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Methods for measuring the performance of electric storage water heaters for household purposes

Méthodes de mesure de l'aptitude à la fonction des chauffe-eau électriques à accumulation à usages domestiques



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IEC Secretariat
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**METHODS FOR MEASURING THE PERFORMANCE
OF ELECTRIC STORAGE WATER HEATERS
FOR HOUSEHOLD PURPOSES**

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IEC 60379 has been prepared by subcommittee SC59C: Electrical heating appliances for household and similar purposes, of IEC technical committee 59: Performance of household and similar electrical appliances. It is an International Standard.

This fourth edition cancels and replaces the third edition published in 1987. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) sustainable development aspects of EU legislation are taken into account, including features such as smart control, V_{40} modification and measuring procedures for multi-tank appliances.

The text of this International Standard is based on the following documents:

Draft	Report on voting
59C/282/FDIS	59C/285/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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METHODS FOR MEASURING THE PERFORMANCE OF ELECTRIC STORAGE WATER HEATERS FOR HOUSEHOLD PURPOSES

1 Scope

This document specifies methods for measuring the performance of electric storage water heaters to produce domestic potable or non-potable hot water for household and similar use.

The object is to state and define the principal performance characteristics of electric storage water heaters and to describe the test methods for measuring these characteristics.

NOTE 1 This document does not apply to:

- storage water heaters that use electricity as a secondary source of heating the water;
- storage water heaters that do not use a tank to store hot water;
- electric storage water heaters that do not meet the minimum (or maximum) output performance of the smallest (or biggest) load profile, as defined in Table 3;
- water-heaters without thermal insulation.

NOTE 2 This document does not specify safety requirements. For safety requirements, see IEC 60335-1 in conjunction with IEC 60335-2-21.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1

storage water heater

water heater that uses electric heating elements as the means of heating water for long-term storage in a thermally insulated container and provided with a device to control the water temperature

3.2

primary function

production of hot water for household and similar needs

3.3

energized storage water heater

storage water heater that is designed to supply hot water and be energized for 24 h per day

3.4**off-peak storage water heater**

storage water heater that is designed to supply hot water and configured or installed, whilst only being supplied with electrical energy at off-peak/low-tariff periods

Note 1 to entry: The off-peak storage water heater is required to fulfil the requirements of the tapping pattern between 7:00 h and 22:00 h without external energy supply, e.g. to enable operation at off-peak/low-tariff periods and/or to operate in conditions of insecurity of energy supply. A product qualifies as "off-peak" if it is only energized for a maximum of 8 consecutive hours anywhere between 22:00 h and 7:00 h during the test with the 24h load profile.

3.5**load profile**

output performance (in terms of flowrates, temperatures, tapping pattern, etc.) of a storage water heater when fulfilling its primary function under specific ambient conditions (see Table 2 and Table 3), as declared by the manufacturer

3.6**energy efficiency**

ratio between the delivered energy in the domestic potable or non-potable hot water for its load profile and the consumed electrical energy

3.7**storage volume**

rated quantity of water stored in the appliance

3.8**smart control**

device that automatically adapts the water heating process to individual usage conditions with the aim of reducing energy consumption

3.9**out-of-the-box mode**

standard operating condition, setting or mode set by the manufacturer at factory level, to be active immediately after the appliance's installation, suitable for normal use by the end-user according to the water tapping pattern for which the product has been designed and placed on the market

3.10**closed water heater**

unvented storage water heater intended to operate at the pressure of the water system, the flow of water being controlled by one or more valves in the outlet system

3.11**cistern-fed water heater**

water heater supplied from a cistern in which the flow of water is controlled by one or more valves in the outlet system, and which is provided with a vent open to the atmosphere and so arranged that the expanded water can return to the feed cistern

3.12**open outlet water heater**

water heater in which the flow of water is controlled by a valve in the inlet pipe and so arranged that the expanded water can overflow through the outlet pipe

3.13**vented water heater**

water heater open to the atmosphere, so that under no condition of use can the pressure at the surface of the water be other than atmospheric

3.14

cistern-type water heater

cistern-fed water heater which has a feed cistern as an integral part of the appliance

3.15

multi-tank water heater

water heater with two or more hydraulic connected containers, designed to have the possibility to work independently in terms of working temperature and/or pressure condition

Note 1 to entry: A multi-tank product has to be defined as directly measurable if it is possible to measure the temperature (immersed or welded sensors) of all the dome tanks without compromising the product's performances, otherwise the product has to be classified as not directly measurable. Based on that definition for the dome tanks' temperature measurement, the multi-tank products are defined as:

- directly measurable, or
- not directly measurable.

3.16

rated capacity

assigned water capacity of the water heater, and marked on it, by the manufacturer

3.17

standing loss per 24 h

energy-consumption of a filled water-heater, after steady-state conditions have been reached, when connected to the electrical supply, during any 24 h duration when no water is withdrawn

3.18

rated voltage

voltage (for three phase-supply, the voltage between phases) assigned to the appliance by the manufacturer

3.19

V_{40Ref}

mixed water quantity delivered at 40 °C with 65 °C storage temperature and 15 °C cold water inlet temperature

3.20

V_{40max}

mixed water quantity delivered at 40 °C with maximum storage temperature setting and 15 °C cold water inlet temperature with heating elements powered on

Note 1 to entry: Maximum rated power of the appliance.

