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Heating systems in buildings — Method for calculation of system energy requirements and system efficiencies — Part 4-3 Space heating generation systems, thermal solar systems

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Foreword

This document (prEN 15316-4-3:2005) has been prepared by Technical Committee CEN/TC 228 “Heating systems in buildings”, the secretariat of which is held by DS.

The subjects covered by CEN/TC 228 are the following:

- design of heating systems (water based, electrical etc.);
- installation of heating systems;
- commissioning of heating systems;
- instructions for operation, maintenance and use of heating systems;
- methods for calculation of the design heat loss and heat loads;
- methods for calculation of the energy performance of heating systems.

Heating systems also include the effect of attached systems such as hot water production systems.

All these standards are systems standards, i.e. they are based on requirements addressed to the system as a whole and not dealing with requirements to the products within the system.

Where possible, reference is made to other European or International Standards, a.o. product standards. However, use of products complying with relevant product standards is no guarantee of compliance with the system requirements.

The requirements are mainly expressed as functional requirements, i.e. requirements dealing with the function of the system and not specifying shape, material, dimensions or the like.

The guidelines describe ways to meet the requirements, but other ways to fulfil the functional requirements might be used if fulfilment can be proved.

Heating systems differ among the member countries due to climate, traditions and national regulations. In some cases requirements are given as classes so national or individual needs may be accommodated.

In cases where the standards contradict with national regulations, the latter should be followed.

Introduction

This standard presents methods for calculation of the solar thermal system input for space heating and/or domestic hot water requirements and the thermal losses and auxiliary consumption of the solar thermal system. The calculation is based on the performance characteristics of the products given in product standards and on other characteristics required to evaluate the performance of the products as included in the system.

This method can be used for the following applications:

— judging compliance with regulations expressed in terms of energy targets;

— optimisation of the energy performance of a planned heat generation system, by applying the method to several possible options;

— assessing the effect of possible energy conservation measures on an existing heat generation system, by calculating the energy use with and without the energy conservation measure – i.e. the energy savings of a solar thermal system is determined by the difference in the calculated energy performance of the building with and without the solar thermal system.

The user shall refer to other European Standards or to national documents for input data and detailed calculation procedures not provided by this standard.

1 Scope

This standard is part of a series of standards on the method for calculation of system energy requirements and system efficiencies. The framework for the calculation is described in the general part (see prEN 15316-1).

The scope of this specific part is to standardise the:

— required inputs;

— calculation method;

— required outputs

of solar thermal systems, including control, for space heating, domestic hot water production and for solar combisystem (space heating and domestic hot water production).

The following typical solar thermal systems are considered:

— domestic hot water systems characterized by EN 12976 (factory made) or ENV 12977 (custom built);

— combi-systems (for domestic hot water and space heating) characterized by ENV 12977 or the Direct Characterisation method developed in Task 26 'Solar Combisystems' of the IEA Solar Heating and Cooling programme;

— space heating systems characterized by ENV 12977**.**

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN ISO 7345:1995*, Thermal insulation - Physical quantities and definitions (ISO 7345:1987)*

EN ISO 9488:2000*, Solar energy - Vocabulary (ISO 9488:1999)*

ISO/DIS 9459-5, *Solar heating – Domestic water heating systems – Part 5: System performance characterization by means of whole-system tests and computer simulation*

EN ISO 13790:2005, *Thermal performance of buildings - Calculation of energy use for space heating and cooling*

EN 12975-1:2006, *Thermal solar systems and components – Solar collectors - Part 1: General requirements*

EN 12975-2:2006, *Thermal solar systems and components – Solar collectors - Part 2: Test methods*

EN 12976-1:2006, *Thermal solar systems and components – Factory made systems - Part 1: General requirements*

EN 12976-2:2006, *Thermal solar systems and components – Factory made systems - Part 2: Test methods*

ENV 12977-1:2001, *Thermal solar systems and components – Custom built systems - Part 1: General requirements*

ENV 12977-2:2001, *Thermal solar systems and components – Custom built systems - Part 2: Test methods*

ENV 12977-3, *Thermal solar systems and components – Custom built systems - Part 3: Performance characterisation of stores for solar heating systems*

prEN ISO 13790:2005*, Thermal performance of buildings – Calculation of energy use for space heating and cooling*

EN ISO 7345:1995, *Thermal insulation - Physical quantities and definitions (ISO 7345:1987)*

prEN 15316-1:2005, *Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 1: General*

prEN 15316-2-3:2005*, Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 2-3: Space heating distribution systems*

prEN 15316-3-1:2005*, Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 3-1: Domestic hot water systems, characterisation of needs (tapping requirements)*

prEN 15316-3-2:2005*, Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 3-2: Domestic hot water systems, distribution*

3 Terms and definitions

3.1 Definitions

To be updated according to the results of CEN/BT WG173

For the purposes of this document, the definitions given in EN ISO 7345:1995 and in the standards above apply.

In order to be compatible with other prEN15316 standards the definitions for some terms used in this document does not comply with ISO EN 9488 – see table below:

	prEN15316-4-3 (this document)	ISO EN 9488 EN 12975 EN 12976
Electricity consumption of pumps, controls, freeze protection devices, etc.	Auxiliary energy Q_{aux}	Parasitic energy Q_{par}
Supplementary heating of storage tank	Back-up energy Q_{bu}	Auxiliary energy Q_{aux}

When using data from EN12975 and EN12976 test reports for the calculations described in this document, one must be careful to use the right values, as these test reports use the definitions according to ISO

Solar combi systems are systems delivering energy to both domestic hot water and space heating.

3.2 Symbols and abbreviations

To be updated according to the results of CEN/BT WG173

For the purposes of this document, the following symbols and units (Table 1) and indices (Table2) apply.

Table 1 — Symbols and units

A	collector aperture area	m²
a_1	heat loss coefficient of solar collector	W/(m².K)
a_2	temperature dependence of the heat loss coefficient	W/(m².K^2)
a, b, c,..	correlation coefficients	-
A_C*	effective collector loop area	m²
c_{cap}	storage tank capacity correction coefficient	-
C_S	thermal heat capacity of the storage tank	MJ/K
f_{sol}	solar fraction	%
f_{aux}	fraction of the storage tank volume used for back-up heating	-
G_{month} G_{annual}	average solar irradiance on the collector plane during the considered period	W/m²
IAM	collector incidence angle modifier	-
P	power	W
Q	quantity of energy	kWh
Q_{load}	space heating or domestic hot water loads	kWh
t_{monthi}	length of month i	hours
U_C	heat loss coefficient of the collector loop (related to collector aperture area)	W/(m².K)
U_C*	effective collector heat loss coefficient (related to effective collector aperture area)	W/(m².K)
UL	overall heat loss coefficient of pipes in the collector loop	W/K
UA	overall heat loss coefficient of the storage tank	W/K
V_n	nominal storage tank volume	litres
V_S	solar storage tank volume	litres
W	electrical auxiliary energy	kWh
x, y	dimensionless factors	-
ΔT	reference temperature difference	K
θ_a	average ambient air temperature over the considered period	°C
θ_{cw}	mains water temperature	°C
θ_o	outside air temperature over the considered period	°C
η_0	zero-loss collector efficiency	-
η_{loop}	efficiency of collector loop taking into account the influence of the heat exchanger	-

Table 2 — Indices

a	average
bu	back up
el	electrical energy
ext	external
hw	hot water
in	input to system
int	internal
nh	non recoverable
nr	non recovered
nom	nominal
out	output from system
p	pump
r	recovered
rl	recoverable
s	solar
sh	space heating
t	tank
w	auxiliary

4 Principle of the method

4.1 Building load requirements influence the energy performance of a solar thermal system

The performance of a solar thermal system depends on the thermal load applied to the system. The thermal load applied to the solar thermal system is the load requirements of the building including the heat losses from the heating transmission (heat emitters) and distribution systems (pumps and pipes). In general, the higher the total load applied to the solar thermal system, the higher the output of the system. Therefore, before starting determination of the system output, it is necessary to know the loads applied to the solar thermal system:

Load applied for the space heating system:

— required space heating load (see EN ISO 13790) ;

— space heating transmission and distribution heat losses (see prEN 15316-2-3).

Load applied for the domestic hot water system:

— required energy for domestic hot water needs (see prEN 15316-3-1);

— domestic hot water transmission and distribution heat losses (see prEN 15316-3-2).

4.2 The solar thermal system influences the energy performance of the building

The influence of a solar thermal system on the energy performance of a building comprises:

— heat output of the solar thermal system to the distribution systems (for space heating and/or for domestic hot water), thus reducing the buildings consumption of other (e.g. conventionally generated) heat;

— recovered losses from the solar thermal system used for space heating, thus reducing the buildings consumption of heat for space heating;

— electricity to be supplied to the solar thermal system, thus increasing the buildings consumption of electricity;

— reduction of operation time of the conventional heating generator. In some cases, the conventional back-up heater can be turned off during summer, thus reducing stand-by heat losses and auxiliary electricity consumption.

