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Thermal solar systems and components - Custom built systems - Part 3: Performance characterisation of stores for solar heating systems

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Thermische Solaranlagen und ihre Bauteile - Kundenspezifisch gefertigte Anlagen - Teil 3: Leistungsprüfung von Warmwasserspeichern für Solaranlagen

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Foreword

This document (prEN 12977-3:2006) has been prepared by Technical Committee CEN/TC 312 “Thermal solar systems and components”, the secretariat of which is held by ELOT.

This document is currently submitted to the CEN Enquiry.

This document will supersede ENV 12977-3:2001.

The annexes A, B, C are normative and annexes D and E are informative.

Introduction

The test methods for stores of solar heating systems as described in this document are required for the determination of the thermal performance of small custom built systems as specified in prEN/TS 12977-1.

These test methods deliver parameters, which are needed for the simulation of the thermal behaviour of a store being part of a small custom built system thermal solar system.

NOTE 1 The already existing test methods for stores of solar heating systems are not sufficient with regard to thermal solar systems. This is due to the fact that the performance of thermal solar systems depends much more on the thermal behaviour of the store (e. g. stratification, heat losses), as conventional systems do. Hence this separate document for the performance characterisation of stores for solar heating systems is needed.

NOTE 2 For additional information about the test methods for the performance characterisation of stores see [1] in Bibliography.

1 Scope

This document (prEN 12977-3:2006) specifies test methods for the performance characterization of stores which are intended for use in small custom built systems as specified in prEN/TS 12977-1.

Stores tested according to this document are commonly used in solar hot water systems. However, also the thermal performance of all other thermal stores with water as storage medium can be assessed according to the test methods specified in this document.

The document applies to stores with a nominal volume between 50 l and 3 000 l.

This document does not apply to combistores. Performance test methods for solar combistores are specified in prEN/TS 12977-4.

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 806-1, *Specifications for installations inside buildings conveying water for human consumption — Part 1: General*

EN 1717, *Protection against pollution of potable water installations and general requirements of devices to prevent pollution by backflow*

EN 12828, *Heating systems in buildings — Design of water-based heating systems*

EN 12976-2, *Thermal solar systems and components — Factory made systems — Test methods*

prEN/TS 12977-1, *Thermal solar systems and components — Custom built systems — Part 1: General requirements for solar water heaters and combi systems*

prEN/TS 12977-2, *Thermal solar systems and components — Custom built systems — Part 2: Test methods for solar water heaters and combi systems*

prEN/TS 12977-4, *Thermal solar systems and components — Custom built systems — Part 4: Performance test methods for solar combistores*

EN ISO 9488, *Solar energy — Vocabulary*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 9488 and the following apply.

3.1
ambient temperature
mean value of the temperature of the air surrounding the store

3.2
charge
process of transferring energy into the store by means of an heat source

3.3
charge connection
pipe connection used for charging the storage device

3.4
combistore
one store used for both domestic hot water preparation and space heating

3.5
constant inlet temperature, $\tilde{\vartheta}_{x,i}$
temperature which is achieved during charge ($x = C$) or discharge ($x = D$), if the mean value $\tilde{\vartheta}_{x,i}$ over the period of 0,5 “reduced charge / discharge volume” (see 3.34) is within ($\tilde{\vartheta}_{x,i}$ ± 1) °C

3.6
constant flow rate, $\tilde{\dot{V}}$
flow rate which is achieved, when the mean value $\tilde{\dot{v}}$ over the period of 0,5 “reduced charge / discharge volumes” (see 3.34) is within ($\tilde{\dot{v}}$ ± 10) %

3.7
constant charge power, $\tilde{P}_c$
charge power which is achieved, when the mean value $\tilde{P}_c$ over the period of 0,5 reduced charge volumes is within ($\tilde{P}_c$ ± 10) %

3.8
conditioning
process of creating a uniform temperature inside the store by discharging the store with $\tilde{\vartheta}_{D,i}$ = 20 °C until a steady state is reached

NOTE The conditioning at the beginning of a test sequence is intended to provide a well defined initial system state, i. e. an uniform temperature in the entire store.

3.9
discharge connection
pipe connection used for discharging the storage device

3.10
dead volume / dead capacity
volume / capacity of the store which is only heated due to heat conduction (e. g. below a heat exchanger)

3.11
direct charge / discharge
transfer or removal of thermal energy in or out of the store, by directly exchanging the fluid in the store

3.12
discharge
process of decreasing thermal energy inside the store caused by the hot water load

3.13
double port
a corresponding pair of inlet and outlet connections for direct charge / discharge of the store

NOTE Often, the store is charged or discharged via closed or open loops that are connected to the store through double ports.