3.21

V_{40}

mixed water quantity delivered at 40 °C with out-of-the-box mode temperature setting and 10 °C cold water inlet temperature

3.22

smart control factor

SCF

factor describing the water heating energy efficiency gain due to smart control

Note 1 to entry: The value is between SCF = 0 and SCF = 1.

3.23

energy-related product

ErP

product that uses energy, or that does not use energy, but has an impact on energy consumption

3.24**conversion coefficient****CC**

factor to indicate how much primary energy is used to generate a unit of electricity

3.25**declared load profile**

load profile declared by the manufacturer for the appliance

4 Symbols and units

Symbol	Unit	Description
η_{elecwh}	[%]	Electric energy efficiency of a storage water heater.
Q_{ref}	[kWh]	Reference energy for the 24 h tapping pattern for the load profile of the water heater.
Q_{elec}	[kWh]	Electricity consumption with the relevant 24 h tapping pattern.
θ_{amb}	[°C]	Ambient temperature during the tests
θ'_{p}	[°C]	Mean water temperature for the determination of θ_{p} , measured at the outlet
θ_{M}	[°C]	Mean water temperature without withdraw from the tank
f	[l/min]	Minimum flow rate at which hot water is contributing to the reference energy as specified in Table 3.
T_{m}	[°C]	Water temperature at which hot water starts contributing to the reference energy as specified in Table 3
T_{p}	[°C]	Minimum water temperature to be achieved during water draw off as specified in Table 3
T_{set}	[°C]	Set-point temperature
$t_{\text{R},50}$		Reheating time for a water temperature rise of 50 K
Q_{testelec}	[kWh]	Measured electricity consumption over 24 h test (step 4 of Figure 1 and Figure 2).
$Q_{\text{H}_2\text{O}}$	[kWh]	Useful energy content of the hot water of n draw-offs
$V_{\text{full-drawing water}}$	[l]	Sum of quantity of hot water totally delivered during the tapping period.
V_{40_exp}	[l]	Measured volume delivered at the mean water temperature.
V_{40}	[l]	Mixed water quantity delivered at 40 °C.
$V_{40\text{Ref}}$	[l]	mixed water quantity delivered at 40 °C with 65 °C storage temperature and 15°C cold water inlet temperature
$V_{40\text{max}}$	[l]	Mixed water quantity delivered at 40 °C with maximum temperature setting and heating elements powered on
C_{R}	[l]	Rated capacity of water heater (given by manufacturer)
C_{act}	[l]	Actual capacity of water heater
m_{act}	[kg]	Actual weight of water contained inside the tank of the Water Heater
m		Number of tanks (containers) of the appliance
θ_{A1tanks}	[°C]	Mean water temperature calculated as average of the j-tank for the first thermostat cut-out
$\theta_{\text{An tanks}}$	[°C]	Mean water temperature calculated as average of j-tank for the last (n) thermostat cut-out
θ_{Mj}	[°C]	Mean water temperature without withdraw of the j-tank
$\theta_{\text{M_mt}}$	[°C]	Mean water temperature without withdraw of all the tanks
θ_{Aij}	[°C]	Measured water temperature after a thermostat cut-out for the j-tank

Symbol	Unit	Description
θ_{Aj}	[°C]	Mean water temperature after a thermostat cut-out for the j-tank
θ_{Eij}	[°C]	Measured water temperature after a thermostat cut-in for the j-tank
θ_{Ej}	[°C]	Mean water temperature after a thermostat cut-in for the j-tank
θ_{up}	[°C]	Measured temperature in the upper section of the tank
<i>smart</i>		Presence or not of smart control (value shall be 0 or 1).
<i>SCF</i>		Efficiency gain by smart control function.

5 Calculation of the electrical energy efficiency (η_{elecwh})

The electrical energy efficiency (η_{elecwh}) of a storage water heater is the ratio between the delivered energy in the hot water for the tapping pattern of its load profile and the consumed energy. The consumed energy is the result of the test of the water heater with adjustments for:

- smart control that can reduce the energy consumption

The electrical energy efficiency of a storage water heater shall be calculated with Formula (1):

$$\eta_{elecwh} = \frac{Q_{ref}}{Q_{elec} (1 - SCF \cdot smart)} \quad (1)$$

where:

Q_{ref} is the delivered energy for the 24 h tapping pattern for the load profile of the water heater, in kWh;

Q_{elec} is the consumption of electric energy with the relevant 24 h tapping pattern, in kWh;

smart indicates the presence of smart control and is yes = 1, no = 0;

SCF factor for efficiency gain by smart control function.

NOTE SCF=0 in case no smart control is detected during testing (see 9.2).

6 Measured parameters

The parameters below shall be established following the measurement methods described in Clause 7 and Clause 9:

- 1) Q_{elec} electricity consumption [kWh/d]
- 2) η_{elecwh} electrical energy efficiency [%]
- 3) C_{act} storage volume [l]

7 General conditions for measurements

Measurements shall be carried out with an electrical supply satisfying the characteristics outlined in Table 1.