4.3 Performance of the solar thermal system

The performance of the solar thermal system is determined by the following parameters:

— product characteristics according to product standards: System performance indicators (annual back-up energy, solar fraction and annual auxiliary energy) or collector parameters (collector aperture area, zero-loss efficiency, heat loss coefficients, etc);

— storage tank parameters (type of storage tank, size, etc);

— collector loop heat losses and transmission heat losses between storage tank and back-up (length, insulation, efficiency, etc);

— control of the system (temperature differential set points, etc);

- climate conditions (solar irradiation, outdoor air temperature, etc);
- auxiliary energy of the solar collector pump and control units;
- heat demand of the space heating distribution system;
- heat demand of the domestic hot water distribution system (or solar combisystem).

4.4 Heat balance of the heat generation subsystem, including control

In order to respect the general structure of the system loss calculation, the performance of the thermal solar subsystem shall be characterised by the following input data:

- type and characteristics of the solar thermal system;
- location of the solar thermal system;
- type of control system;
- heat requirement.

This standard requires input data according to other parts of this standard (see prEN 15316-1).

Based on these data, the following output data are calculated in the thermal solar subsystem module:

- heat delivered by the solar thermal system;
- thermal losses of the solar storage tank;
- auxiliary consumption of pump and control equipment in the collector loop;
- recoverable and recovered auxiliary energy;
- recoverable and recovered thermal losses of the solar storage tank.

Heat balance of solar thermal systems are given in **Figure 1 and 2,** showing the energy flows directly influencing the energy performance of the building (grey boxes) together with the energy flows not directly influencing the energy performance of the building (white boxes).

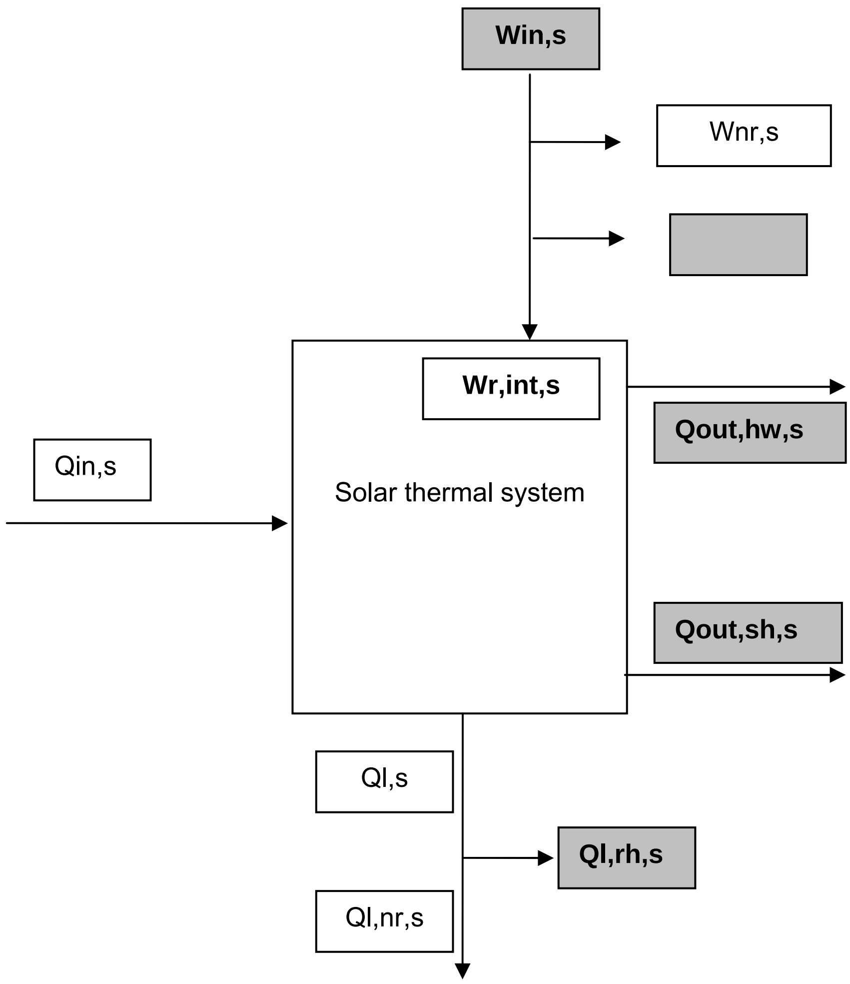

Figure 1 — Heat balance for a solar preheat system / solar only system – grey/bold indicated parameters influence directly the energy performance of the building.

$Q_{out,hw,s}$: heat delivered by the solar thermal system to domestic hot water distribution system

$Q_{out,sh,s}$: heat delivered by the solar thermal system to space heating distribution system

$Q_{out,s}$: total heat delivered by the solar thermal system

$W_{in,s}$: total auxiliary energy for pumps and controllers

$Q_{l,r,s}$: heat losses from solar thermal system recovered/utilised for space heating

$Q_{in,s}$: incident solar energy on the plane of the collector array

$W_{p,r,s}$: recovered auxiliary electrical energy for pumps and controllers. Part of the auxiliary electrical energy which is transferred as useful heat to the building

$W_{p,r,int,s}$: internally recovered auxiliary electrical energy for pumps and controllers. Part of the auxiliary electrical energy which is transferred as useful heat to the system

$W_{p,nr,s}$: non recovered auxiliary electrical energy for pumps and controllers. Part of the auxiliary electrical energy which is not transferred into useful heat to the building or to the system

$Q_{l,s}$: total losses from the solar thermal system

$Q_{l,nr,s}$: non recovered losses from the solar thermal system. Part of the system losses not useful for space heating

NOTE: In case of a solar preheat system the load for the external heat generator is reduced by Qout,hw,s + Qout,sh,s

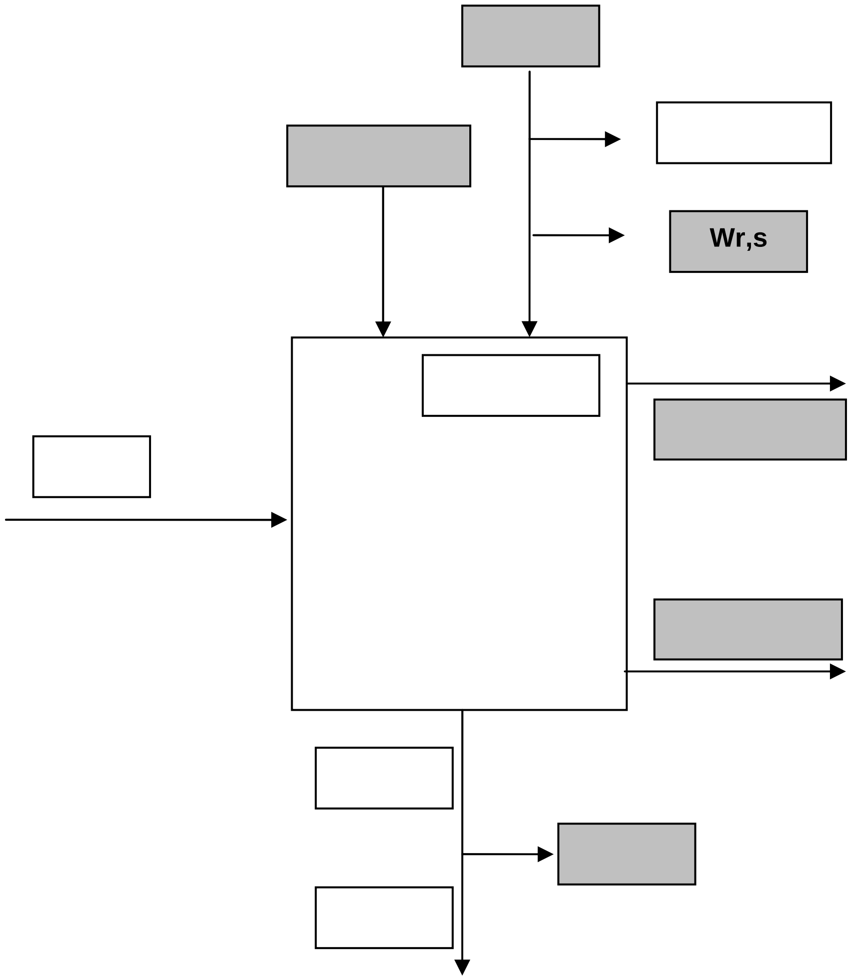

Figure 2 — Heat balance for a solar-plus-supplementary system– grey/bold indicated parameters influence directly the energy performance of the building

$Q_{out,hw,s}$:	heat delivered by the solar thermal system to domestic hot water distribution system
$Q_{out,sh,s}$:	heat delivered by the solar thermal system to space heating distribution system
$Q_{out,s}$:	total heat delivered by the solar thermal system
$W_{in,s}$:	total auxiliary energy for pumps and controllers
$Q_{l,r,s}$:	heat losses from solar thermal system recovered/utilised for space heating
$Q_{bu,int,s}$:	internal back-up heat input required
$Q_{in,s}$:	incident solar energy on the plane of the collector array
$W_{p,r,s}$:	recovered auxiliary electrical energy for pumps and controllers. Part of the auxiliary electrical energy which is transferred as useful heat to the building
$W_{p,r,int,s}$:	internally recovered auxiliary electrical energy for pumps and controllers. Part of the auxiliary electrical energy which is transferred as useful heat to the system
$W_{p,nr,s}$:	non recovered auxiliary electrical energy for pumps and controllers. Part of the auxiliary electrical energy which is not transferred into useful heat to the building or to the system
$Q_{l,s}$:	total losses from the solar thermal system
$Q_{l,nr,s}$:	non recovered losses from the solar thermal system. Part of the system losses not useful for space heating

4.5 Auxiliary energy

Auxiliary energy is required to operate the thermal solar subsystem, e.g. for the pump of the collector loop, freezing protection, …. Auxiliary energy is accounted for in the generation subsystem as long as no transport energy is transferred to the distribution system outside the thermal solar subsystem.

