ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

LBNL # 5187E

Review of International Methods of Test to Rate the Efficiency of Water Heaters

Jim Lutz

Energy Analysis Department
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

January 2011

This work was sponsored by the Gas Technology Institute (GTI) which is funded by the California Energy Commission, Public Interest Energy Research (PIER) Program, under Residential Water Heating Program Contract No. 500-08-060

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State, and Community Programs, of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

DISCLAIMER

Review of International Methods of Test to Rate the Efficiency of Water Heaters

Jim Lutz, Lawrence Berkeley National Laboratory

January 25, 2011

The American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) Standards Project Committee (SPC) 118.2, Method of Testing for Rating Residential Water Heaters, is seeking to improve the test procedure used for measuring the energy efficiency of residential gas and electric water heaters. ASHRAE is seeking to develop an improved test procedure in part to support the U.S. Department of Energy's (DOE's) desire to update and amend the water heater test procedure underlying the minimum energy efficiency standards for water heaters. DOE's test procedures are often based on or reference ASHRAE standards.

DOE's most recent minimum energy performance standards (MEPS) for residential water heaters were promulgated in 2010.[1] The associated test procedures are stipulated in the Code of Federal Regulations (CFR).[2] Although DOE currently is conducting a rulemaking to review and possibly amend the test procedures for residential water heaters, that rulemaking pertains to accounting for energy consumed during standby and off modes. In its notice of proposed rulemaking published in the *Federal Register* on August 30, 2010, DOE tentatively concluded that the test procedure for water heaters already fully accounts for and incorporates the energy consumed during standby and off modes [3].

Current Test Procedure

Under ASHRAE's current test procedure, two separate performance metrics are calculated: (1) recovery efficiency and (2) standby loss. Further calculations produce an efficiency descriptor (energy factor, or EF) that represents the overall efficiency of the water heater in providing a representative daily amount of hot water. Annual energy consumption and cost are estimated by extending the daily EF to a year (365 days). The test procedure describes methods for evaluating gas and electric storage water heaters, heat-pump water heaters, and instantaneous (tankless) water heaters.[4]

SPC 118.2 is not alone in encountering difficulties in devising an improved test procedure—difficulties that to date have proved frustrating. To aid in the development of the test procedure, the status and content of water heater test procedures for other countries were investigated. Current water heater test procedures for other countries and organizations (Australia, the European Union [EU], and the International Organization for Standardization [ISO]) are described below in conjunction with their efforts to revise those test procedures.

Issues Surrounding the Test Procedure

A primary goal of any test procedure is that it be applicable to the full range of types and sizes of water heaters. A test procedure should be capable of evaluating all technologies fairly, including the newer ones, such as small gas-fired storage water heaters with a large burner. The current ASHRAE test procedure evaluates product efficiency for delivering 64.3 gallons of hot water in 24 hours based on six relatively large draws. The same hot water load is applied regardless of the storage volume of the water heater or, in the case of tankless water heaters, whether the burner consumes 50,000 or 200,000 British thermal units per hour. The current test procedure with six major hot water draws tends to rate tankless water heaters higher than if the test consisted of more draws. Because of the cyclic losses associated with each draw, tankless water heaters tend to be less efficient at providing a larger number of smaller draws.

In addition to a need to broaden the applicability of the test procedures, another fundamental issue is the need to specify a draw (or tapping) pattern that describes the realistic field usage of a water heater. The current test procedure is based on a pattern of six draws in 24 hours. The flow rate for all draws is 3 gallons per minute for about 10 gallons. The draws are taken one hour apart, for a total of 64.3 gallons. After the sixth draw, the water heater is left in standby mode for the rest of the 24 hours. There is general agreement among the standard project committee members that the current draw pattern is not reflective of the way hot water is used. There currently is, however, no agreement on a better draw pattern. Internationally, different countries have different types of water heaters and use them differently. The test procedures for water heating appliances are not well harmonized throughout the world. The Collaborative Labelling and Appliance Standards Program (CLASP) is funding a study to assess international opportunities for harmonizing energy efficiency for all types of appliances. The initial assessment of the possibilities for harmonizing test procedures for water heaters concludes that the prospects are not bright.