Table 1 – Electricity

Measured quantity	Unit	Value	Permissible deviation (average over test period)	Uncertainty of measurement (accuracy)	Notes
Electricity					
Power	W			±2 %	
energy	kWh			±2 %	
voltage	V	Rated value	±2 %	±0,5 %	
electric current	A			±0,5 %	
frequency	Hz	Rated value	±1 %		

Table 2 gives additional test conditions and tolerances for test outputs (i.e. thermal energy).

Table 2 – Test conditions, outputs, set values and tolerances.

Measured quantity	Unit	Value	Permissible deviation (average over test period)	Permissible deviations of individual measured values	Uncertainty of measurement (accuracy)	Notes
Time						
Time	s				±0,1 s	
Maximum interval between samples (during the delivery of hot water)	s	3				
Maximum interval between samples (during the non-deliver of hot water)	s	60				
Domestic potable or non-potable water						
Cold water temperature for 9.1.5 to 9.2	°C/ K	10 °C	±1 K	±1 K	±0,5 K	
Cold water temperature for 9.3 to 9.7	°C/ K	15 °C	±1 K	±1 K	±0,5 K	
Cold-water pressure	MPa	0,3 MPa			± 5 %	
Hot-water temperature	°C/ K	pattern			±0,5 K	a, b
Volume flowrate	l / min	pattern			≥ 5 l/min: ±1% < 5l/min: ±0,05 l/min	
Volume measurements	l				± 0,5 %	
Thermal energy	kWh	pattern	≥ 0,5 kWh: ±2 % < 0,5 kWh: 10 Wh	≥ 0,5 kWh: ±2 % < 0,5 kWh: 10 Wh	≥ 0,5 kWh: ±2 % < 0,5 kWh: 10 Wh	c

Measured quantity	Unit	Value	Permissible deviation (average over test period)	Permissible deviations of individual measured values	Uncertainty of measurement (accuracy)	Notes
Ambient air						
Temperature	°C/K	20 °C	±1 K		±1 K	
Humidity	%	< 85				d
^a To be measured with a "rapid response thermometer", meaning an instrument that registers within 1 s at least 90 % of the final temperature rise from 15 °C to 100 °C when the sensor is plunged in still water. ^b Thermocouple with a maximum diameter of 0,5 mm, centred in stream, directly at outlet. ^c Apart from the maximum deviation, a correction factor $Q_{\text{ref}}/Q_{\text{H}_2\text{O}}$ is applied, whereby Q_{ref} is taken from Table 3 and $Q_{\text{H}_2\text{O}}$ is the energy content of the useful water actually delivered during the test. "Useful water" is water with a temperature higher than a threshold value T_m for tapings in a profile specified in Table 3. ^d The values for temperature and relative humidity are only valid at steady-state conditions and not at the moment when hot water is withdrawn from the water heater.						

All other installation requirements are carried out in accordance with the manufacturer's instructions. All pipe connections of the test setup shall be thermally insulated, in accordance with the values given in Table B.1.

8 Reference conditions

Table 3 specifies the tapping patterns for the chosen load profile. Parameters in the table are:

- a) load profile [XXS-4XL, in header row of table];
- b) h: hour [hh:mm] starting at 0:00 h;
- c) Q_{tap} [kWh]: useful energy content of water withdrawal to be achieved in the draw-off;
- d) f [l/min]: minimum flow rate to be reached during tapping;
- e) T_m [°C]: temperature from which counting of useful energy content starts;
- f) T_p [°C]: minimum (peak) temperature to be achieved during tapping;
- g) Q_{ref} [kWh/d]: daily (24 h) useful energy content of all water draw-offs, effectively the sum of all Q_{tap} .

As much as possible, the test method uses a 'black-box' approach, i.e. largely technology-independent. This means, among other things, that the laboratory uses the original appliance thermostat, in the out-of-the-box mode.

Table 3 – Load profile of the water heater (reference test tapping patterns)

h	XXS						XS						S						M						L						XL						h	XXL						3XL						4XL																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
	Q _{tap}		T _m		T _p		Q _{tap}		T _m		T _p		Q _{tap}		T _m		T _p		Q _{tap}		T _m		T _p		Q _{tap}		T _m		T _p		Q _{tap}		T _m		T _p			Q _{tap}		T _m		T _p		Q _{tap}		T _m		T _p																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							
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XXS										XS				S			
h	Q_{tap}	f	T_m	T_p	Q_{tap}	f	T_m	T_p	Q_{tap}	f	T_m	T_p					
	kWh	l/min	°C	°C	kWh	l/min	°C	°C	kWh	l/min	°C	°C					
	f		°C		f		°C		f		°C						
18.00	0,105	2	25						0,105	3	25						
18.15	0,105	2	25						0,105	3	40						
18.30	0,105	2	25														
19.00	0,105	2	25														
19.30	0,105	2	25														
20.00	0,105	2	25														
20.30					1,050	3	35	-	0,420	4	10	55					
20.45	0,105	2	25														
20.46																	
21.00	0,105	2	25														
21.15	0,105	2	25														
21.30									0,525	5	45						
21.35	0,105	2	25														
21.45	0,105	2	25														
Qref	2,100				2,100				2,100								

