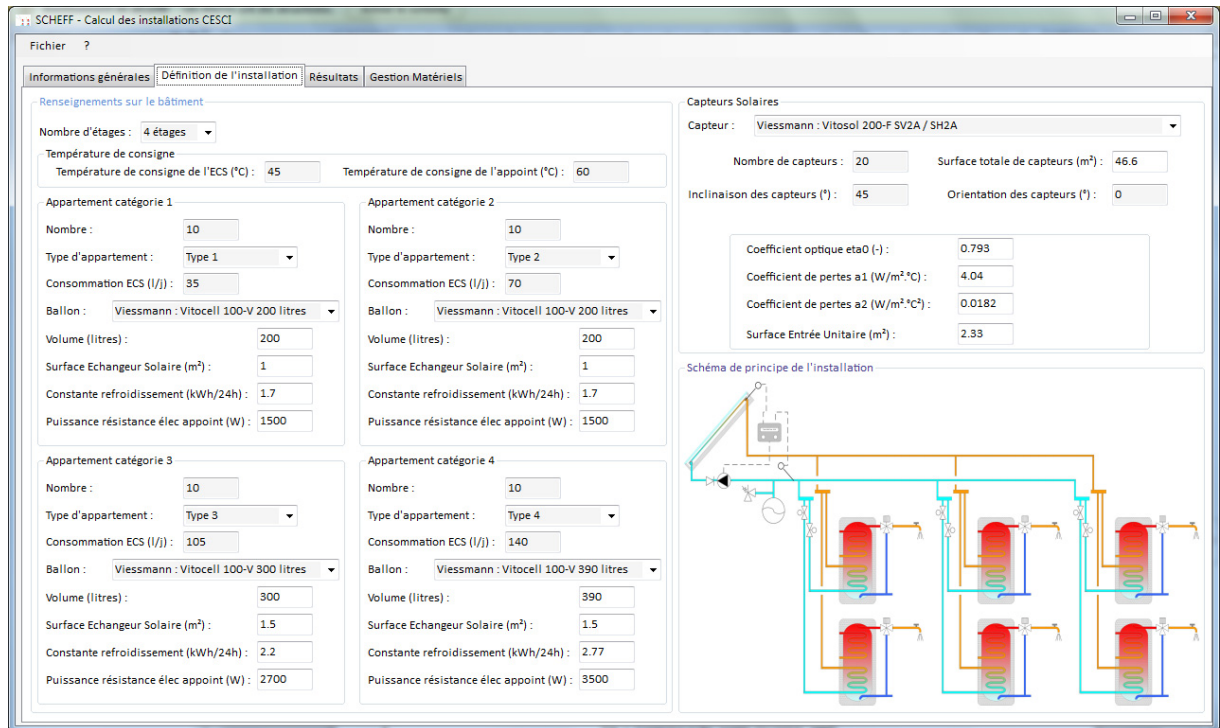


Fig. 5. Screenshot of the “system description” page

Thanks to the database, the description of the technical components is reduced to its name and the numbers. Regarding the building description, parameters are the number of storeys, and the number of flats in each category (two rooms, three rooms, ...).

Once all parameters have been entered, the calculation can be launched. First, a XML description file is created, then the standalone Matlab application is started using the data saved in the XML file. The results are saved in a XML result file and a simple report (Fig. 6) is written which provides the description of the system and the main results : collector gains, auxiliary energy used, thermal storage losses, and DHW loads.