In case of hydraulic decoupling between the generation and various distribution systems, e.g. by a buffer storage tank, the extra collector pump for storage loading is accounted for in the generation subsystem.

NOTE: The term auxiliary energy used in this document is named parasitic energy in EN ISO 9488 (it comprises consumption of pumps, fans and control), while the term back-up used in this document is named auxiliary in EN ISO 9488.

4.6 Recoverable, recovered and unrecoverable heat losses

The calculated heat losses are not necessarily lost. Part of the losses are recoverable, and part of these recoverable losses are actually recovered.

Recoverable heat losses $Q_{l,rl,s}$ are e.g. the distribution losses between the solar collector and the back-up heater.

4.7 Calculation periods

The objective of the calculation is to determine the annual heat output of the thermal solar subsystem. This may be done in one of the following two different ways:

— by using annual data for the system operation period and perform the calculations using annual average values;

— by dividing the year into a number of calculation periods (e.g. months, operation periods as defined in EN ISO 13790) and perform the calculations for each period using period-dependent values and adding up the results for all the periods over the year.

5 Solar thermal system calculation

5.1 Calculation procedures

In the following, two methods are given for determination of solar output, auxiliary consumption and recoverable losses from the solar thermal system and other output data related to the system and required for performing the energy performance calculation of a building with a solar thermal system.

The two methods enable the use of different type of input data:

— method A (see 5.2) uses system data, i.e. input data from system tests or default system input values given in the format of EN 12976-2 (performance indicators) – also system simulations (simulated tests) can be used;

— method B (see 5.3) uses component data, i.e. input data from component tests (or default component input values).

With method A, specific system parameters/characteristics (i.e. control strategies) can be better taken into account. Method B uses only test results (or default values) for components.

NOTE: Method A can also be used for solar combi systems with collector areas smaller that 6 m^2. Limiting condition for testing these systems according to EN 12976-2 is that it is possible to test the domestic hot water function apart from the space heating function. In this case, system data only apply to domestic hot water and space heating using solar thermal is not considered.

5.2 Method A - using system data (results from system tests)

This calculation method comprises the following steps:

- Look up performance indicators in test results from test reports according to EN 12976-2;
- Determine the solar output;
- Determine the auxiliary consumption of the solar thermal system auxiliaries;
- Calculate the losses of the solar thermal system:
  - determine the losses of the solar storage tank;
  - determine the heat losses of the distribution between the solar thermal system and the back-up heater;
- Calculate the recoverable heat losses of the solar thermal system:
  - determine the recoverable auxiliary consumption;
  - determine the recoverable heat losses of the solar storage tank;
  - determine the recoverable heat losses of the distribution between the solar thermal system and the back-up heater

NOTE: So far this method is only valid for systems delivering only domestic hot water and which have been tested according to EN 12976-2. The test results shall include performance indicators for the actual climate and for a load higher than or equal to the actual load as well as for a load lower than or equal to the actual load. The intention is to make this method applicable also for use of results from recognised simulation tools.

5.2.1 Definition of load applied to the solar thermal system

The load applied to the solar thermal system depends on the solar thermal system configuration (preheat system, solar-plus-supplementary system, solar only system).

In order to simplify and to avoid iterative calculation procedures, the following assumptions are made:

- for all configurations, the load to be applied shall take into account the needs (domestic hot water) and the distribution heat losses. The value of this load is an input to this method;
- for a solar preheat system, the heat losses between the solar thermal system and the back-up heater shall not be added to the load applied.
- heat losses of the solar thermal system (losses from solar storage tank and solar collector loop) shall not be added to the load applied.

5.2.2 Output from solar thermal system

In order to determine the output from the solar thermal system, performance indicators according to EN 12976-2 shall be available for the system and the actual operation conditions.

Performance indicators for the actual climate and for a load higher than or equal to the actual load as well as for a load lower than or equal to the actual load shall be available.

5.2.2.1 Solar-only and solar preheat systems **- determination of monthly solar output**

The annual output of a solar-only system or a solar preheat system is calculated by:

$$Q_{out,s,annual} = f_{sol} * Q_{load,s} \qquad [kWh] \qquad (eq\ 1)$$

where

f_{sol}: solar fraction determined by interpolation to match the actual annual load (see below)

$Q_{load,s}$ actual annual load applied to the system in kWh determined according to 5.2.1

<u>Determination of f_{sol} for the actual load:</u>

$Q_{load,s}$ given in kWh is converted to MJ to comply with the performance indicator Q_d calculated according to EN 12976-2:

$Q_d = Q_{load,s}*3.6$

f_{sol} is determined by interpolation from test reports:

$$f_{sol} = f_{sol,i-1} + (f_{sol,i+1} - f_{sol,i-1})/(Q_{d,i+1} - Q_{d,i-1})*(Q_d - Q_{d,i-1}) \qquad [\%] \qquad (eq\ 2)$$

The indices i-1 and i+1 correspond to the nearest set of values below and above the actual value of Q_d (standard interpolation procedure).

<u>Determination of monthly output:</u>

The monthly outputs of the solar thermal system are assumed to be proportional to the monthly irradiance and are determined by:

$$Q_{out,s,month} = (G_{month}*t_{month})/(G_{annual}*t_{annual}) * Q_{out,s,annual} \qquad [kWh] \qquad (eq\ 3)$$

where:

G_{month} average hourly solar irradiance on the collector plane during the considered period. The values are defined in B.5 [W/m²]

t_{month} length of the month in hours (28 days: 672 hours, 30 days: 720 hours, 31 days: 744 hours)

G_{annual} average hourly solar irradiance on the collector plane during the entire year. The values are defined in B.5 [W/m²]

t_{annual} length of the year in hours: t_{annual} = 8760 hours

<u>Limitation of the solar thermal system output</u>

The solar thermal system output can not become negative: If the solar thermal system output determined above is negative, then the output is set equal to 0.

The solar thermal system output can not become higher than the load: If the solar thermal system output determined above is higher than the load, then the output is set equal to the load.

5.2.2.2 Solar-plus-supplementary system - determination of monthly solar output

The annual output of a solar-plus-supplementary system is calculated by:

$$Q_{out,s,annual} = Q_{load,s} - Q_{aux,net} \qquad [kWh] \qquad (eq\ 4)$$

where

$Q_{aux,net}$ energy demand of the solar heating system delivered by the back-up heater to the store, determined by interpolation to match the actual load (see below)

$Q_{load,s}$ actual annual load applied to the system in kWh determined according to 5.2.1

Determination of $Q_{aux,net}$ for the actual load:

$Q_{load,s}$ given in kWh is converted to MJ to comply with the performance indicator Q_d calculated according to EN 12976-2::

$Q_d = Q_{load,s}*3.6$

$Q_{aux,net}$ is determined by interpolation from test reports:

$$Q_{aux,net} = Q_{aux,net,i-1} + (Q_{aux,net,i+1} - Q_{aux,net,i-1})/(Q_{d,i+1} - Q_{d,i-1})*(Q_d - Q_{d,i-1}) \quad [kWh] \qquad (eq\ 5)$$

The indices i-1 and i+1 correspond to the nearest set of values below and above the actual value of Q_d (standard interpolation procedure).

Determination of monthly output:

The monthly outputs of the solar thermal system are assumed to be proportional to the monthly irradiance and are determined by:

$$Q_{out,s,month} = (G_{month}*t_{month})/(G_{annual}*t_{annual}) * Q_{out,s,annual} \quad [kWh] \qquad (eq\ 6)$$

where:

G_{month} average hourly solar irradiance on the collector plane during the considered period. The values are defined in B.5 [W/m^2]

t_{month} length of the month in hours (28 days: 672 hours, 30 days: 720 hours, 31 days: 744 hours)

G_{annual} average hourly solar irradiance on the collector plane during the entire year. The values are defined in B.5 [W/m2]

t_{annual} length of the year in hours: t_{annual} = 8760 hours

Limitation of the solar thermal system output

The solar thermal system output can not become negative: If the solar thermal system output determined above is negative, then the output is set equal to 0.

The solar thermal system output can not become higher than the load: If the solar thermal system output determined above is higher than the load, then the output is set equal to the load.

5.2.3 Auxiliary consumption of solar thermal system auxiliaries

Some solar thermal systems use auxiliary energy (electricity) and some do not:

- for a thermosiphon solar water heater (self-circulation solar thermal system), auxiliary consumption is zero;

- for a forced circulation system, auxiliary consumption by pumps and controllers are taken into account.

NOTE: Additional auxiliary consumptions (e.g. freezing protection) can be included in national annexes.

The annual auxiliary consumption by pumps and controllers is taken from test reports for the performance indicator Q_{par} calculated according to EN 12976-2.