M						L				XL			
h	Q_{tap}	f	T_m	T_p	Q_{tap}	f	T_m	T_p	Q_{tap}	f	T_m	T_p	
	kWh	l/min	°C	°C	kWh	l/min	°C	°C	kWh	l/min	°C	°C	
	f		°C		f		°C		f		°C		
18.00	0,105	3	25		0,105	3	25		0,105	3	25		
18.15	0,105	3	40		0,105	3	40		0,105	3	40		
18.30	0,105	3	40		0,105	3	40		0,105	3	40		
19.00	0,105	3	25		0,105	3	25		0,105	3	25		
19.30													
20.00													
20.30	0,735	4	10	55	0,735	4	10	55	0,735	4	10	55	
20.45													
20.46									4,420	10	10	40	
21.00									3,605	10	10	40	
21.15	0,105	3	25						0,105	3	25		
21.30	1,400	6	40		0,105	3	25		4,420	10	10	40	
21.35													
21.45													
Qref	5,845				11,655				19,070				

XXL						3XL				4XL			
h	Q_{tap}	f	T_m	T_p	Q_{tap}	f	T_m	T_p	Q_{tap}	f	T_m	T_p	
	kWh	l/min	°C	°C	kWh	l/min	°C	°C	kWh	l/min	°C	°C	
	f		°C		f		°C		f		°C		
18.00	0,105	3	25										
18.15	0,105	3	40										
18.30	0,105	3	40						3,36	24	25	6,72 48 25	
19.00	0,105	3	25										
19.30													
20.00													
20.30	0,735	4	10	55					5,88	32	10	55 11,76 64 10 55	
20.45													
20.46									6,240	16	10	40	
21.00													
21.15	0,105	3	25										
21.30	6,240	16	10	40					12,04	48	40	24,08 96 40	
21.35													
21.45													
Qref	24,530				46,760							93,520	

9 Test procedures

9.1 Standard test procedure

9.1.1 General

Subclauses 9.1.2 to 9.1.10 describe the test procedure to establish the electricity consumption Q_{elec} during a 24 h test. The different types of water heaters are described in Annex B (Figure B.1).

9.1.2 Installation

Install the product in the test environment in accordance with the manufacturer's instructions.

Designated floor-standing appliances are to be placed on a floor with low thermal leakage (e.g. 20 mm-thick medium density fibreboard can be placed under the test object 100 mm above the floor of the test room).

Wall-mounted products shall be mounted on a panel at least 150 mm from any structural wall with a free space of at least 250 mm above and below the product and at least 600 mm to the sides. Products designated to be built-in shall be mounted in accordance with the manufacturer's instructions.

Products with declared load profiles 3XL and/or 4XL may be tested on-site, provided test conditions are equivalent, possibly with correction factors, to the ones referenced here.

9.1.3 Stabilisation

Keep product at ambient conditions (test room) until all parts of the product have reached ambient conditions $\pm 5\text{K}$ (at least for 24h).

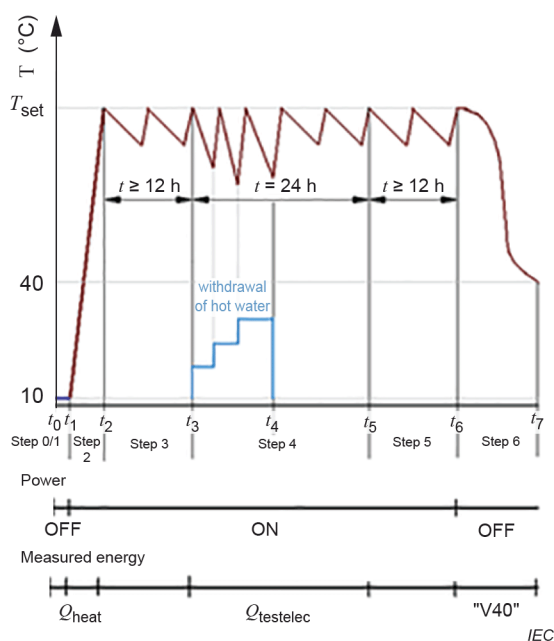


Figure 1 – Test procedure for "energized appliances"

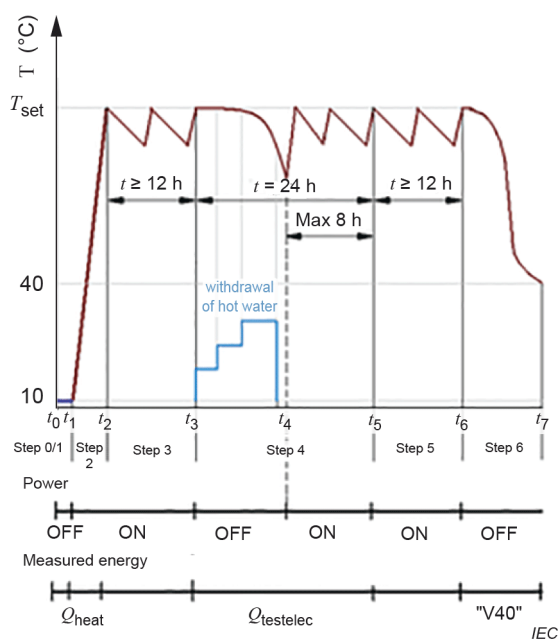


Figure 2 – Test procedure for "off-peak appliances"

9.1.4 Storage volume

Step 0 of Figure 1 and Figure 2: the volume of the tank in a storage electric water heater is measured as follows.

