

Energy calculations CEN-CE

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Two interrelated CEN standards, EN 15316-5 (Storage) and EN 15316-4-3 (Solar thermal systems) are described along with the corresponding training materials, as an example of the work done within Task 3.3 of the CEN-CE project and applicability of the training materials. The proposals for considered CEN standards corrections and improvements are provided as well.

Keywords: energy calculation, CEN EPB standards, training materials, storage, temperature stratification, solar thermal system, parametric analysis

Introduction

Energy calculations are often formally required for issuing energy performance certificates (EPCs) and to obtain the building permit for new or renovated buildings, i.e. for verification of the national minimum energy performance requirements.

Design of nZEBs (Nearly Zero Energy Buildings) requires more detailed dynamic calculations with hourly time step, taking into account all technical system compo-

nents and optimization of technical solutions. The new CEN EPB standards (ed.2017) enable to some extent such a step up from the previous edition (2007–2008) that was based on monthly steady state calculations.

As there is a lack of knowledge / skills among designers and engineers in energy calculations, especially for nZEBs and complex buildings/technical systems, an adequate training supported by the calculation tool is needed.

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Task 3.3 of the CEN-CE project deals with the energy calculation of space heating and domestic hot water systems according to the new CEN EPB standards developed under M/480 in CEN TC/228 [1]. Also, on-site wind mills are included based on EN 15316-4-7 / TR 15316-6-12 Wind turbines.

The developed training materials for each standard comprise ppt presentations, handbooks, spreadsheets, commented input / output list of data, didactics for trainers, exam questions and answers.

In addition to the training purposes, CEN-CE training materials (handbooks, spreadsheets) can be used for correcting the first edition of new EN 15316 series [1] and in development of integral software for energy performance calculations.

Once the software is developed, it can be used not only for issuing EPCs and building permits, but also for optimizing technical systems at design stage (cost. optimal solutions), sizing of the system components (e.g. solar collectors, PV, boilers) and comparison with measured energy consumption.

EN 15316-5 (Storage)

One of the highlights of new CEN EPB standards [1] is a separate, stand-alone standard for the water-based space heating and domestic hot water (DHW) storage systems. As in the previous set of EPB standards (ed. 2007–2008) the calculation procedures included only

monthly (and seasonal) methods, storage calculations were described within the energy generation sub-systems. In these calculation methods, the role of the storage tank was only to increase the thermal losses of the analyzed technical system (except in the case of solar thermal system calculations, where the volume of the storage tank is also used in the f-chart based methods)

EN 15316-5 [2] together with EN 15316-4-3 [3] are the only fully dynamic methods in the entire set of new EN 15316 series [1] and, as such, gives a dynamic character to the entire calculation method (emission, distribution, storage and generation sub-system). The standard describes two calculation methods: Method A and Method B. Method A considers temperature stratification inside a tank, while Method B treats the tank with a uniform temperature. Due to the multi-node model, Method A enables temperature stratification inside the tank which allows more realistic modeling of technical system and allowing better predictions of the renewable energy appliances operation (e.g. solar collector heat output, [4]). In this paper, the CEN-CE proposed procedure for Method A is described more in detail.

Calculation procedure

CEN-CE proposal of the calculation method based on the EN 15316-5 standard (Figures 1 and 2) is shown on flowchart on Figure 3. After determination of product descriptive and technical data, and system design data, the calculation procedure consists of 10 steps in total (one more than the in the standard).