Interpolation to match the actual load is performed (corresponding to procedures given above for interpolation of performance indicators). The value is then converted from MJ to kWh:

$$W_{p,s} = Q_{par,i} / 3.6 \qquad [kWh]$$

where:

$Q_{par,i}$ annual interpolated value of Q_{par} (MJ)

The monthly values of auxiliary consumption are determined by distribution of the annual auxiliary consumption corresponding to the monthly distribution of the solar irradiance from B.5 (e.g. if January irradiance is 5% of annual irradiance, then January auxiliary consumption of the pump is 5% of the annual auxiliary consumption of the pump).

5.2.4 Losses

The losses are calculated according to 5.3.4.

5.2.5 Recoverable losses

The recoverable losses are calculated according to 5.3.5.

5.3 Method B - using component data (results from component tests)

This calculation method, based on the f-chart method (see [1]), comprises the following steps:

- Define the load(s) applied to the solar thermal system (data input to this calculation):
  - calculate the ratio of space heating load to the total load (P_{sh});
  - calculate the ratio of domestic hot water load to the total load (P_{hw});
- Calculate the ratio X (similar to a loss / load ratio):
  - determine collector aperture area A;
  - determine heat loss coefficient of the collector loop $U_{c;}$
  - determine collector loop efficiency $\eta_{loop;}$
  - calculate reference temperature difference ΔT;
  - calculate storage tank capacity correction coefficient c_{cap} depending on the system configuration (preheat system or solar-plus-supplementary system);
  - attribute the solar storage tank volume to space heating or domestic hot water;
- Calculate the ratio Y (similar to a solar / load ratio):
  - determine collector zero-loss collector efficiency η_0;
  - determine solar irradiance G on the collector plane;
- Calculate the thermal solar output for space heating and for domestic hot water and the total thermal solar output;
- Calculate the auxiliary consumption of the solar thermal system auxiliaries;

- Calculate the losses of the solar thermal system:
  - determine the losses of the solar storage tank;
  - determine the losses of the distribution between the solar thermal system and the back-up heater;
- Calculate the recoverable losses of the solar thermal system:
  - determine the recoverable auxiliary consumption;
  - determine the recoverable losses of the solar storage tank;
  - determine the recoverable losses of the distribution between the solar thermal system and the back-up heater.

5.3.1 Definition of load applied to the solar thermal system

The load applied to the solar thermal system depends on:

- the uses to satisfy (domestic hot water production and/or space heating);
- the solar thermal system configuration (preheat system, solar-plus-supplementary system, solar only system).

In order to simplify and to avoid iterative calculation procedures, the following assumptions are made:

- for all uses, the load to be applied takes into account the needs (building heat demand, domestic hot water, etc) and the distribution heat losses. The value of this load is an input to this method.
- for a solar preheat system, the heat losses between the solar thermal system and the back-up heater shall not be added to the load applied;
- heat losses of the solar thermal system (losses from solar storage tank and solar collector loop) shall not be added to the load applied.

NOTE: In this method it is considered, that the back-up heater does not compensate the losses of the domestic hot water distribution.

5.3.2 Output from solar thermal system

For calculation of the output from the solar thermal system, three cases are distinguished:

a) only domestic hot water production

In this case, the output from the solar thermal system, $Q_{out,hw,s}$ is calculated with the following general calculation method using only the applied domestic hot water load and the characteristics of the domestic hot water system (collector area, solar storage tank volume, etc.).

b) only space heating

In this case, the output from the solar thermal system, $Q_{out,sh,s}$ is calculated with the following general calculation method using only the applied space heating load and the characteristics of the space heating system (collector area, solar storage tank volume, etc.).

c) solar combisystem (domestic hot water and space heating)

For a solar combisystem system (see [2]), the solar output for domestic hot water production and the solar output for space heating requirements are calculated in succession with the following general calculation method. The method is applied twice by dividing the collector aperture area and the solar storage tank volume (if there is only one store) into two according to the space heating load ratio and the domestic hot water load ratio.

The total solar output is given by:

$$Q_{out,s} = Q_{out,hw,s} + Q_{out,sh,s} \quad \text{[kWh]} \qquad \text{(eq 7)}$$

where:

$Q_{out,hw,s}$	solar output for domestic hot water	[kWh]
$Q_{out,sh,s}$	solar output for space heating	[kWh]

Dividing the collector aperture area

The general calculation of solar output (eq. 10) applies individually to solar output for space heating and solar output for domestic hot water, assuming that:

— one part of the collector aperture area is used for space heating and another part is used for domestic hot water, proportional to the space heating load and the domestic hot water load, respectively.

For determination of the parameters X, Y and C_{cap}, the collector area is multiplied by the coefficient P_{sh} in order to calculate output from the solar thermal system for space heating and by the coefficient P_{hw} in order to calculate output from the solar thermal system for domestic hot water requirements:

$$P_{sh} = Q_{load,sh,s} / (Q_{load,sh,s} + Q_{load,hw,s}) \quad \text{[-]} \qquad \text{(eq 8)}$$

$$P_{hw} = Q_{load,hw,s} / (Q_{load,sh,s} + Q_{load,hw,s}) \quad \text{[-]} \qquad \text{(eq 9)}$$

Dividing the solar storage tank volume

For a one-tank system:

— the storage tank volume used for calculation of the solar output for space heating is the volume of the solar storage tank multiplied by P_{sh};

— the tank volume used for calculation of the solar output for domestic hot water is the volume of the solar storage tank multiplied by P_{hw}.

If the system includes two solar storage tanks – one for space heating and one for domestic hot water – each of these is taken into account in the respective calculation (one storage tank may be a solar floor as in annex B).

NOTE: It is important to note, that calculation of storage tank volumes for space heating and domestic hot water is monthly. Otherwise the splitting-up according to load ratios will determine too small storage tank volumes for domestic hot water.

General calculation of solar output

The output of the solar thermal system is calculated, month by month, by:

$$Q_{out,s} = (aY + bX + cY^2 + dX^2 + eY^3 + fX^3) * Q_{load,s} \quad \text{[kWh]} \qquad \text{(eq 10)}$$

where:

$Q_{load,s}$	load applied to the solar thermal system The load to be applied for calculation of solar output is determined according to definitions above	[kWh]
a, b, c, d, e,	correlation coefficients depending on storage tank type. The values, given in the f-chart method ([1]), are defined in B.1	[-]
f	new correlation coefficient specific to direct solar floor ([3]). Value is defined in B.1	[-]
X and Y	dimensionless factors	[-]

Limitation of the solar thermal system output

The solar thermal system output can not become negative: If the solar thermal system output determined above is negative, then the output is set equal to 0.

The solar thermal system output can not become higher than the load: If the solar thermal system output determined above is higher than the load, then the output is set equal to the load.

Determination of X

The value X is calculated according to eq. 11. It depends on the collector loop heat loss coefficient and the temperature difference, but also on the storage tank volume taken into account by the storage tank capacity correction coefficient:

$$X = A \; U_C \; \eta_{loop} \; \Delta T \; c_{cap} \; t_{month} \; / \; (Q_{load,s} * 1000) \qquad [-] \qquad \text{(eq 11)}$$

where:

A	collector aperture area according to EN 12975-2	[m²]
U_C	heat loss coefficient of the collector loop (collector and pipes) / see eq. 12	[W/(m².K)]
η_{loop}	efficiency of the collector loop taking into account influence of heat exchanger. The value is defined in B.2	[-]
ΔT	reference temperature difference / see eq. 13	[K]
c_{cap}	storage tank capacity correction coefficient. The values are given in B.3	[-]
t_{month}	length of the month in hours	[h]
$Q_{load,s}$	load applied to the solar thermal system according to definitions above	[kWh]

The heat loss coefficient of the collector loop, collectors and pipes, is determined by the collector characteristics and the insulation of the pipes. The heat loss coefficient is calculated by:

$$U_C = a_1 + a_2 \,.\, 40 + UL/A \qquad [W/(m^2.K)] \qquad \text{(eq 12)}$$

where:

a_1 heat loss coefficient of solar collector related to the aperture area. This parameter is obtained according to EN 12975-2. Default values are given in B.2

a_2 temperature dependence of the heat loss coefficient related to the aperture area. This parameter is obtained according to EN 12975-2. Default values are given in B.2

UL overall heat loss coefficient of all pipes in the collector loop including pipes between collectors and array pipes between collector array and solar storage tank :

— If the pipe and insulation for the collector loop are known, then UL can be calculated using the formulas for insulated pipes (see [1]);

— if the collector loop characteristics are not known, then UL is to be determined according to B.2

The reference temperature differential is calculated by:

$$\Delta T = \theta_{ref} - \theta_o \quad [K] \quad (eq\ 13)$$

where:

θ_o average outside air temperature over the considered period, values are given in B.4

θ_{ref} reference temperature depending on application and storage tank type, values are defined in B.4

Determination of Y

The value Y is calculated according to eq. 14. It depends on the collector data (zero-loss collector efficiency) and the solar irradiance on the collector plane:

$$Y = A\ IAM\ \eta_0\ \eta_{loop}\ G_{month}\ t_{month}\ /\ (Q_{load,s}*1000) \quad [-] \quad (eq\ 14)$$

where:

A	collector aperture area according to EN 12975-2	[m²]
IAM	incidence angle modifier of the collector = $K_{50}(\tau\alpha)$ from the collector test standard EN 12975-2. Default values are given in B.5	[-]
η_0	zero-loss collector efficiency from the collector test standard EN 12975-2 and related to the aperture area. Default values are given in B.2	[-]
η_{loop}	efficiency of the collector loop taking into account influence of heat exchanger. The values are defined in B.2	[-]
G_{month}	average solar irradiance on the collector plane during the considered period. The values are defined in B.5	[W/m²]
t_{smonth}	length of the month in hours	[h]
$Q_{load,s}$	load applied to the solar thermal system according to definitions above	[kWh]

5.3.3 Auxiliary consumption of solar thermal system auxiliaries

Some solar thermal systems use auxiliary energy (electricity) and some do not:

— for a thermo-siphon solar water heater (self-circulation solar thermal system), auxiliary consumption by auxiliaries is zero;

— for a forced circulation system, auxiliary consumption by pumps and controllers are taken into account.