> The current situation for water heating appliances is fairly bleak. There are many different product types and most are complex in their design and operation. Water heater energy consumption is heavily affected by hot water demand, which is highly variable at a regional level, and by many climatic factors, which are also very variable.
>
> There is very little international harmonisation in test procedures and efficiency metrics for water heaters and even for simple appliances, such as electric storage water heaters, the comparison of settings is very complex due to testing and efficiency metric differences. … In the near term, however, harmonisation prospects are not good for this group of products. [5]

Approaches to a New Test Procedure

The goal of any revised test procedure of course is to measure the energy efficiency of all types and sizes of water heaters fairly and consistently. There are two primary philosophical approaches for estimating the field energy consumption of water heaters based on laboratory tests.

One is to perform a simulated use test using a 24-hour draw pattern that is considered a realistic representaton of how the water heaters are used in the field. Operating conditions (water and air temperatures) and draw patterns (timing, flow, and duration of draws) in the laboratory test are intended to represent typical use and conditions in the field. The energy consumption of the water heater in the test, would therefore represent the performance of the water heater in the field.

The other method is to run separate tests to determine key parameters of the water heater (such as recovery efficiency, standby loss, and cyclic losses). The parameters are then combined algorithmically to calculate energy use for any specified operating condition and draw pattern. The calculations could be performed using simple algorithms such as the one used to evaluate the annual energy use of commercial water heaters or the input/output (I/O) protocol.[6, 7] Alternatively, more complicated methods such as transient system simulation models (TRNSYS) can be applied.[8] No consensus has been reached on whether it is better to apply a 24-hour simulated use test or measure parameters and apply an algorithm.

The following table compares various aspects of the two general approaches to water heater testing.

24-Hour Simulated Use Test		**Parametric Tests and Algorithm**	
Rating	Aspect	Rating	Aspect
+	Method easy to understand	-	Method more difficult to understand
+	Covers all water heater technologies	-	Different water heater technologies may require different types of tests
-	It is not obvious what draw pattern to use	-	It is not obvious what draw pattern to use
-	Results apply only to operating conditions and draw pattern used in test	+	Parameters can be applied to a range of operating conditions and draw patterns
-	Changing the draw pattern would require retesting	+	Changing the draw pattern would require only recalculation, not retesting

24-Hour Simulated Use Test		Parametric Tests and Algorithm	
Rating	Aspect	Rating	Aspect
-	Water heaters having different capacities would be tested with different draw patterns	+	Water heaters having different capacities would be tested the same way; only the energy use calculations would differ
-	Inappropriate draw pattern and operating conditions may bias the results by technology type	-	Inappropriate parametric tests may bias the results by technology type
-	May need to measure the water temperature inside the tank to correct for changes of stored energy during the test	+	May not need to measure the water temperature inside the tank to correct for changes of stored energy during the test
		-	Unclear what is the best method is to calculate energy use
		-	Need to validate or confirm that the selected energy calculation method

<u>Sizing</u>

Currently in the United States, all water heaters, regardless of size, are tested based on DOE's draw pattern that totals 64.3 gallons per day. Yet water heaters are designed and built to have a range of capacities. It seems reasonable that a water heater having a small capacity would be installed in applications where little hot water is needed. One potentially useful approach is to test a given water heater using a draw pattern that better matches its intended use.

The maximum amount of hot water a water heater can deliver in 15 minutes may provide a good rating of delivery capacity. Household usage varies, of course, with days of different hot water demand, but this rated delivery capacity coincidentally seems to equal an appropriate daily average amount of hot water use for testing a water heater of a given capacity. This approach is based on both current manufacturer sizing recommendations and a study that examined how people use hot water and the product capacity needed to avoid frequent run outs of hot water [9].