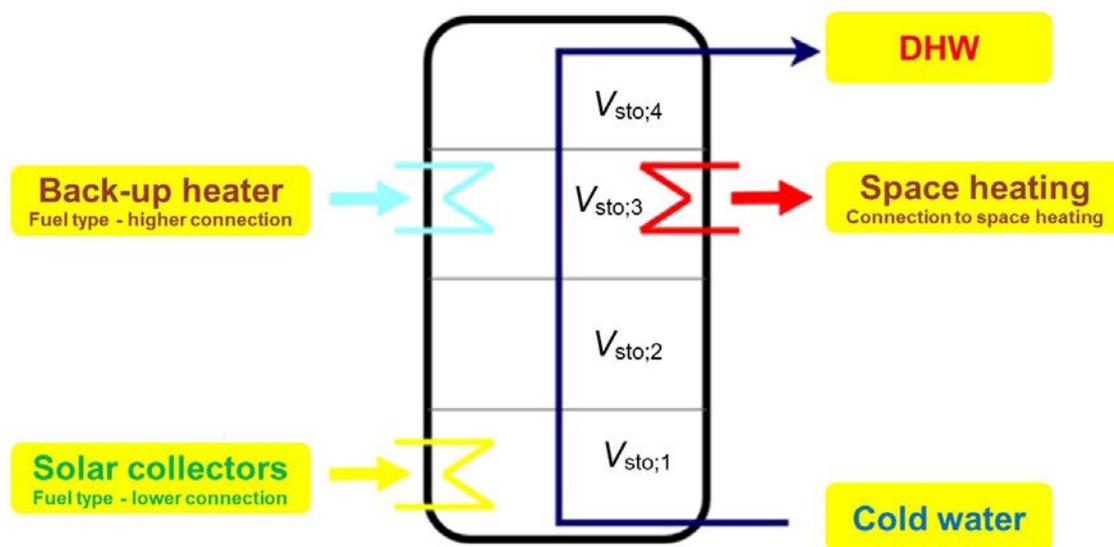


Figure 1. Graphical representation of a storage module mathematical model (Method A).

In the developed spreadsheet calculator, the volume of the storage tank is divided into 4 segments of arbitrary volume (Figure 1), although the described procedure can be applied to a user-defined number of segments. Figure 1 shows standard solar storage tank, where entry of cold water and solar thermal collectors' connections are introduced in the lowest segment (Segment 1). Back-up heater and space heating connections are introduced in Segment 3. Exit of the DHW is introduced in Segment 4. Heating element can be modelled as internal (e.g. electric back-up heater), by heat exchanger (internal or external) or by direct connection of fluid. Position of each connection can be modified.

Step 1 – Initialization

In the first step, temperatures of each storage tank segments are collected from the previous hour (except the first hour in a year when the storage set point temperature can be used).

Step 2

Step 2 is, in some way, a modification of a procedure described in Annex D of the standard. The calculation of the withdrawn volume from the storage for DHW is calculated by taking into account stored $Q_{sto;W;vol,i}$ and usable $Q_{sto;W;vol;i;ubl}$ energy of each module:

$$Q_{sto;W;vol,i} = V_{sto;vol,i} \cdot \rho_W \cdot c_W \cdot (\theta_{sto;vol,i} - \theta_{W;cold}) \text{ [kWh]}$$

$$Q_{sto;W;vol;i;ubl} = \begin{cases} Q_{sto;W;vol,i} & \text{if } \theta_{sto;vol,i} \geq \theta_{W;out,min} \\ 0 & \text{if } \theta_{sto;vol,i} < \theta_{W;out,min} \end{cases} \text{ [kWh]}$$

Step 3

In the Step 3, full mathematical description of the calculation procedure graphically shown in Annex D of the standard has been developed within the CEN-CE project. The entire set of equations have been written in the Handbook and programed in the spreadsheet calculator.

In general, the total volume of withdrawn water from the storage tank unit is replaced with the identical quantity of cold water. It is assumed that the water of the upper module is ideally mixed with the quantity of withdrawn water at the temperature of the lower segment. This is graphically shown in Figure 2.

Step 4

Step 4 explains how to consider DHW distribution system losses when there is no DHW consumption (e.g. distribution losses of the circulation loop). These losses were not originally taken into account.