5.3.3.1 Pumps

The auxiliary consumption by pumps in the solar thermal system is calculated by:

$$W_{p,s} = P_p*t_p/1000 \quad [kWh] \quad (eq\ 15)$$

where

P_p total nominal input power of pumps in Watts, i.e. the power stated on the pump's label.
For a multi stage pump, the power corresponding to the typical operation mode is chosen. If the nominal power is not known, default values are given in B.2

t_p pump operation time in hours. The annual operation time according to EN 12976 is 2000 hours. The monthly operation time is determined by distribution of the annual operation time corresponding to the monthly distribution of the solar irradiance from B.5 (e.g. if January irradiation is 5% of annual irradiation, then January operation time of the pump is 5% of the annual operation time of the pump).

5.3.4 Losses

5.3.4.1 Solar storage tank(s) losses

The heat losses of solar storage tank(s) are determined by the overall heat loss coefficient UA (W/K).

UA can be obtained from test reports according to ENV 12977-3 or determined as indicated in B.6.

For domestic hot water, heat losses are calculated by:

$$Q_{l,t,s} = UA \cdot (\theta_{set\ point} - \theta_a) \cdot (Q_{out,s} / Q_{load,s}) * t_{month} / 1000 \quad [kWh] \quad [eq\ 16]$$

where:

t_{month} length of the month in hours [h]

$\theta_{set\ point}$ set point temperature of domestic hot water = 60°C

θ_a average ambient air temperature:

if the solar storage tank is installed in the heated space: $\theta_a = 20°C$

if the solar storage tank is installed in an un-heated space: $\theta_a = \theta_o + (20°C - \theta_o) / 2$

if the solar storage tank is installed outside: $\theta_a = \theta_o$ (see B.4)

For space heating, heat losses are calculated by:

$$Q_{l,t,s} = UA \cdot (\theta_{set\ point} - \theta_a) \cdot (Q_{out,s} / Q_{load,s}) * t_{month} / 1000 \quad [kWh] \quad [eq\ 17]$$

where:

$\theta_{set\ point}$ set point temperature: mean temperature of the distribution system under design conditions (input data to this standard)

5.3.4.2 Distribution losses between the solar thermal system and the back-up heater

Calculation of the distribution losses is given in B.7.

5.3.5 Recoverable losses

5.3.5.1 Recoverable auxiliary consumption

The recoverable part of the auxiliary consumption $W_{p,rl,s}$ is defined in B.8.

5.3.5.2 Recoverable losses from solar tank(s)

The recoverable part of the heat losses from the solar tanks $Q_{l,rl,t,s}$ is defined in B.8.

5.3.5.3 Recoverable distribution losses between the solar thermal system and the back-up heater

The recoverable part of the distribution losses $Q_{l,rl,d,s}$ is defined in B.8.

5.3.5.4 Total recoverable losses from the solar thermal system

The total recoverable losses from the solar thermal system are calculated by:

$$Q_{l,rl,s} = W_{p,rl,s} + Q_{l,rl,t,s} + Q_{l,rl,d,s} \quad \text{(eq 18)}$$

Other recoverable losses are treated in other parts of this standard:

- recoverable heat losses from domestic hot water transmission and distribution system;
- recoverable heat losses from space heating transmission and distribution system;
- recoverable losses from separate back-up heater(s).

5.3.6 Determination of reduced operation time of non-solar heat generator(s)

A solar thermal system reduces operation time of other (back-up) heat generator(s). This influences auxiliary consumption and in some cases heat losses of the non-solar heat generator and hence the energy performance of the building due to:

- reduced auxiliary consumption;
- reduced stand-by heat losses.

5.3.6.1 Reduction of auxiliary consumption of non-solar (back-up) heat generator(s)

It is assumed, that the auxiliary consumption of the non-solar (back-up) heat generator(s) is reduced proportional to the fraction of the load covered by the solar thermal system. This solar fraction is given by:

$$f_{sol} = Q_{out,s} / Q_{load,s} \quad \text{(eq 19)}$$

The corrected auxiliary consumption of the non-solar (back-up) heat generator(s), taking into account the solar thermal system, is given by:

$$W_{bu,s} = W_{bu,nom} * (1 - f_{sol}) \quad \text{(eq 20)}$$

5.3.6.2 Reduction of heat losses from non-solar (back-up) heat generator(s)

If the solar thermal system for a longer period covers all loads, the non-solar (back-up) heat generator(s) can be turned off and heat losses from it saved. However, in doing so, microbiological safety of the domestic hot water shall be guaranteed at any time.

It is assumed, that the non-solar (back-up) heat generator(s) can not be turned off for a “longer period” if the fraction of the load covered by the solar thermal system (on a monthly basis) is less than 80% of all loads.

It is assumed, that the non-solar (back-up) heat generator(s) can be turned off for a period proportional to the fraction of the load covered by the solar thermal system (on a monthly basis), if this fraction is 80% or more.

Using the definition of f_{sol} above, a heat loss reduction factor can be calculated by:

$$f_{sol} < 80\% \Rightarrow \quad Q_{bu,l,s} = Q_{bu,l,nom}$$

$$f_{sol} \geq 80\% \Rightarrow \quad Q_{bu,l,s} = Q_{bu,l,nom} * (1 - f_{sol})$$

where $Q_{bu,l,nom}$ is the “nominal”[1] heat losses from the non-solar (back-up) heat generator(s).

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[1] The ”nominal” heat losses are defined as the heat losses from the non-solar heat generator(s) in the case of no solar thermal system.

Annex A
(informative)

Examples on determination of thermal performance of solar thermal systems

This annex elucidates the use of the simplified calculation method:

- for a solar DHW system with external back-up heater;
- for a solar combisystem.

For these two systems, major characteristics have been described as well as the way to determine their thermal performance.

A.1 DHW - Solar-plus-supplementary system

The first example presents a solar DHW system with a solar collector measured according to EN12975-2 with an area of 2.702 m^2, an zero-loss collector efficiency of 0.8026 and a first order heat loss coefficient of 3.723 W/ (m^2K). In the drainback collector loop, there is a pump with nominal power of 50 W. After filling the collector loop, the pump switches back to a power of 20 W. The solar storage tank has an internal collector-side heat exchanger and direct tap water draw-off. The solar storage tank volume according to the specifications of the manufacturer is 120 litres. The solar storage tank and pump are located in the first floor, which is a heated part of the house. The heating season is from October up to and including March. The external back-up heater is always standby. Pipes between the solar storage tank and the back-up heater are insulated. Mains pressure is used for transport of tap water through solar DHW system and its back-up heater.

Question is to determine the thermal performance of this solar DHW system for a hot water demand of 110 litres per day based on a temperature step from 15°C to 65°C, for location De Bilt, The Netherlands. The collector has a tilt of 45° and is facing South. Table A.1 lists the monthly values of average outside ambient temperature and solar irradiance and irradiation in the collector plane.

Table A.1 — Monthly values of average outside air temperature and solar irradiance and irradiation in a plane with a tilt of 45° facing South for Test Reference Year De Bilt, The Netherlands.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
θ_o [°C]	2.5	2.7	5.6	8.0	11.9	15.5	17.0	16.4	13.8	11.2	6.0	3.4
G [W/m^2]	40	65	126	167	193	209	187	206	139	94	51	33
H [kWh/m^2]	30	44	94	120	143	151	139	154	100	70	37	25

Calculation of the thermal performance follows the steps given in 5.2.

A.1.1 Determination of the heat load

First of all the hot water load is determined. The daily hot water demand is 110 litre x 1 kg/litre x 4180 J/(kgK) x 50 K = 6.39 kWh/day. In this example, heat losses of the pipes between back-up heater and tapping points are 10% of the load, corresponding to 0.64 kWh/day. According to 5.2.1, heat losses between solar storage tankand back-up heater shall not be taken into account. Table A.3 lists the monthly hot water load.

A.1.2 Determination of system data

Most system data needed for determination of X, Y and $Q_{out,hw,s}$. are available. Only the storage tank capacity correction coefficient should be calculated: c_{cap} = ((2.702 m^2 x 75 litre/m^2)/120 litre)$^{0.25}$ = 1.14. The collector loop efficiency is not known; so it is taken from B.2. Table A.2 lists all characteristics needed for the simplified calculation of the solar thermal system output.