The empty water heater is to be weighed; the weight of the taps on inlet and/or outlet pipes and/or tubes shall not change when measuring the filled and empty tank.

Then the storage water heater is filled with cold water at a temperature of $13\text{ °C} \pm 5\text{ °C}$ in accordance with the manufacturer's instruction at cold water pressure. The water supply is then cut off.

The filled water heater is to be weighed.

NOTE Water in the feed cistern of a cistern-fed water heater is excluded from the quantity withdrawn.

The difference of the two weights (m_{act}) is to be converted into the volume in litres.

$$C_{\text{act}} = \frac{m_{\text{act}}}{0,9997} \quad (2)$$

This volume is to be reported in litres to the nearest one-tenth of a litre. The measured value (actual value) shall be within the tolerance of the rated value stated in Table 4.

Table 4 – Tolerance of the rated storage volume

Storage volume [l]	Tolerance
$V \leq 30$	–5 % to +10 %
$V > 30$	–5 % to +5 %

9.1.5 Filling and heat-up

Step 1 of Figure 1 and Figure 2: products with storage facilities shall be filled with cold water (10 ± 2) °C. Filling stops at the applicable cold water pressure (see Table 2).

Step 2 of Figure 1 and Figure 2: the product is energized to reach out-of-the-box mode, e.g. for storage temperature. The product's own means of control (thermostat) shall be used. The next stage starts at thermostat cut-out.

The time required for heating up the water by 50 K, $t_{R,50}$ is calculated from the following formula and expressed in hours and minutes:

$$t_{R,50} = t_R \times \frac{50}{\theta_R - \theta_C} \quad (3)$$

Where:

t_R is the heating time during the first heating up of the water heater during step 2;

θ_R is the measured reference temperature at thermostat cut-out;

θ_C is the measured cold-water temperature at the beginning of step 2.

9.1.6 Stabilisation at zero-load and cyclic temperature variation (differential)

Step 3 of Figure 1 and Figure 2: keep the product at normal operating conditions as specified by the manufacturer without draw-offs during at least 12 h. This stage ends – and next stage starts – at the first thermostat cut-out after 12 h.

The mean water temperature after a thermostat cut-out θ_A is the average value of n temperatures θ_{Ai} recorded after each cut-out of the thermostat and is given by:

$$\theta_A = \frac{\sum_{i=1}^n \theta_{Ai}}{n} \quad (4)$$

The mean water temperature after a thermostat cut-in θ_E is the average value of n temperatures θ_{Ei} recorded after each cut-in of the thermostat and is given by:

$$\theta_E = \frac{\sum_{i=1}^n \theta_{Ei}}{n} \quad (5)$$

The cyclic temperature variation of the thermostat $\Delta\theta$ is expressed by the formula:

$$\Delta\theta = \theta_A - \theta_E \quad (6)$$

9.1.7 Tapping

Step 4 of Figure 1 and Figure 2: for the selected load profile, draw-offs are made in accordance with the specifications of the appropriate 24 h tapping pattern in Table 3. Tapping pattern starts directly after thermostat cut-out from stabilisation part with the first tapping at 7:00 h time-value as implied in Table 3. The tapping period ends 24 h later. The required useful energy content of the hot water is the total Q_{ref} [in kWh] in Table 3.

During the tapping stage, technical parameters (power, temperature, etc.) are established in accordance with specifications in Table 3. During draw-offs, the recommended maximum sample rate is 3 s (see Table 2). Recorded values shall be part of the technical test report.

Electricity consumption over the 24 h test Q_{testelec} [kWh electricity] shall be measured over 24 h (i.e. $t_5 - t_3$).

Useful energy content of the hot water drawn-off Q_{H2O} [kWh] is determined as described below:

- from the average inlet/outlet temperature difference during the useful tapping period in K, the tapped useful water volume in litres, and the specific heat of water c_w ($1,163 \times 10^{-3}$ kWh/(kg × K)):

$$Q_{H2O}[i] = \Delta T[i] \times V[i] \times c_w \quad (7)$$

where:

- $Q_{H2O}[i]$ is the energy content of one draw-off in [kWh];
- $\Delta T[i]$ is the average in-/outlet temperature difference during the useful tapping period in [K];
- $V[i]$ is the tapped useful water volume [l];
- c_w is the specific heat of water ($1,163 \times 10^{-3}$ kWh/(kg × K))

For all the n draw-offs of one tapping profile, the energy content is the sum:

$$Q_{H2O} = \sum Q_{H2O}[i] \quad (8)$$

This formula can have many formats, for example more dynamic formats using flowrate and instantaneous temperature differences, but it comes down to the same result.

Products to be classified as off-peak appliances shall be energized for a maximum period of 8 consecutive hours ($t_5 - t_4$) between 22:00 h and 7:00 h of the 24 h tapping pattern as specified in Table 3.

In addition, $V_{water}^{full-drawing}$ [l] will be recorded; it is the sum of quantity of hot water totally delivered during the tapping period.