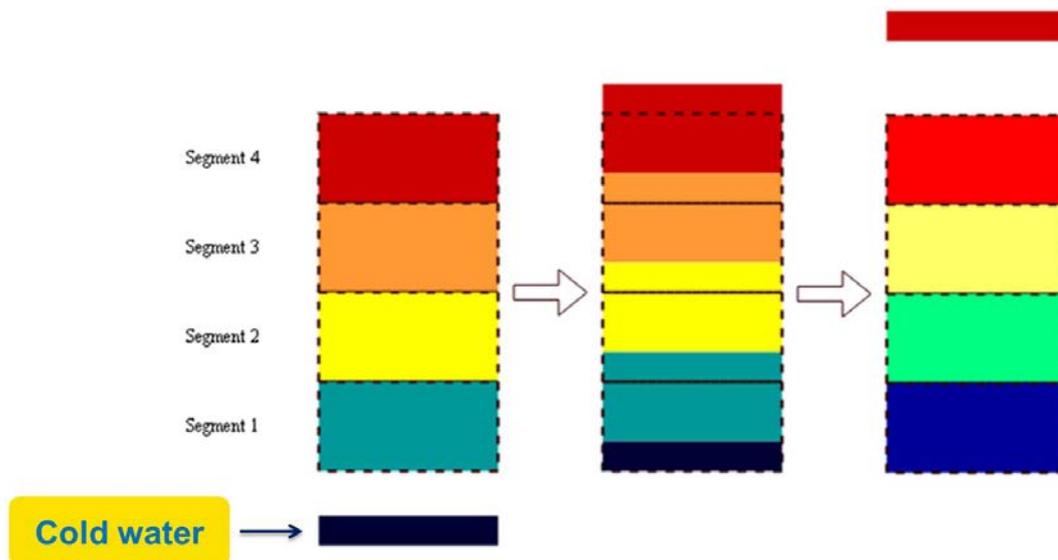


Figure 2. Graphical representation of Step 3.

Step 5

Energy supplied to space heating $Q_{H,out}$ is calculated by taking also into account simultaneous heating of the storage tank with the back-up heater:

$$Q_{H,out} = \min(Q_{H,sto,out,req}; Q_{sto,H} + Q_{sto,bu,max}) \quad [\text{kWh}]$$

where $Q_{sto,H}$ is total usable energy for space heating. Simultaneous heating of the storage tank with the back-up heater $Q_{sto,bu,max}$ has only been considered for Method B of the standard.

Furthermore, in the CEN-CE proposal energy stored for space heating service of each segment is moved from the Step 1 to Step 5 and can be calculated as:

$$Q_{sto,H;vol,i} = \max[\rho_w \cdot c_{p,w} \cdot V_{sto,i} \cdot (\vartheta_{sto,vol,i} - \vartheta_{H,out,min}); 0] \quad [\text{kWh}]$$

where usable energy $Q_{sto,H;vol,i;ubl}$ accounts only for energy stored in segments where the connection to space heating is placed and in segments below. This is also not clearly defined in the standard.

Step 6

In step 6, temperature drop caused by energy delivered to DHW distribution losses and space heating are calculated. Method uses simplification of storage unit mathematical model, employing only one segment for the energy and mass balance.

Step 7

Energy input from heaters to the storage tank unit are calculated in Step 7. CEN-CE proposed procedure takes into account maximum energy available from the heating element and the rise of heated water inside the tank (temperature stratification).

Step 8.

Mixing of the segments is described in Step 8. If the temperature of the segment i is higher than the one of the upper segments, two segments are ideally mixed.

$$\vartheta_{sto,vol,i} = \vartheta_{sto,vol,i+1} = \frac{\vartheta_{sto,vol,i} \cdot V_{sto,vol,i} + \vartheta_{sto,vol,i+1} \cdot V_{sto,vol,i+1}}{V_{sto,vol,i} + V_{sto,vol,i+1}} \quad [^{\circ}\text{C}]$$

Originally written in standard, this iterative process is proceeded until the temperature of the segment i is lower or equal to the temperature of the segment $i+1$. In the CEN-CE proposal, a method for solving this iterative procedure in a defined number of steps has been developed. Thus, for 4 segments selected, 5 steps are required to obtain the final vertical temperature distribution. This procedure is especially convenient for implementing in the commercial software as it significantly shortens the time needed for calculation.

Step 9

Step 9 includes corrected procedure from the standard for determining the needed temperature regime of the generation sub-system. CEN-CE proposed procedure takes into account heat exchange rate of the heat exchanger ($H_{exh,i}$) and segments temperature ($\vartheta_{sto,vol,i}$):

Step 10

In Step 10 thermal losses of each segment and final temperatures are calculated.

EN 15316-4-3 (Thermal solar systems)

Standard EN 15316-4-3 is part of EN 15316 series [1] that defines calculation procedure to determine energy performances of solar thermal systems for heating of DHW and space heating, as well as of PV systems for electricity production. This standard provides six methods to calculate the energy performance from which three address solar thermal applications (Method 1, Method 2, Method 3) and other three address PV systems (Method 4, Method 5, Method 6). This paper deal only with solar thermal applications.

Method 1 allows to estimate the energy performance of solar DHW systems, using overall system performance data in conformity with product standards.

Method 2 is based on f -chart monthly method (as it was in older version of the standard) and it can be used to estimate the fraction of the required output energy covered by the thermal solar system. Method 3 is valid for the calculation of solar system thermal output that can be used for domestic hot water and space heating, using specific component data with a time step of one hour. It is important to note that this method takes into the account dynamic effects within the solar collectors.