Table A.2 — System characteristics for calculation of the thermal solar output.

solar collector		collector loop		solar storage tank	
A	2.702 m^2	η_{loop}	0.8	V	120 litres
η_0	0.8026	P_p	20 W	c_{cap}	1.14
IAM	0.94				
U_C	3.723 W/(m^2K)				

A.1.3 Determination of X, Y and solar thermal system output

Values of X, Y and $Q_{out,hw,s}$ are calculated for each month using the monthly hot water load and the system characteristics as listed in Table A.2. Value of $Q_{out,hw,s}$ in December is – 4 kWh; this is set to zero. The annual system output is 1049 kWh.

Table A.3 — Monthly values of the hot water load, X, Y and thermal solar output for the solar DHW system with external back-up.

	$Q_{load,hw,s}$ [kWh]	X [-]	Y [-]	$Q_{out,hw,s}$ [kWh]
Jan	218	3.47	0.222	3
Feb	197	3.46	0.364	27
Mar	218	3.25	0.703	91
Apr	211	3.08	0.932	122
May	218	2.79	1.074	148
Jun	211	2.53	1.167	158
Jul	218	2.42	1.043	149
Aug	218	2.46	1.150	162
Sep	211	2.65	0.776	106
Oct	218	2.85	0.522	66
Nov	211	3.22	0.285	17
Dec	218	3.41	0.185	0
Year	**2564**			**1049**

A.1.4 Determination of the auxiliary electrical consumption

The energy consumption of the pump in the collector loop is calculated according to eq. 15 where the pump power is 20 W and the annual pump operation time is 2000 hours distributed over the months according to the solar irradiation in Table A.1. Values for the auxiliary electricity consumption are listed in Table A.4. The annual total is 40 kWh.

Table A.4 — Monthly values of the energy consumption of the pump in the collector loop.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
$W_{p,s}$ [kWh]	1.1	1.6	3.4	4.3	5.2	5.5	5.0	5.6	3.6	2.5	1.3	0.9	40

A.1.5 Determination of the heat losses of the solar thermal system

The overall heat loss coefficient has not been measured, hence, its value is calculated using eq. B6.1: UA = 0.16 x $120^{0.5}$ = 1.75 W/K. As the solar storage tank is situated in the heated space of the house, θ_a = 20°C. The ratio $Q_{out,s}/Q_{load,hw,s}$ is derived from Table A.3. With this information, the heat loss from the solar storage tank is calculated according to eq. 16. Table A.5 lists the results. The annual storage tank heat loss is 251 kWh.

Heat losses from the pipes between the solar storage tank and the back-up heater can be calculated with eq. B7.1. Table A.5 lists the results of the calculations. The annual heat loss of the pipes is 21 kWh.

Table A.5 — Monthly values of the heat losses of the solar storage tank and the pipes between storage tank and back-up heater.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
$Q_{l,t,s}$ [kWh]	0.6	6.6	21.8	29.3	35.5	37.8	35.7	38.7	25.3	15.8	4.2	0	251
$Q_{l,d,s}$ [kWh]	0.1	0.5	1.8	2.4	3.0	3.2	3.0	3.2	2.1	1.3	0.3	0	21

A.1.6 Determination of the recoverable losses of the solar thermal system

Part of the auxiliary consumption and heat losses of the solar thermal system are recoverable and can be attributed to heating of the house during the heating season, according to B.8:

— 40% of the auxiliary consumption;

— 100% of the heat losses of the solar storage tank and the pipes between this store and the back-up heater, as store and back-up heater are located in the heated part of the house.

Table A.6 lists the recoverable losses. Total recoverable losses are 57 kWh.

Table A.6 — Monthly values of the recoverable losses of the solar heat store.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
$W_{p,rl,s}$ [kWh]	0.4	0.6	1.4							1.0	0.5	0.4	
$Q_{l,rl,t,s}$ [kWh]	0.6	6.6	21.8							15.8	4.2	0	
$Q_{l,rl,d,s}$ [kWh]	0.1	0.5	1.8							1.3	0.3	0	
$Q_{l,rl,s}$ [kWh]	1.1	7.8	25.0							18.1	5.1	0.4	57

A.2 Solar combisystem

The second example presents a solar combisystem with 8.4 m^2 solar collector area and 800 litres solar storage tank. The top 200 litres of the storage tank is heated by back-up for domestic hot water. For space heating, the storage tank acts as pre-heat system, i.e. pre-heated water is heated by back-up before it enters the distribution system. Back-up heat is available at all times due to regulations with respect to microbiological safety of the domestic hot water. The back-up heater includes a pump for both heat distribution in the space heating loop and transport of back-up heat into the 200 litres top of the storage tank for domestic hot water. Typical operation time of the pump in conventional combisystems (without solar) with corresponding functionality is 1000 hours per year. Power of the pump in the back-up part is 70 W. Properties of the solar collector, collector loop and pump are the same as in the first example. So are collector tilt and storage tank location.

The system is applied on and in a single family house with an annual space heating demand of 100 kWh/m² floor area and 140 litres per day hot water draw-off based on a temperature step from 15°C to 65°C. It is located in Zürich. Table A.7 lists the monthly values of average outside air temperature and solar irradiance and irradiation in the collector plane.

Question is to determine the thermal performance of this solar combisystem. Calculation of the thermal performance follows the steps given in 5.2.

Table A.7 — Monthly values of average outside air temperature and solar irradiance and irradiation in a plane with a tilt of 45° facing South for Zürich weather as indicated in Annex B.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
θ_o [°C]	0.1	0.5	4.8	8.0	12.5	15.2	18.8	18.1	14.5	9.9	4.1	1.6
G [W/m²]	72	105	141	164	183	190	214	204	171	121	72	57
H [kWh/m²]	54	71	105	118	136	137	159	152	123	90	52	42

A.2.1 Determination of the heat load

The daily hot water load is 140 litre x 1 kg/litre x 4180 J/(kgK) x 50 K = 8.13 kWh/day. Again, heat losses of the pipes between back-up heater and tapping points are assumed to be 10% of the load, corresponding to 0.81 kWh/day. Space heating load involves the other major input to the calculation method. Table A.8 lists the monthly values of heat load for domestic hot water and heat load for space heating as well as ratios of these heat loads to the sum of both. The load ratios P_{hw} and P_{sh} are needed for subsequent calculation of the thermal solar output.

Table A.8 — Monthly values of heat load to domestic hot water and to space heating as well as contribution of these loads to the sum of both.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$Q_{load,hw,s}$ [kWh]	277	250	277	268	277	268	277	277	268	277	268	277
$Q_{load,sh,s}$ [kWh]	2943	2357	1748	993	260	0	0	0	118	969	2167	2686
P_{hw} [-]	0.09	0.10	0.14	0.21	0.52	1.00	1.00	1.00	0.69	0.22	0.11	0.09
P_{sh} [-]	0.91	0.90	0.86	0.79	0.48	0	0	0	0.31	0.78	0.89	0.91

A.2.2 Determination of system data

Most system data needed for determination of X, Y and $Q_{s,out}$ are available. Only the storage tank capacity correction coefficient should be calculated: $c_{cap} = ((8.4\ m^2 \times 75\ litre/m^2)/(800\text{-}200)\ litre)^{0.25} = 1.012$. Table A.9 lists all characteristics needed for the simplified calculation of the solar thermal system output.

Table A.9 — System characteristics for calculation of the thermal solar output.

solar collector		collector loop		solar heat store	
A	8.4 m^2	η_{loop}	0.8	V	600 litres
η_0	0.8026	P_p	20 W	c_{cap}	1.012
IAM	0.94				
U_C	3.723 W/(m^2K)				

A.2.3 Determination of X, Y and solar thermal system output

Values of X, Y and $Q_{out,s}$ are calculated twice, i.e. once for thermal solar output for domestic hot water and the other time for thermal solar output for space heating. $Q_{out,hw,s}$ and $Q_{out,sh,s}$, respectively, are determined for each month using the monthly load values from Table A.8 and the system characteristics as listed in Table A.9. Collector area is multiplied by P_{hw} respectively P_{sh} from Table A.8. Table A.10 presents the calculations for domestic hot water and Table A.11 presents the calculation for space heating. For the period June – August, calculated thermal solar output for domestic hot water is larger than the demand. Hence, the output has been maximized to the values of the demand. The annual system output for domestic hot water is 1598 kWh and for space heating 1807 kWh. In total, thermal solar output is 3405 kWh/year.

Table A.10 — Monthly values of the hot water load, X, Y and thermal solar output for domestic hot water for the solar combisystem.

	$Q_{load,hw,s}$ [kWh]	X [-]	Y [-]	$Q_{out,hw,s}$ [kWh]
Jan	277	0.56	0.084	14
Feb	250	0.62	0.137	24
Mar	277	0.79	0.263	56
Apr	268	1.12	0.475	98
May	277	2.36	1.285	227
Jun	268	4.15	2.586	268
Jul	277	3.58	2.912	277
Aug	277	3.69	2.776	277
Sep	268	2.96	1.617	252
Oct	277	1.11	0.366	76
Nov	268	0.65	0.108	18
Dec	277	0.59	0.073	10
Year	**3263**			**1598**

Table A.11 — Monthly values of the space heating load, X, Y and thermal solar output for space heating for the solar combisystem.