9.1.8 Reporting of Q_{elec}

$Q_{testelec}$ shall be corrected for any energy surplus or deficit outside the strict 24 h tapping period, i.e. a possible energy difference before and after the tapping cycle is taken into account. Furthermore, any surplus or deficit in the delivered useful energy content of the hot water is taken into account in the following equation for Q_{elec} :

$$Q_{elec} = \left(\frac{Q_{ref}}{Q_{H2O}} \right) \times \left\{ Q_{testelec} + \frac{1,163 \times C_{act} \times (T_3(t_3) - T_5(t_5))}{1000} \right\} \text{ [kWh]} \quad (9)$$

where T_3 and T_5 are water temperatures measured at the dome of water heater, respectively at t_3 and t_5 .

9.1.9 Re-stabilisation at zero-load

Step 5 of Figure 1 and Figure 2: keep product at nominal operating conditions without draw-offs during at least 12 h. For products with storage-facilities subject to a control cycle, this stage ends at the first thermostat cut-out after 12 h.

9.1.10 Mixed water quantity delivered at 40 °C

Step 6 of Figure 1 and Figure 2: quantity of water at 40 °C, which has the same heat content (enthalpy) as the hot water which is delivered above 40 °C at the output of the water heater.

Immediately following the measurement in accordance with "re-stabilization at zero-load" (step 5, see 9.1.9), the water heater is switched off after the last cut-out of the thermostat.

Then, a quantity of water equal to the rated capacity is withdrawn through the outlet at a constant rate of flow by supplying cold water; the flow of water from open outlet water heaters is controlled by the inlet valve. The flow in any other type of water heaters is kept constant by means of a valve fitted in the outlet or the inlet.

The rate of flow is adjusted to the maximum value showed on the "water heater load profile" chosen to perform the appliance during the tapping cycle.

θ_{up} [°C] is the water temperature, without withdrawal of water, measured with a thermocouple placed inside the upper section of the tank. For metal tanks, the thermocouple may be placed on the outer surface of the tank as well, as shown in Figure B.2. This value is the water temperature measured after the last cut-out of the thermostat during the "re-stabilization at zero-load" step (see 9.1.9).

θ_c [°C] is the average temperature of inlet cold water during the test.

θ'_p [°C] is the average temperature of outlet water and its normalized value is named θ_p [°C]; it is to be calculated in accordance with the following formula:

$$\theta_p = (\theta_{up} - 10) * \frac{(\theta'_p - \theta_c)}{\theta_{up} - \theta_c} + 10 \quad (10)$$

Temperature readings are preferably taken continuously. Alternatively, they may be taken at equal intervals evenly spread over the discharge, for example every 5 litres (maximum). If there is a sharp drop in temperature, additional readings can be necessary in order to correctly calculate the average value θ'_p .

Outlet water temperature shall always be ≥ 40 °C, which is to be taken into account for the calculation of θ_p .

The volume V_{40_exp} [l], which corresponds to the quantity of water delivered at at least 40 °C, is to be considered.

The quantity of hot water V_{40} [l] delivered with a temperature of at least 40 °C shall be calculated with the following equation:

$$V_{40} = V_{40_exp} \times \frac{(\theta_p - 10)}{30} \quad (11)$$

9.2 Smart control test procedure

9.2.1 Measurement procedure

The smart control test procedure is based on two periods of test; they are named "reference period" and "smart period". During the first period, "reference period", the smart control does not influence the heating procedure and the appliance uses the factory settings for the temperature; in the second period, "smart period", which will be reached automatically, the appliance works to reduce any electricity consumption to achieve a minimum performance goal (i.e. smart control factor: SCF) compared with the first period of test.

During both periods, the chosen tapping profiles shall be fulfilled.

The total test period is called "smart cycle".

The whole test is carried out using the product's thermostat.

9.2.2 Installation

Step 0 of Figure 3: the appliance is installed following the methodology given in 9.1.2.

9.2.3 Stabilisation

Step 1 of Figure 3: the appliance is stabilised following the methodology given in 9.1.3.

9.2.4 Filling and heat-up

Step 2 of Figure 3: the appliance is filled and heated-up following the methodology given in 9.1.5.

It is heated up to the temperature ($T_{\text{set}} \pm 3 \text{ }^{\circ}\text{C}$); θ_{up} is the water temperature measured at the dome (see Figure B.2) of the appliance; this value is given by the manufacturer to achieve a minimum performance goal (i.e. SCF).