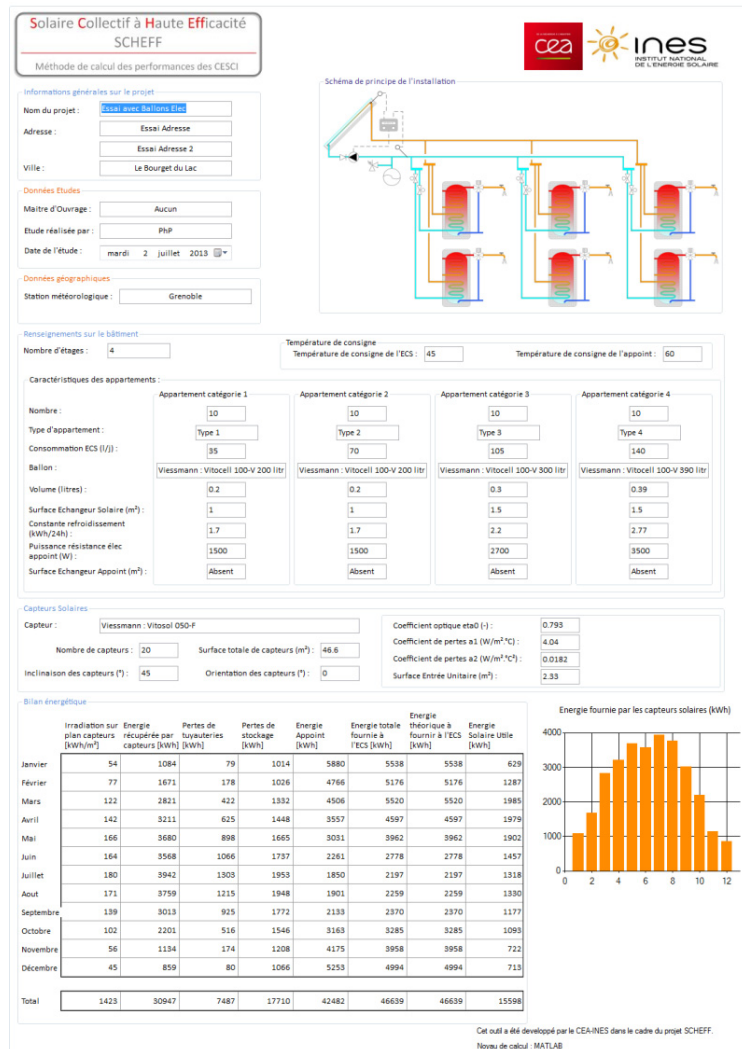


Fig. 6. Simulation report

5. Validation of the design tool

For the validation of this simplified design tool, many CESC systems have been simulated with TRNSYS using detailed components which have been validated against measurements (Type 832 for collector, Type 340 for water tank), and the results have been compared with our tool.

The reference case is a building with 40 flats and 4 storeys, located in Grenoble, with 46.6 m² of collectors. The DHW load is 3500 l/day as an annual mean value. Detail about flats is provided in Table 4.

Table 4. Detail of the flats

Flat	Number	Mean DHW load (l/day)	Volume of the bivalent storage (l)
“one room”	10	35	200
“two rooms”	10	70	200
“three rooms”	10	105	300
“four rooms”	10	140	390

The detailed results for this reference case are provided in Table 5.

Table 5. Simulation results of the reference case

	Collector gains (kWh)	Pipe losses (kWh)	Storage losses (kWh)	Auxiliary energy (kWh)
TRNSYS	30287	8588	18756	44177
SCHEFF tool	30947	7487	17709	42482
Difference	2.2%	-12.8%	-5.6%	-3.8%

Additional comparisons between TRNSYS and SCHEFF tool have been realized. They are based on the reference case, and the main results are provided in Table 6.

Table 6. Main results of the comparisons

	Collector gains (kWh)			Auxiliary energy (kWh)		
	TRNSYS	SCHEFF	Diff.	TRNSYS	SCHEFF	Diff.
Perpignan	36658	37335	1.85%	35791	35070	-2.01%
92.3 m ² collector	49403	51915	5.08%	30967	32107	3.68%
23.3 m ² collector	17416	17788	2.14%	52843	49341	-6.63%
Temp set point for auxiliary = 50°C instead of 60°C	32914	32154	-2.31%	35328	36234	2.56%
Collector slope = 20° instead of 45°	29378	30555	4.01%	45160	42937	-4.92%
Collector slope = 90° instead of 45°	17618	18688	6.07%	52154	48503	-7.00%

Deviations less than 7% are observed in the validation process we perform up to now, which is acceptable for a simplified tool compared to a detailed reference software like TRNSYS. Further investigations will be continued in order to detect errors, and complete the validation of this simplified tool.

6. Outlook and conclusion

The objectives related to a user-friendly interface, reliability of the results and calculation time have been reached. Available as a beta-version for the project partners, the SCHEFF tool will be released soon. The chosen architecture offers significant advantages in the software elaboration process:

- The scientist engineer focuses on the simulation core, having the expertise of scientific software but without specific knowledge about the habits of engineering offices.
- The software engineer focuses on the GUI, he should be in close relationship with buildings engineering companies and manufacturers in order to know exactly their expectations, but he doesn't need to worry about numerical methods.

Additionally, as the core calculation part of the software use XML file as input, it can easily be used also in connection with Building Management System for smart performance monitoring.

Acknowledgement

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