	$Q_{load,sh,s}$ [kWh]	X [-]	Y [-]	$Q_{out,sh,s}$ [kWh]
Jan	2943	0.59	0.084	140
Feb	2357	0.65	0.137	224
Mar	1748	0.93	0.263	341
Apr	993	1.45	0.475	343

	$Q_{load,sh,s}$ [kWh]	X [-]	Y [-]	$Q_{out,sh,s}$ [kWh]
May	260	3.51	1.285	197
Jun	0	0.00	0.000	0
Jul	0	0.00	0.000	0
Aug	0	0.00	0.000	0
Sep	118	4.72	1.617	100
Oct	969	1.51	0.366	243
Nov	2167	0.75	0.108	131
Dec	2686	0.64	0.073	88
Year	**14240**			**1807**

A.2.4 Determination of the auxiliary electrical consumption

The energy consumption of the pump in the collector loop is calculated according to eq. 15 where the pump power is 20 W and the annual pump operation time is 2000 hours distributed over the months according to the solar irradiation in Table A.7. Values for the auxiliary electricity consumption are listed in Table A.12. The annual total is 40 kWh.

Table A.12 — Monthly values of the energy consumption of the pump in the collector loop.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
$W_{p,s}$ [kWh]	1.7	2.3	3.4	3.8	4.4	4.4	5.1	4.9	4.0	2.9	1.7	1.4	**40**

A.2.5 Determination of the heat losses of the solar thermal system

The overall heat loss coefficient has not been measured, hence, its value is calculated using eq. B6.1: UA = 0.16 x $(800\text{-}200)^{0.5}$ = 3.92 W/K. As the solar storage tank is situated in the heated space of the house, T_a = 20°C. The ratio $Q_{out,hw,s}/Q_{load,hw,s}$ is derived from Table A.10 and $Q_{out,sh,s}/Q_{load,sh,s}$ from Table A.11. With this information, the heat loss from the solar storage tank is calculated twice according to eq. 16, i.e. first for domestic hot water and then for space heating. Table A.13 lists the results. The annual storage tank heat loss is 743 + 151 = 893 kWh.

Heat losses from the pipes between the solar storage tank and the back-up heater can be calculated with eq. B7.1. Table A.13 lists the results of the calculations. The annual heat loss of the pipes is 35 + 36 = 71 kWh.

Table A.13 — Monthly values of the heat losses of the solar storage tank and the pipes between storage tank and back-up heater.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
$Q_{l,t,hw,s}$ [kWh]	5.7	10.2	23.7	41.2	95.6	131	145	142	106	32.1	7.5	4.2	**743**
$Q_{l,t,sh,s}$ [kWh]	2.8	5.0	11.4	19.5	44.2	0	0	0	47.8	14.6	3.4	1.9	**151**
$Q_{l,d,hw,s}$ [kWh]	0.3	0.5	1.1	2.0	4.5	6.2	6.9	6.7	5.0	1.5	0.4	0.2	**35**
$Q_{l,d,hw,s}$ [kWh]	2.8	4.5	6.8	6.9	3.9	0	0	0	2.0	4.9	2.6	1.8	**36**

A.2.6 Determination of the recoverable losses of the solar thermal system

Part of the auxiliary consumption and heat losses of the solar thermal system are recoverable and can be attributed to heating of the house during the heating season, according to **B.8**:

- 40% of the auxiliary consumption;
- 100% of the heat losses of the solar storage tank and the pipes between this store and the back-up heater, as store and back-up heater are located in the heated part of the house.

Table **A.14** lists the recoverable losses. Total recoverable losses are 539 kWh.

Table A.14 — Monthly values of the recoverable losses of the solar heat store.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
$W_{p,rl,s}$ **[kWh]**	0.7	0.9	1.4	1.5	1.8				1.6	1.2	0.7	0.5	
$Q_{l,rl,t,s}$ **[kWh]**	8.5	15.2	35.1	60.7	140				154	46.7	11.0	6.1	
$Q_{l,rl,d,s}$ **[kWh]**	3.1	5.0	7.9	8.8	8.5				7.0	6.4	3.0	2.0	
$Q_{l,rl,s}$ **[kWh]**	12.3	21.1	44.4	71.0	150				162	54.3	14.6	8.6	**539**

A.2.7 Determination of the reduction of auxiliary consumption of the back-up heater

Contribution of solar heat to the heat load reduces auxiliary consumption of the pump in the back-up part of the system. The reduction corresponds to the fraction of the load covered by solar heat as indicated in eq. 19: S_F = (1598+1807)/(3263+14240) = 0.195. Original auxiliary consumption of the back-up pump is: 70 W x 1000 hours = 70 kWh leading to a corrected auxiliary consumption of the back-up heater of (1 - 0.195) x 70 kWh = 56 kWh and a saved auxiliary consumption of 0.195 x 70 kWh = 14 kWh.

Annex B
(informative)

Informative values for use in the calculation methods

B.1 System type coefficients

The system type coefficients are given in **Table B.1**.

Table B.1 — System type coefficients

Correlation coefficients	Type of system	
	Water storage [2]	Direct solar floor [3]
a	1.029	0.863
b	-0.065	- 0.147
c	-0.245	-0.263
d	0.0018	0.008
e	0.0215	0.029
f [4]	0	0.025

B.2 Solar thermal system default values

In general, two types of default values are given:

- typical values – for use when the purpose is to make a calculation of a typical solar thermal system
- penalty values – used for giving penalty to "unknown" components (i.e. systems and components not tested and/or certified) in order to encourage use of high quality data for the calculation

NOTE: These values are only given for general purpose. It is not necessary to define both types of value in national annexes.

Typical values:

[2] The collector array is connected to the storage tank. A set of correlation coefficients has been determined in the f-chart method for this system type (see [1]).

[3] The collector array is directly connected to the heating floor; the floor acts as both the storage tank and the heat exchanger. New set of correlation coefficients has been determined for this system type (see [3]).

[4] New correlation coefficient introduced to better fit with direct solar floor system.

1) Efficiency of the collector loop η_{loop},

The typical efficiency of the collector loop η_{loop} is 0.9.

NOTE: η_{loop} takes into account the influence of the heat exchanger.
η_{loop} can be calculated from:

η_{loop} = 1 - $\Delta\eta$

where:

$\Delta\eta$ = $(\eta_0 * A * a_1)/(UA)_{hx}$ (see ENV12977-2)

and:

η_0 zero-loss collector efficiency determined in accordance with EN 12975-2

A collector aperture area [m2]

a_1 first order heat loss coefficient of solar collector determined in accordance with EN 12975-2.

$(UA)_{hx}$ heat exchanger heat transfer value (UA-value) [W/K]

2) Heat loss coefficient of the collector a

$a = a_1 + 40 * a_2$

where:

a_1 first order heat loss coefficient of solar collector determined in accordance with EN 12975-2.

a_2 second order heat loss coefficient of solar collector determined in accordance with EN 12975-2.

Typical values:

a_1 = 1.8 W/m²K (evacuated tubular collectors)

a_1 = 3.5 W/m²K (glazed collector)

a_1 = 15 W/m²K (unglazed collector)

a_2 = 0 W/m²K^2

3) Overall heat loss coefficient of the collector loop pipes UL

$$UL = 5 + 0.5\,A \quad [W/(m^2K)] \quad \text{[eq B2/1]}$$

where

A collector aperture area [m2]

4) zero-loss collector efficiency η_0

The zero-loss collector efficiency η_0 is determined in accordance with EN 12975-2.

Typical value : η_0 = 0.8

5) Nominal power of solar pump Pp

$$Pp = 25 + 2A \quad [W] \quad \text{[eq B2/2]}$$

where

A collector aperture area [m2]

Penalty values:

1) Efficiency of the collector loop η_{loop},

The penalty efficiency of the collector loop η_{loop} is 0.8.

2) Heat loss coefficient of the collector a

$a = a_1 + 40 * a_2$

where:

a_1 first order heat loss coefficient of solar collector determined in accordance with EN 12975-2.

a_2 second order heat loss coefficient of solar collector determined in accordance with EN 12975-2.

If collector characteristics are not known, the following penalty default values are adopted:

a_1 = 3 W/m²K (evacuated tubular collectors)

a_1 = 6 W/m²K (glazed collector)

a_1 = 20 W/m²K (unglazed collector)

a_2 = 0 W/m²K^2 3) Overall heat loss coefficient of the collector loop pipes UL UL = 5 + 0.5 A [W/(m^{2}K)] [eq B2/1]

where

A collector aperture area [m2]

4) zero-loss collector efficiency η_0

The zero-loss collector efficiency η_0 is determined in accordance with EN 12975-2.

Penalty value : $\eta_0 = 0.6$

5) Nominal power of solar pump Pp

$$Pp = 50 + 5A \quad [W] \qquad [eq B2/2]$$

where

A collector aperture area [m2]

B.3 Storage tank capacity correction coefficient c_{cap}

In the case of water storage tank, the storage tank correction coefficient c_{cap} is given by:

$$c_{cap} = (V_{ref}/V_S)^{0.25} \quad [-] \qquad [eq B3/1]$$

where

V_{ref} reference volume equal to 75 litres per m² of collector.