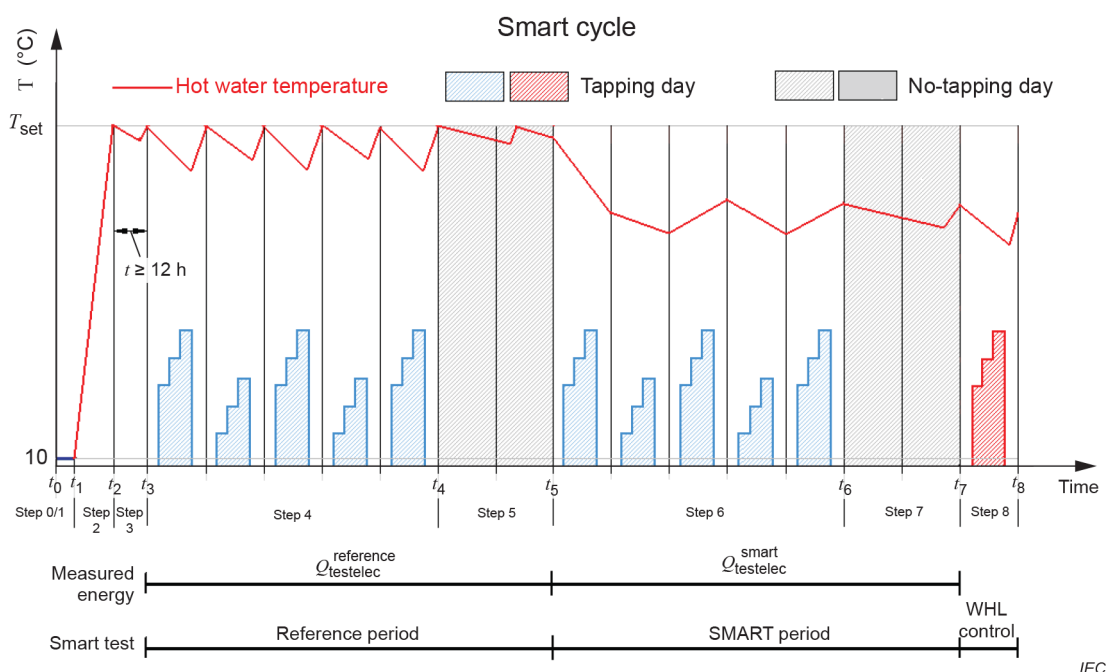


Figure 3 – Test procedure for "smart cycle"

9.2.5 Stabilisation before reference period

Step 3 of Figure 3: keep the product at normal operating conditions as specified by the manufacturer without draw-offs during at least 12 h. This stage ends – and the next stage starts – at the first thermostat cut-out after 12 h.

At the end of this step, the water temperature measured at the dome shall be $(T_{\text{set}} \pm 3 \text{ °C})$ at t_3 .

9.2.6 Reference period

Steps 4 and 5 of Figure 3: this test period allows consumer behaviour learning and measuring energy consumption with smart control activation.

Steps 4 and 5 can last 7 days or 14 days; the manufacturer will decide to use either the one- or two-week procedure, and the product will be tested in accordance with the one chosen.

The first 5 days of testing, in terms of tapping profiles, will be chosen randomly by the lab between the load profile declared by the manufacturer for the product (WHL), and the immediately lower load profile (WHL-1). It means five water heater loads shall be defined (i.e. three "WHL" and two "WHL-1") and the lab can decide to use them randomly (e.g. WHL = M → MMMSS, SSMMM, MSMSM, ...). In the (unlikely) case that WHL-1 is the smallest load profile XXS, the product shall be tested using only the load profile WHL (e.g. XXS) for all five days.

On the 6th and 7th days of testing, there will be no tapping. An example is given in Table 5.

In the case of a 2-week period, the second week is identical to the first week.

Table 5 – Tapping profiles

Reference period	Smart period
Day 1: WHL	Repetition in the same order
Day 2: WHL-1	
Day 3: WHL	
Day 4: WHL-1	
Day 5: WHL	
Day 6: no tapping	
Day 7: no tapping	

If a second week in the reference period is used, it shall have the same WHL and WHL-1 sequence and order as the first week. It means five water heater loads shall be defined (i.e. three "WHL" and two "WHL-1") and the lab can decide to use them randomly during the first week (e.g. WHL = M → first week: MMMSS, second week: MMMSS ...).

Smart control is manually/automatically activated, in accordance with the manufacturer's instructions, at time t_3 (Figure 3), and it stays on from t_3 to t_8 .

For the selected load profiles, draw-offs are made in accordance with the specifications of the appropriate 24 h tapping pattern in Table 3. Tapping patterns start at t_3 (7:00 h) as implied in Table 3. The tapping period ends 24 h later for each day.

During the tapping step, technical parameters (power, temperature, etc.) are established in accordance with specifications in Table 2. During draw-offs, the recommended sample rate is 3 s or less. Recorded values shall be part of the technical test report.

Electricity consumption over each 24 h test, $Q_{\text{testelec}}^{\text{reference}} [i]$ [kWh electricity], will be measured and a total energy content will be defined for the "Reference period".

$$Q_{\text{testelec}}^{\text{reference}} = \sum_{i=1}^{7n} Q_{\text{testelec}}^{\text{reference}} [i] \quad (12)$$

where $n = 1$ if the reference period is based on one week, or $n = 2$ if it is based on two weeks.

During the reference period, the water temperature at the dome of the appliance shall be fixed as

$$T_{\text{set}}^{\text{reference}} \leq T_{\text{set}} + 5 \quad (13)$$

In this way, the electronic thermostat of the product can be considered reliable.

Now, useful energy content of the hot water drawn-off Q_{H2O} [kWh] shall be determined as described in 9.1.7. For each day, a $Q_{\text{H2O}}^{\text{reference}} [i]$ value shall be measured, and a weekly value can be measured; it can be expressed as

$$Q_{\text{H2O}}^{\text{reference}} = \sum_{i=1}^{7n} Q_{\text{H2O}}^{\text{reference}} [i] \quad (14)$$

where $n = 1$ if the reference period is based on one week, or $n = 2$ if it is based on two weeks.