3.14
effective volume / effective capacity
volume / capacity which is involved in the heat storing process if the store is operated in a usual way

3.15
electrical (auxiliary) heating
electrical heating element immersed into the store

3.16
external auxiliary heating
auxiliary heating device located outside the store. The heat is transferred to the store by direct or indirect charging via a charge loop. The external auxiliary heating is not considered as part of the store under test

3.17
heat loss capacity rate, $(UA)_{s,a}$
overall heat loss of the entire storage device per K temperature difference between the store temperature and the ambient air temperature

NOTE The heat loss capacity rate depends on the flow conditions inside the store. Hence a stand-by heat loss capacity rate and a operating heat loss capacity rate are defined. If $(UA)_{s,a}$ is mentioned without specification, $(UA)_{s,a}$ represents the stand-by heat loss capacity rate.

3.18
heat transfer capacity rate
thermal power transferred per K temperature difference

3.19
immersed heat exchanger
heat exchanger which is completely surrounded with the fluid in the store tank

3.20
indirect charge / discharge
transfer or removal of thermal energy into or out of the store, via a heat exchanger

3.21
load
heat output of the store during discharge. The load is defined as the product of the mass, specific thermal capacity and temperature increase of the water as it passes the solar hot water system

3.22
mantle heat exchanger
heat exchanger mounted to the store in a way, that it forms a layer between the fluid in the store tank and ambient

3.23
measured store heat capacity
measured difference in energy of the store between two steady states on different temperature levels, divided by the temperature difference between this two steady states

3.24
measured energy, $Q_{\mathrm{x,m}}$
time integral of the measured power over one or more test sequences, excluding time periods used for conditioning at the beginning of the test sequences

3.25
measured power, $P_{\mathrm{x,m}}$
power calculated from measured volume flow rate as well as measured inlet and outlet temperature

3.26
mixed
state when the local store temperature is not a function of the vertical store height

3.27
model parameter
parameter used for quantification of a physical effect, if this physical effect is implemented in a mathematical model in a way which is not analogous to its appearance in reality, or if several physical effects are lumped in the model (e. g. a stratification number)

3.28
nominal flow rate, $\dot{V}_{\mathrm{n}}$
the nominal volume of the entire store divided by 1 h

3.29
nominal heating power, P_{n}
the nominal volume of the entire store multiplied by 10 W/l

3.30
nominal volume, V_{n}
fluid volume of the store as specified by the manufacturer

3.31
operating heat loss capacity rate, $(UA)_{op,s,a}$
heat loss capacity rate of the store during charge or discharge

3.32
predicted energy, Q_{xp}
time integral of the predicted power over one or more test sequences, excluding time periods used for conditioning at the beginning of the test sequences

3.33
predicted power, P_{xp}
power calculated from measured volume flow rate, as well as measured inlet temperature and calculated outlet temperature. The outlet temperature is predicted by numerical simulation

3.34
reduced charge / discharge volume
integral of a charge / discharge flow rate divided by the store volume

3.35
stand-by
state of operation in which no energy is deliberately transferred to or removed from the store

3.36
stand-by heat loss capacity rate, $(UA)_{sb,s,a}$
heat loss capacity rate of the store during stand-by

3.37
steady state
state of operation at which at charge or discharge during 0,5 “reduced charge / discharge volume” (see 3.34) the standard deviation of the temperature difference, between store inlet and store outlet temperature of the charging / discharging circuit is lower than 0,05 K

NOTE In cases of an isothermal charged store rather constant temperature differences between the inlet and outlet temperature of the discharge circuit may occur during the discharge of the first store volume before the outlet temperature drops rapidly. These state is not considered as steady state.