V_S solar storage tank volume.

In the case of solar preheat system, V_S equals V_n (nominal volume).

In the case of solar-plus-supplementary system, the solar storage tank volume V_S is given by:

$$V_S = V_n.(1 - f_{aux}) \quad [litres] \qquad [eq B3/2]$$

where:

f_{aux} fraction of the storage tank volume used for back-up heating

V_n nominal storage tank volume

The effective fraction f_{aux} is calculated by:

$$f_{aux} = x.\ V_{bu}/V_n \qquad [-] \qquad \text{[eq B3/3]}$$

where

V_{bu} back-up storage tank volume contained between the top of the tank and the bottom of the back-up element (electric element or heat exchanger)

x control coefficient equal to

- 1 if the back-up is a permanent power supply
- 0.7 night back-up
- 0.3 emergency back-up

The default value of f_{aux} is:

- 0.50 for a vertical tank
- 0.66 for a horizontal tank.

B.4 Reference temperature θ_{ref}

θ_{ref} depends on the system and the application:

Space heating system:

θ_{ref} =100°C

Domestic hot water systems:

$$\theta_{ref} = 11.6 + 1.18\ \theta_{hw} + 3.86\ \theta_{cw} - 1.32\ \theta_o \text{ °C} \qquad \text{[eq B4/1]}$$

where:

θ_{hw} desired hot water temperature taken as equal to 40°C

θ_{cw} mains water supply temperature [°C] according to Table B.2 (identical for each month)

θ_o average outside air temperature for the considered period, [°C] according to Table B.2

Table B2 lists values of θ_{cw} and θ_o for the reference locations/climates (informatively) used in the elaboration of solar domestic hot water and solar combisystem tests, such as in EN 12976-2 and ENV 12977-2.

Table B.2 — Annual average mains water supply temperature and monthly outside air temperatures for different European climates and locations (source for ambient temperatures: Meteonorm v5.0).

Location/ Climate	θ_{cw} [ºC]	θ_o [ºC]											
		Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Athens (Gr)	17.8	9.3	9.8	11.7	15.5	20.2	24.6	27	26.6	23.3	18.3	14.4	11.1
Carpentras (F)	13.5	5.5	5.8	9.8	11.3	15.1	18.9	22.9	21.3	18.4	13.9	8.7	5.4
Davos (CH)	5.4	-5.1	-5	-1.6	1.5	6.1	8.9	12.5	11.8	8.9	5.3	-0.7	-3.4
Stockholm (S)	8.5	-2.8	-3	0.1	4.6	10.7	15.6	17.2	16.2	11.9	7.5	2.6	-1.0
Würzburg (D)	10.0	0.6	1.1	5.6	8.3	13.3	16.7	18.3	18.3	15	9.4	4.4	1.7
Zürich (CH)	9.7	0.1	0.5	4.8	8.0	12.5	15.2	18.8	18.1	14.5	9.9	4.1	1.6

B.5 Solar irradiance on the collector plane and incidence angle modifier

G_{month} is the average solar irradiance on the collector plane during the considered period expressed in W/m².

Three categories of orientation of collectors are possible:

1) where collectors face between south-east and south-west and are angled in the range from latitude-20° till latitude+5° from the horizontal and are not shadowed by any obstacles. The values for G_{month} are as given in Table B.3 below for different climatic zones;

2) for all other cases, the values for G_{month} are the values given in Table B.3 multiplied by a coefficient of 0.8, provided that the orientation of collectors is within the range of +/-90° of south (between east and west) and the average height of obstacles on the horizon is less than 20° (tilt angle is arbitrary);

3) for all other configurations, no account is taken of the solar installation (no influence on the building energy performance).

Table B.3 lists values of G_{month} for the reference locations/climates (informatively) used in the elaboration of solar domestic hot water and solar combisystem tests, such as in EN 12976-2 and ENV 12977-2.

Table B.3 — Monthly solar irradiance on a flat plane facing South with a tilt angle of 45° for different European climates and locations (source: Meteonorm v5.0).

location/ climate	G_{month} [W/m^2]											
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Athens (Gr)	150	154	164	206	220	236	250	267	252	193	142	117
Carpentras (F)	141	163	208	220	234	255	270	267	238	177	138	119
Davos (CH)	173	215	251	249	231	217	229	217	208	195	153	141
Stockholm (S)	37	84	150	190	237	245	222	204	148	94	45	36
Würzburg (D)	67	108	145	184	204	209	210	200	177	121	67	53
Zürich (CH)	72	105	141	164	183	190	214	204	171	121	72	57

The incidence angle modifier IAM depends on the collector type. Default values are:

— for flat plate glazed collectors, IAM = 0.94

— for unglazed collectors, IAM = 1.00

— for evacuated tubular collectors with flat absorber, IAM = 0.97

— for evacuated tubular collectors with circular absorber, IAM = 1.00

B.6 Heat losses of the solar storage tank

If the overall heat loss coefficient of the storage tank UA is not known, it can be calculated by:

$$UA = 0.16\ V_s^{0.5}$$ {W/K] [eq. B6/1]

where:

V_S solar storage tank volume [l]

B.7 Distribution losses between the solar thermal system and the back-up heater

The distribution losses are calculated by:

if the pipes are insulated:

$$Q_{l,r,d,s} = 0.02 * Q_{load,s} * (Q_{out,s} / Q_{load,s}) \quad \text{[eq B7/1]}$$

if the pipes are not insulated:

$$Q_{l,r,d,s} = 0.05 * Q_{load,s} * (Q_{out,s} / Q_{load,s}) \quad \text{[eq B7/2]}$$

B.8 Recoverable part of solar thermal system losses

The recoverable part of the pump auxiliary consumption is 50%.

The recoverable part of the solar tank losses and the distribution losses between the solar thermal system and the back-up heater could be recovered only during the heating season. During the heating season, the recoverable part of these losses is:

- 100% if the component is installed in the heated space;
- 50% if the component is installed in an un-heated space;
- 0% if the component is installed outside.

Annex C
(informative)

Product classification

C.1 Solar collectors

Characteristics are:

A collector aperture area, (m²),

η_0 zero-loss collector efficiency, (-)

a_1 first order heat loss coefficient of solar collector. (W/m².K)

a_2 second order heat loss coefficient of solar collector (temperature dependence). (W/m².K)η_0, a_1 and a_2 are determined according to EN 12975-2

C.2 Solar hot water heaters

This applies to factory made solar hot water heaters sold as complete and ready to install kits, with fixed configurations and assessed as a whole according to EN 12976-2.

Where no classification is given, a solar hot water heater can be defined by its components:

- collector;
- storage tank;
- collector loop pipework.

Characteristics are:

A collector aperture area (m²)

V_n nominal storage tank volume (litres).

NOTE: The following characteristics are intermediate parameters calculated according to ISO/DIS 9459-5, but not indicated on the official test results given in EN 12976-2:

A_C* effective collector loop area (m²)

C_S thermal heat capacity of the storage tank (MJ/K)

U_C* effective collector heat loss coefficient (W/m².K)

f_{aux} fraction of the storage tank volume used for back-up heating, (-)

C.3 Storage tanks

Characteristics are:

V_n nominal storage tank volume (litres)

UA overall heat loss coefficient of the storage tank (W/K)

If UA is not known, but the cooling constant C_r (Wh/l.K.day) is, the following equation is used:

$$UA = C_r.V_n/24 \quad [W/K]$$

NOTE: This equation applies only if the cooling constant of the storage tank is less than or equal to the default value of the hot-water bulb, i.e.: $C_r \leq 4.2\ V_n^{-0.45}$.

V_S solar storage tank volume, obtained from the following equation:

$$V_S = V_n.(1 - f_{aux}) \quad [litres]$$

where:

f_{aux} fraction of the storage tank volume used for back-up heating :

- f_{aux} may be determined directly by tests carried out in accordance with EN 12976-2
- f_{aux} is zero when the bulb does not have an integrated back-up.

Annex D
(informative)

Savings calculation

To determine the resulting influence of a solar thermal system on the energy performance of a building, i.e. the savings due to the installation of a solar thermal system, two calculations have to be performed:

— C0: Calculation of the primary energy consumption of the building without the solar thermal system;

— C1: Calculation of the primary energy consumption of the building with the solar thermal system.

The energy savings due to the installation of the solar thermal system is determined as the primary energy consumption of the building without the solar thermal system (C0) minus the primary energy consumption of the building with the solar thermal system (C1):

$$S_{solar} = C0 - C1$$

Bibliography

[1] John A. Duffie and William A. Beckman: Solar Engineering of Thermal Processes. Wiley-Interscience ed., 1991

[2] Weiss, W. (ed), Bales, Ch., Drück, H., et al.
Solar Heating Systems for Houses, A Design Handbook for Solar Combisystems, International Energy Agency (IEA), James & James (Science Publishes), 2003, London, ISBN: 1902916468

[3] Roger Pelletret, Marc Bazalgette, Thomas Letz, Philippe Papillon
Méthode mensuelle d'évaluation des performances des planchers solaires directs
Rapport CSTB-S 1440, Avril 1998