<u>Current Status</u>

Along with the United States, the European Union (EU), Australia, and the International Organization for Standardization (ISO) are all in the process of revising their test procedures for water heaters. Japan recently finished revising its test procedure for gas water heaters , but the results have yet to be translated into English.[10]

ASHRAE

The current ASHRAE Standard is 118.2-2006, *Method of Testing for Rating Residential Water Heaters*.[4] That test procedure is a revision of ANSI/ASHRAE Standard 118.2-1993 by the same name. Among changes made to the 1993 standards were to require one pre-draw, require a 24-hour soak-in period before the test, and account for recovery periods that span multiple draws. The tolerances allowed in some measurements were reduced, and references to other standards were updated. Because of widespread dissatisfaction with the repeatability and appropriateness of the test, a revision committee was founded soon after the changes were adopted.

Australia

To date Australia's approach has been to do parameter testing. There have been Minimum Energy Performance Standard (MEPS) for electric storage water heaters since 1999.[11] The current test procedure for rating electric storage water heaters is standing heat loss test. [12] Because the heat can go nowhere except into the water, the resistance elements are assumed to be 100% efficient.

Australia currently has no standards or labels for gas water heater efficiency. Starting in 2005, the Australian government began an effort to bring gas water heaters into a consistent regulatory framework, similar to the one governing electric water heaters. Legal deficiencies in the regulatory guidance caused some delays. The test method is being revised to ensure that it provides a solid basis for MEPS and/or a labeling program.

The current Australian test procedure uses bench tests to measure key performance parameters under defined conditions. Those measurements then are used to estimate the energy consumption for delivering a particular amount of hot water per day [13]. Key stakeholders, however, have raised questions concerning the accuracy and reproducibility of the test. In late 2005 and early 2006, the Australian Greenhouse Office sponsored a round-robin comparative test program that used accredited test laboratories to assess the repeatability and reproducibility of the test method for gas water heaters. The labs came up with different results, in most cases varying more than expected given the specified measurement accuracy. The variations among key parameters, including burner efficiency for storage systems, maintenance rate (standby losses), and startup energy, indicated much greater uncertainty than expected [13].

A consultant was hired to recommend improvements to the test procedure for gas water heaters. One of the important recommendations was to operate the product as it likely would be used in the field; that is, with cold water drawn into the inlet, hot water drawn through the outlet, and the unit allowed to recover under its own controls [14]. Harrington also recommended measuring the recovery efficiency of storage water heaters by conducting full-tank draw-offs down to the minimum usable delivery temperature. The draw-offs would be repeated until a consistent efficiency is observed (typically after three full-tank draw-offs), then the process repeated for an additional four or five draw-offs. This series of full draw-off cycles also establishes a consistent pre-conditioning prior to the standby testing. Although direct measurement of internal water temperatures is desirable, for many tank designs it is physically impossible to accomplish without compromising the integrity of the insulation. If performed consistently, full-tank draw-offs provide an indirect way of measuring the stored energy (heat) in the tank.

The recommended new test method would determine standby loss at the end of the series of full draw-off cycles to provide a standardized pre-condition. Energy correction for temperature decrease or increase in the tank at the end of the maintenance period would be included in the calculation based on one temperature probe.

Thermal interactions in storage systems are complex. Many factors vary during normal operation, and it may be impossible to provide a representative set of conditions that will provide test data from which in-use energy consumption can be calculated accurately.

For tankless water heaters, Harrington's recommendation was to determine the slope of energy output versus water delivery for the linear, steady-state part of a draw. The nonlinear part at the beginning would be characterized as an offset in terms of wasted water and startup energy. The startup energy until the time when hot water is first delivered would be added for each draw based on steady slope.

Harrington recommended that data from the above tests be input to a modified version of TRNSYS to calculate energy use. TRNSYS would enable the simulation of a wide range of delivery tasks under various conditions. The simulation model would be checked to confirm that it can replicate the range of laboratory task tests.

Harrington's proposed approach to testing newer hybrid units (which typically have a small storage volume and a large burner that can deliver hot water at a designated flow rate) was to test them separately as a tankless water heater and determine the maintenance rate as described above for storage water heaters.

Following up on Harrington's recommendations, Working Group 11 of the Australian Standards Association drafted a new trial test procedure that was evaluated in four laboratories. Another consulting company evaluated the results, with an eye to simplifying the procedure. One of the recommendation is perhaps to use a simple 24-hour simulated use test for storage water heaters. A proposed test procedure has not been released for public review yet. The situation in Australia clearly is uncertain and in flux.