3.38
store temperature
temperature of the store medium

3.39
stratified
state when thermal stratification is inside the store

3.40
stratified charging
increase of thermal stratification in the store during charging

3.41
stratifier
device that enables stratified charging of the store. Common used stratifiers are e. g. convection chimneys or pipes with radial holes

3.42
theoretical store heat capacity
sum over all thermal capacities $m_i \times c_{p,i}$ of the entire store (fluid, tank material, heat exchangers) having part of the heat store process

3.43
thermal stratification
state when the local store temperature is a function of the vertical store height, with the temperature decreasing from top to bottom

3.44
transfer time, $t_{x,f}$
time period during which energy is transferred through the connections for charge ($x = C$) or discharge ($x = D$). The transfer time is calculated over one or more test sequences, excluding time periods used for conditioning at the beginning of the test sequences

4 Symbols and abbreviations

C_s	thermal capacity of the entire store, in J/K
c_p	specific heat capacity, in J/(kg K)
P_n	nominal heating power, in W
$P_{x,m}$	measured power transferred through the charge ($x = C$) or discharge ($x = D$) circuit, in W
$P_{x,p}$	predicted power transferred through the charge ($x = C$) or discharge ($x = D$) circuit, in W
$Q_{x,m}$	measured energy transferred through the charge ($x = C$) or discharge ($x = D$) circuit, in J
$Q_{x,p}$	predicted energy transferred through the charge ($x = C$) or discharge ($x = D$) circuit, in J
t_{st}	time required to achieve a steady state, in s
$t_{x,f}$	transfer time for charging ($x = C$) or discharging ($x = D$), in s
ϑ_a	ambient temperature, in °C
ϑ_s	store temperature, in °C
$\tilde{\vartheta}_{x,i}$	inlet temperature of the charge ($x = C$) or discharge ($x = D$) circuit, in °C
$\vartheta_{x,i}$	constant inlet temperature of the charge ($x = C$) or discharge ($x = D$) circuit, in °C
$\vartheta_{x,o}$	outlet temperature of the charge ($x = C$) or discharge ($x = D$) circuit, in °C
$(UA)_{hx,s}$	heat transfer capacity rate between heat exchanger and store, in W/K
$(UA)_{s,a}$	heat loss capacity rate of the store, in W/K
$(UA)_{op,s,a}$	operating heat loss capacity rate of the store, in W/K
$(UA)_{sb,s,a}$	stand-by heat loss capacity rate of the store, in W/K
V_n	nominal volume of the store, in l

$\dot{V}_n$ nominal flow rate, in l/h

$\tilde{\dot{V}}_x$ constant flow rate of the charge ($x = C$) or discharge ($x = D$) circuit, in l/h

$\Delta\vartheta_m$ mean logarithmic temperature difference, in K

$\varepsilon_{x,P}$ relative error in mean power transferred during charge ($x = C$) or discharge ($x = D$), in %

$\varepsilon_{x,Q}$ relative error in energy transferred during charge ($x = C$) or discharge ($x = D$), in %

ρ density, in kg/m³

5 Store classification

Hot water stores are classified by distinction between different charge and discharge modes. Five groups are defined as shown in Table 1.

Table 1 — Classification of the stores

Group	Charge mode	Discharge mode
1	direct	direct
2	indirect	direct
3	direct	indirect
4	indirect	indirect
5	stores that cannot be assigned to groups 1 to 4	

NOTE 1 All stores may have one or more additional electrical heating elements.

6 Laboratory store testing

6.1 Requirements on the testing stand

6.1.1 General

The hot water store shall be tested separately from the whole solar system on a store testing stand.

The testing stand configuration shall be determined by the classification of hot water stores as described in clause 5.

An example of a representative hydraulic testing stand configuration is shown in Figure 1 and Figure 2.

The circuits are intended to simulate the charge and discharge loop of the solar system and to provide fluid flow with a constant or well controlled temperature. The full test stand consists of one charge and one discharge circuit.

NOTE 1 If the store consists of more than one charge or discharge devices (e.g. two heat exchangers), then these are tested separately.

The testing stand shall be located in an air-conditioned room where the room temperature of 20 °C should not vary more than ± 1 K during the test.

Both circuits shall fulfil the following requirements:

— The flow rate shall be adjustable between 0,05 m³/h and 3 m³/h, by deviation < 2 %;

— the working temperature range shall be between 10 °C and 90 °C;

— the minimum heating power of the charge circuit shall be 15 kW;

— the minimum cooling power in the discharge circuit shall be 5 kW at a fluid temperature of 20 °C;

NOTE 2 If mains water at a constant pressure and a constant temperature below 20 °C is available, it is recommended to design the discharge circuit in a way, that it can be operated as closed loop or as open loop using mains water to discharge the store.