Products classified as off-peak appliances shall be energized for a maximum period of 8 consecutive hours during 22:00 h and 7:00 h of the 24 h tapping pattern as specified in Table 3.

9.2.7 Smart period

Steps 6 and 7 of Figure 3: immediately after the reference period, the test of the "smart period" is performed for the same duration (one or two weeks), using the same repetition of tapping profile defined during the reference period; the smart control function is activated. The energy consumption is measured during this step as well, and it shall be compared to the energy consumption of the reference period step. This percentage of saving is named "smart control factor" (SCF).

The main parameters of this test can be expressed as: electricity consumption over each 24 h test, $Q_{\text{testelec}}^{\text{smart}} [i]$ [kWh electricity], shall be measured and a total energy content shall be defined for the smart period:

$$Q_{\text{testelec}}^{\text{smart}} = \sum_{i=1}^{7n} Q_{\text{testelec}}^{\text{smart}} [i] \quad (15)$$

where $n = 1$ if the reference period is based on one week, or $n = 2$ if it is based on two weeks.

And useful energy content of the hot water drawn-off Q_{H2O} [kWh] shall be determined as described in 9.1.7. For each day, a $Q_{H2O}^{smart} [i]$ value shall be measured, and a weekly value can be expressed as:

$$Q_{H2O}^{smart} = \sum_{i=1}^{7n} Q_{H2O}^{smart} [i] \quad (16)$$

where $n = 1$ if the reference period is based on one week, or $n = 2$ if it is based on two weeks.

Products to be classified as off-peak appliances shall be energized for a maximum period of 8 consecutive hours between 22:00 h and 7:00 h of the 24 h tapping pattern, as specified in Table 3.

9.2.8 Reporting of the smart control factor

The smart control factor shall be corrected for any energy surplus or deficit outside the strict 24 h tapping period (and weekly period as well), i.e. a possible energy difference before and after the tapping cycle is taken into account. The difference between the measurement results of Q_{H2O} after the first week and Q_{H2O} after the second week shall be lower than 2 %. Furthermore, any surplus or deficit in the delivered useful energy content of the hot water is taken into account in the following formula:

$$SCF = \left(1 - \frac{Q_{testelec}^{smart}}{Q_{testelec}^{ref}} \right) \quad (17)$$

9.2.9 WHL control cycle

Step 8 of Figure 3: immediately after the "smart period", an additional 24 h (named "WHL control cycle") shall be performed and requirements are fulfilled; in this step, the product is tested in accordance with the water heater load of the first day (day 1) of the reference period. In this step, electricity consumption shall not be measured.

9.3 Measurement of stored water temperatures

9.3.1 Measurement of water temperature without withdrawal of water are made with a thermocouple placed inside the upper section of all the containers. However, for metal containers, the thermocouple may be placed on the outer surface of the containers (see Figure B.2).

The mean water temperature after a thermostat cut-out of the j-tank θ_{Aj} is the average value of n temperatures θ_{Aij} recorded after each cut-out, and is given by:

$$\theta_{Aj} = \frac{\sum_{i=1}^{i=n} \theta_{Aij}}{n} \quad (18)$$

The mean water temperature after a thermostat cut-in of the j -tank θ_{Ej} is the average value of n temperatures θ_{Eij} recorded after each cut-out and is given by:

$$\theta_{Ej} = \frac{\sum_{i=1}^{i=n} \theta_{Eij}}{n} \quad (19)$$

The mean water temperature after a thermostat cut-out θ_A is the average value of the m tanks and is given by:

$$\theta_A = \frac{\sum_{j=1}^m \theta_{Aj}}{m} \quad (20)$$

The mean water temperature after a thermostat cut-in θ_E is the average value of the m tanks and is given by:

$$\theta_E = \frac{\sum_{j=1}^m \theta_{Ej}}{m} \quad (21)$$

9.3.2 Measurements of temperature of withdrawn water are made in the outflow that shall be continuous. The temperature is measured to an accuracy of $\pm 0,5$ K and, if a thermometer is used, it is to be a type that records quickly and accurately in any position.

Temperature readings should be taken continuously. Alternatively, they may be taken at equal intervals evenly spread over the discharge, for example ten readings at 5 %, 15 %, etc. of the rated capacity. If there is a sharp drop in temperature, additional readings can be necessary in order to correctly calculate the average value θ'_p .

NOTE An example of a suitable apparatus for this measurement is given in Figure B.3.

9.4 Thermostat setting

The thermostat of water heaters where adjustment is provided is set so that the mean water thermostat temperature θ_M , as measured in 9.5.2, is $65\text{ °C} \pm 3\text{ °C}$.

The thermostat-setting is to remain unchanged throughout the measurements. If the thermostat has a dial to indicate the temperature, the equivalent dial-reading θ is to be recorded.

For water heaters where regulation of the water-heater thermostat is not provided for the user, an external thermostat is used to adjust the mean water temperature θ_M , as measured in 9.5.2, to $65\text{ °C} \pm 3\text{ °C}$.

NOTE For heat-loss measurement, an external thermostat is used.