In this paper, the CEN-CE proposed procedure for Method 3 is described in more detail.

Calculation procedure

The efficiency of solar thermal collector is related to the temperature of water in storage tank which calls for iterative calculation with Method A from EN 15316-5. In the first step, the average collector water temperature is estimated with assumed collector efficiency of 40% according to:

$$\vartheta_{col,avg,h} = \vartheta_{sol,loop,in,h-1} + \frac{0.4 \cdot I_{sol,h} \cdot A_{sol}}{\dot{m}_{col} \cdot c_W \cdot 2} [^{\circ}C]$$

Calculation then enters iteration loop. In the first step the reduced temperature difference is calculated. Afterwards, the collector efficiency obtained from specific product data is calculated in dependence on the operating conditions (reduced temperature difference T^*_h and solar radiation $I_{sol,h}$):

$$\eta_{col,h} = \eta_0 \cdot K_{hem}(50^{\circ}) - a_1 \cdot T^*_h - a_2 \cdot T^*_h{}^2 \cdot I_{sol,h} [-]$$

This standard provides default values for efficiency parameters, incidence angle modifier, first and second order heat loss coefficients. For more precise results product data efficiency parameters should be used. With calculated efficiency, thermal performances, such as collector output heat, heat losses can be calculated. At the end of iteration loop new average collector water temperature is calculated:

$$\vartheta_{col,avg,h} = \frac{\vartheta_{sol,loop,in,h-1} + \vartheta_{sol,loop,in,h}}{2} + \frac{Q_{sol,loop,out,h} \cdot 1000}{\dot{m}_{col} \cdot c_W \cdot 2} [^{\circ}C]$$

The iteration is performed three times and after final iteration loop, the auxiliary energy consumption of solar pump and controller and recoverable thermal losses of the solar loop are calculated.

The novelty added by CEN-CE team to this standard is that stagnation operating regime is also included into the calculation method. At each time step, collector output temperature is limited with the reference temperature setpoint (e.g. 90°C). If the collector output temperature is above the threshold value, the absorbed incident solar radiation is not transferred to the storage tank. If the absorbed energy $Q_{sol,stag,h}$ is greater than collector heat losses $Q_{col,ls}$ at given temperature, the average water temperature in collector will increase until the collector heat losses

become greater than the absorbed energy, when collector starts cooling down.

$$Q_{sol,stag,h} = \eta_{col,h} \cdot I_{sol,h} \cdot A_{sol,mod} \cdot t_{ci} [kWh]$$

$$Q_{col,ls} = A_{sol,mod} \cdot \Delta\vartheta_{col} \cdot (a_1 + a_2 \cdot \Delta\vartheta_{col}) \cdot t_{ci} [kWh]$$

CEN-CE Training materials: Power Point presentation, Handbook and Excel

For each series of standard, a PowerPoint, Handbook and Excel file are created. The concept of the handbook is that it follows calculation procedure created within Excel, becoming in this way a calculation algorithm. Handbook provides information about input data, calculation procedure, influencing factors and output data. Excel file uses several sheets to perform calculation described in standard. Each Excel file is designed to be used as a standalone module or in combination with other standards. The first and, for an user, the most important sheet is “Interface” **Figure 3** in which all information regarding solar collector e.g. type of the collector, heat loss coefficients, reference module area and number of collector modules, location of the main part of collector loop piping, orientation and tilt of the collector are defined. Sheets “Input series” and “Output series” are used to perform calculation for whole year or specific interval (e.g. only summer period). Sheets “Method input” and “Method output” provides information about input and output data to