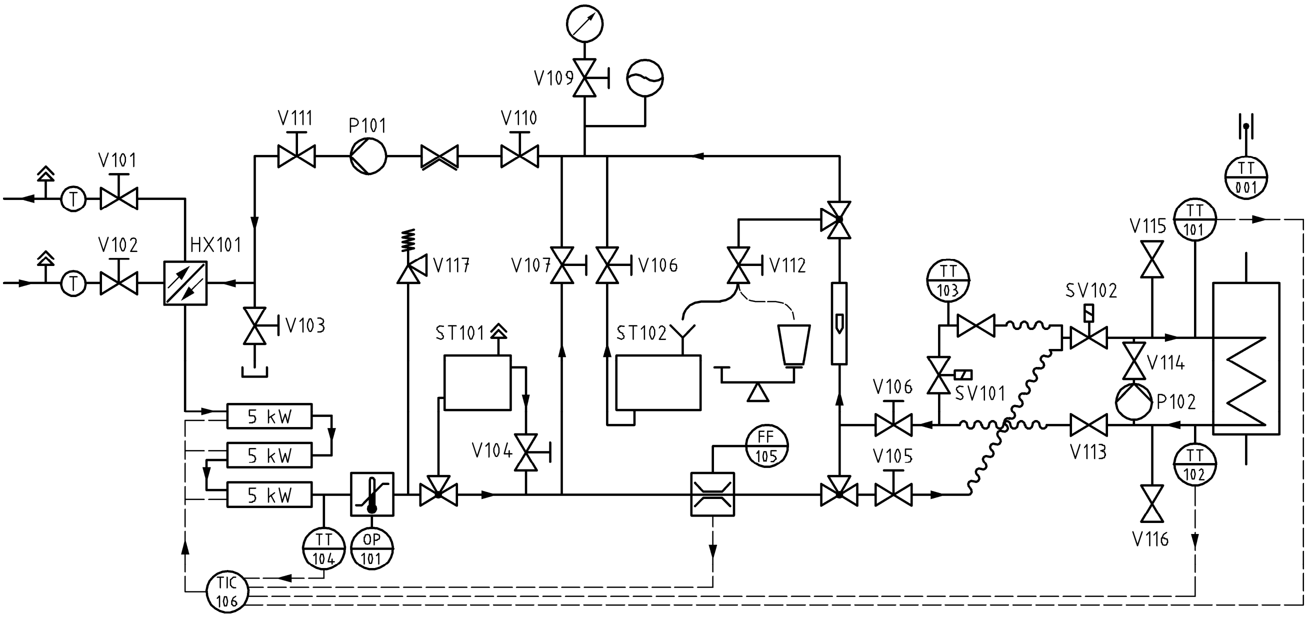
— the minimum heating power of the discharge circuit shall be 5 kW;

— the control deviation of the store inlet temperature shall be less than 0,05 K;

— the minimum heating up rate of the charge circuit with disconnected store shall be 3 K/min;

— the minimum available electrical heating power for electrical auxiliary heaters shall be 6,0 kW.

NOTE 3 The electrical power of the pump (P102) shall be chosen in such a way that the temperature increase induced by the pump (P102) is less than 0,6 K/h when the charge circuit is "short circuited" and operated at room temperature. (“short circuited” means that no storage device is connected and SV102, V113, V115 and V116 are closed, see Figure 1).



Key

FF Flow meter

HX Heat exchanger

OP Overheating protection

P Pump

ST Store

SV Solenoid valve

TT Temperature sensor

TIC Temperature indicator and controller

V Valve

Figure 1 — Charge circuit of the store testing stand

The heating medium water in the charge circuit (see Figure 1) is pumped through the cooler (HX101) and the temperature controlled heaters (TIC106) by the pump (P101). A buffer tank (ST101) is used to balance the remaining control deviations. By means of the bypass (V107) the flow through the store can be regulated, it also ensures a continuously high flow through the heating section and therefore good control characteristics. With the solenoid valve (SV101) the heating medium can bypass the store to prepare a sudden increase of the inlet temperature into the store.

The temperature sensors are placed near the inlet (TT101) and outlet (TT102) connections of the store, the connection to the store is established through insulated flexible pipes.

The charge circuit can be operated closed, under pressure (design pressure 2,5 bar, membrane pressure expansion tank and pressure relief valve (V109)) as well as open (valve (V108) open) with the tank (ST102) serving as an expansion tank. A calibration of the installed flow meter (FF105) is possible by weighing the mass of water leaving the valve (V112). The installation is equipped with the usual safety devices, i. e. pressure relief valve (V117) and overheating protection device (OP101).