Product descriptive data				
Collector type	Glazed collector			
Collector module reference area	$A_{sol,mod}$	$A_{sol,mod}$	m ²	2.51
Number of collector modules installed	N_{col}	N_{col}	-	2
Name	Symbol	Value		
Product technical input data list				
Collector module reference area	$A_{sol,mod}$	2.51		
Peak collector efficiency	η_0	0.741	Product data	
First order heat loss coefficient	a_1	3.491	Product data	
Second order heat loss coefficient	a_2	0.015	Product data	
Hemispherical incidence angle modifier	$K_{hem}(50^{\circ})$	0.94	Default value	
Mass flow rate collector loop per m ²	$\dot{m}_{loop,h}$	0.02	Default value	
Power of collector pump	$P_{sol,pmp}$	35.04	Default value	
Power of collector pump controller	$P_{sol,ctr}$	2.51	Default value	
Load default data				
SYSTEM DESIGN DATA				
Storage location				
	Heated space	HS		
Name	Symbol	Value		
System design data				
Location of the main part of the collector loop piping	SOL_LOC	HS		
Number of collector modules installed	N_{col}	2		
Tilt angle of the collector	$\alpha_{opt,tilt}$	45		
Azimuth angle of the collector	$\alpha_{opt,azi}$	0		
Mass flow rate solar loop	\dot{m}_{sol}	0.1004		
Heat losses of the solar loop supply piping	$H_{sol,loop}$	7.51		
Air temperature in a heated room	θ_{int}	20		
Load meteo data				

Figure 3. Excel sheet “Interface” example.

the method, while in the sheet “Method calculation” calculation procedure for single time step is shown with the list of all applied equations and their reference to the handbook. Sheet “Output interface” (Figures 4a, 4b and 5) enables easy manipulation with calculated data (table and various graphical output data presentation). In Figure 4a the final step temperature stratification is shown for the hour when solar system starts heating up the tank. Figure 4b presents graphically all calculation steps for the case from Figure 4a. Figure 5 shows chosen output data by user over a desired time period. In this particular case, backup heater and solar system operation periods during a day can be monitored vs. storage tank average temperature, which can be used in designing the system, e.g. for avoiding overheating, system control operation adjustment, changing of solar collector area and/or storage tank volume.

Power Point training presentation is structured in six major chapters: Introduction, Fundamentals, Input data, Calculation method, Output data and Example. Introduction gives a brief information about standard,

what is calculated and relationship and interaction with other standards. In the next chapter Fundamentals detailed information regarding particular standard related systems, equipment and physics are provided, e.g. solar radiation, variance due to orientation and inclination etc. is given. Furthermore, collector types, how to obtain efficiency curves and influencing parameters on operation of solar collector are extensively discussed. Chapters Input data, Calculation method and Output data explains how to use Excel file for this method. Finally, in the last chapter, numerical example calculated with this method is presented, including parametric analysis.

Integral solar system & storage calculation: parametric analysis

As the collector efficiency depends on the temperature of the heat storage tank that is in turn related to the collector heat output, i.e. collector efficiency, calculation procedures described in EN 15316-4-3 and EN 15316-5 requires a detailed description of the standards interconnection. The iterative procedure is needed in order to determine the final calculation conditions. This interconnection described within EN 15316-4-3. In the CEN-CE project, a separate spreadsheet calculator was developed for connecting calculations between two standards.

Example calculation using EN 15316-5 and EN 15316-4-3 solar DHW system is shown in Table 1. The analyzed case is family house with 4 household members. The total solar collector area is 5.02 m². The parametric analysis, with the Case 1 (2 flat plate solar collectors, 400 l storage tank) as a reference case, describes influence of the storage tank volume and type of collector on solar system energy output, i.e. on energy from back-up heater to be delivered to the storage as well as the solar system thermal efficiency. The parameter being changed is shown bold in the table.



Figure 4. a) Storage tank temperatures in a chosen hour; b) Insight of each calculation step temperature stratification).

In Case 2 storage tank volume is decreased. Compared to the reference Case 1, the energy input from solar collectors is lower due to reduced collector efficiency as a consequence of higher storage tank temperatures and overheating in the summer period. This entails higher amount of delivered back-up energy. In Case 3, storage volume tank is increased, resulting in the increased collector efficiency and consequently the higher input from solar collectors. The delivered back-up energy is also decreased in spite of the higher thermal losses of the storage tank. In Cases 4, 5 and 6, flat plate collectors are replaced with the evacuated

tube ones. In the all cases, 500 ℓ storage tank was used with the various total collector area. In Case 4, the collector efficiency is notably the highest while the storage tank losses are the lowest, all as a consequence of the least pronounced overheating in the summer period and higher efficiency in the winter period compared to the cases with plate solar collectors. Although the total collector area in Case 6 is higher than in Cases 4 and 5, the delivered back-up energy is also higher, due to prevailing effect of longer overheating period in summer months (with no solar energy input and higher storage tank thermal losses).

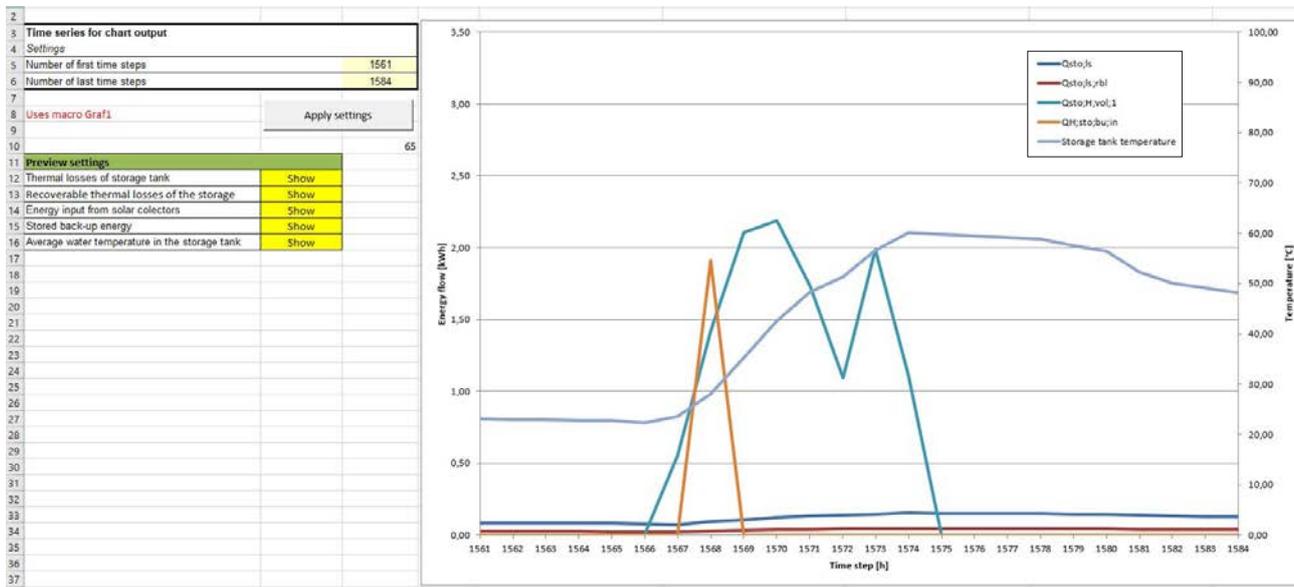


Figure 5. "Output interface" sheet diagrams with energy output data in a selected time period.

Table 1. Parametric analysis results.

Input value	Unit	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Storage tank volume	ℓ	400	300	500	500	500	500
Daily energy required for DHW	kWh	4.8	4.8	4.8	4.8	4.8	4.8
Collector type	–	Flat plate			Evacuated tube		
Collectors reference area	m ²	5,02	5,02	5,02	3.48	4.64	5.02
Solar loop mass flow rate	kg/m ² s	0.02	0.02	0.02	0.02	0.02	0.02
Output data (annual)							
Thermal losses of storage tank	kWh	655.1	520.1	705.4	598.9	723.0	792.2
Energy input from solar collectors	kWh	1813.5	1648.2	1912.9	1657.8	1835.31	1795.0
Delivered back-up energy	kWh	581.1	611.4	532.0	680.7	647.2	736.7
Average collector efficiency	%	25.8	23.4	27.2	34.0	28.2	25.5

To resume, comparison at fixed storage volume shows that Case 3 results in the lowest delivered back-up energy, while Case 4 in the highest collector efficiency. Direct comparison between plate (Case 3) and evacuated tube collectors (Case 6), at the same storage tank volume and total collector area, indicates better energy performances of the solution with plate solar collectors (less delivered back-up energy, lower storage tank thermal losses and higher collector efficiency).

Similar parametric analysis can be performed in each subsystem as a part of the overall system optimization. However, the final choice of the solar system configuration (and of the all other subsystems) is dependent on the overall system energy performance as well as on the economic aspects (equipment, installation and energy costs). ■

References

- [1] CEN standard series 15316:2017 see: <https://epb.center/support/overview-epb-standards/m3/>
- [2] EN 15316-4-3 Energy performance of buildings – Method for calculation of system energy requirements and system efficiencies – Part 4-3: Heat generation systems, thermal solar and photovoltaic systems, Module M3-8-3, M8-8-3, M11-8-3.
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