The discharge circuit (see Figure 2) is constructed in a similar way. It includes two coolers – (HX201) and (HX202) – and a temperature controlled heating element (TIC206) with 5 kW heating power. The discharge circuit can either be operated in open circulation with water from the net or it can be operated in closed circulation. During open operation the water is led via the safety equipment (V201) and flows through the coolers, the heating section and the flow meter (FF205) into the store. The hot water leaving the store flows through the solenoid valve (SV201) and the valve (V210) into the drain. The valve (V212) is closed.

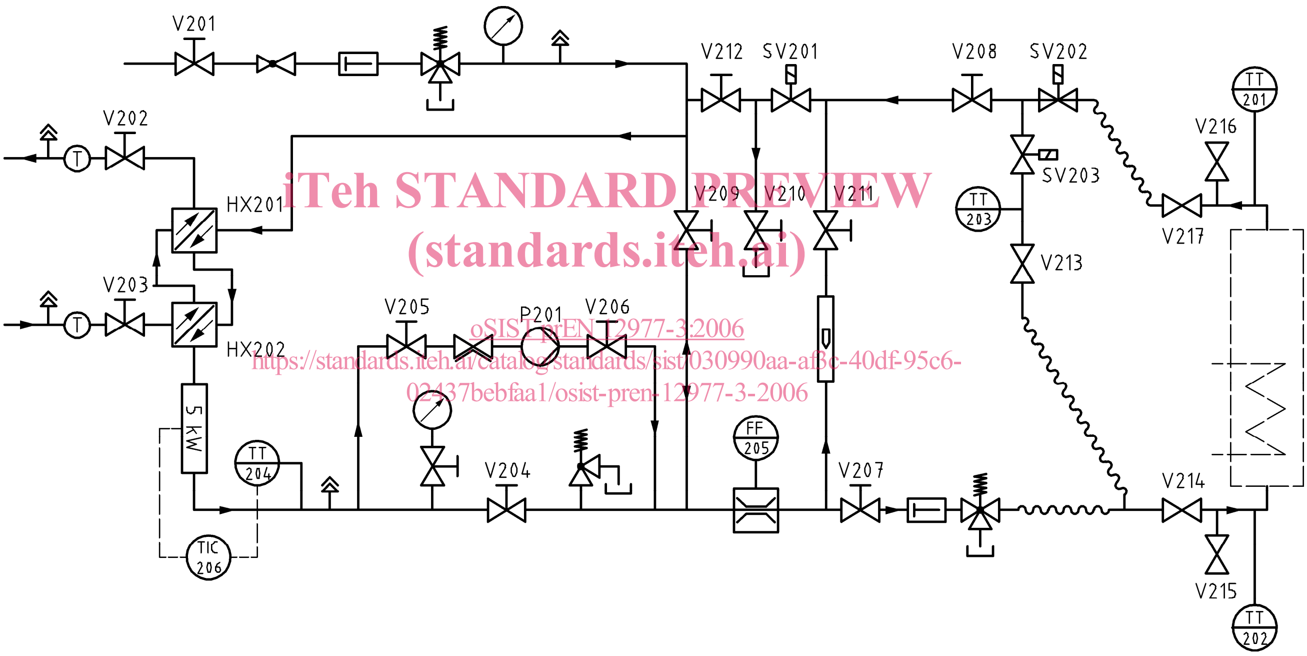
For heating the water it is recommended to increase the flow through the heating section with the pump (P201) in order to improve the control performance; the additional volume flow returns through the bypass (V209).

During closed-circle operation, the valve of the safety equipment and the cut-off valve (V210) remain closed, the valve (V212) is open and the water is circulated by the pump (P201).

NOTE 4 For periodical checks of the measuring accuracy, it is recommended to integrate a reference heater into the testing stand. Instead of a store, this reference heater is connected to the testing stand. The reference heater is supplied with an electric heating device.

NOTE 5 See [2] and [3] in Bibliography for further information on the use of reference heaters.

The heat transfer fluid used for testing may be water or a fluid recommended by the manufacturer. The specific heat capacity and density of the fluid used, shall be known with an accuracy of 1 % within the range of the fluid temperatures occuring during the tests.



Key

FF Flow meter

HX Heat exchanger

P Pump

SV Solenoid valve

TT Temperature sensor

TIC Temperature indicator and controller

V Valve

Figure 2 — Discharge circuit of the store testing stand