European Union

The EU's attempt to develop a test procedure for water heaters, meanwhile, represents one of their efforts to harmonize Europe-wide Ecodesign standards for all appliances based on life-cycle performance. Council Directive 92/75/EEC of 22 September 1992 established, for all member countries, a uniform labeling program that required household appliances to display their consumption of energy and other resources.[15] Although the European Commission has issued directives regarding the performance labeling of many appliances (such as washing machines, dryers, refrigerators, electric ovens, air-conditioners, and dishwashers), they have not done so for water heaters, in part because they have not finalized the necessary test procedure.

In 2005, the European Parliament and the Council of the European Union issued a directive that established a framework for setting so-called ecodesign requirements for energy-using products (EuP) in Europe [16]. Ecodesign integrates environmental aspects into product design with the aim of improving the environmental performance of the EuP throughout its life cycle. Measures adopted to implement the directive stipulated ecodesign requirements for EuPs. In 2009 the directive was expanded and recast to cover energy-related products [17].

In 2007 VHK performed a preparatory study on the ecodesign of water heaters [18]. The study was developed with stakeholders and interested parties from the EU and non-member countries. Although the study was completed, it did not propose a test procedure for evaluating the efficiency of water heaters.

In the summer of 2010, proposed ecodesign and labeling requirements, as well as transitional testing and calculation methods, were announced for water heaters. The EU's Regulatory Committee is expected to vote on the transitional testing methods in early 2011 [19]. The transitional methods are intended to be used until a standards body, such as the European Committee for Standardization (CEN) or the European Committee for Electrotechnical Standardization (CENELEC), promulgate standards for test procedures [20].

The proposed water heater test procedure is based on a 24-hour simulated use test. Ten different load profiles are available. Table 1 shows an early version of the load profiles along with the intended range of hot water supplied by the water heater being tested [21].

Table 1. Illustrative Load Profiles and Daily Volumes of Hot Water

Load Profile	Range of 'Specified Demand' (liters per day @ 60 °C)	
XXS	<20l	Single point–not shower
XS	<50l	Single point, including shower
S	< 80l	
M	35–150l	
L	70–300 l	
XL	120–500l	
XXL	150–650l	
3XL	280–15,000l	
4XL	550l–	

Each water heater is tested and rated under the largest load profile that it is capable of meeting. The load profiles consist of a multiple draws scheduled throughout a 24-hour period. Each draw is specified in terms of flow rate and useful energy content. For most draws, the useful energy content is measured once the delivered water exceeds a specified water temperature. For some draws, all the useful energy content is counted. The water must reach a specified peak temperature during the draw.

The number of draws per day and delivered hot water energy varies according to the load profile. Different peak and useful temperatures are assigned to the draws in each load profile. Table 2 summarizes the parameters associated with the EU water heater test procedure load profiles. The equivalent parameters for the ASHRAE test procedure are shown for comparison. A detailed table of all the load profiles is included as Appendix 1.

Table 2: Parameters associated with transitional EU test procedure for water heaters.

Load Profile	**No. Draws**	**Delivered Energy (kBtu/day)**	**Max. Flow (gpm)**	**Useful Temp.(ºF)**		**Peak Temp. (ºF)**	
				Min.	**Max.**	**Min.**	**Max.**
3XS	23	1.177	2	77	77	N/A	N/A
XXS	20	7.165	2	77	77	N/A	N/A
XS	3	7.165	4	95	95	N/A	N/A
S	11	7.165	5	50	113	131	131
M	28	19.943	6	50	104	104	131
L	24	39.767	10	50	104	104	131
XL	25	65.067	10	50	104	104	131
XXL	30	83.696	16	50	104	104	131
3XL	10	159.545	48	50	104	104	131

4XL	10	319.090	96	50	104	104	131
ASHRAE EF	6	40.632	3	135	135	135	135

In addition to the draws in the load profile, the transitional test protocol cycle comprises five stages. The first is a 24-hour stabilization period to allow the water heater to adjust completely to ambient test temperatures. For storage water heaters, the next stage is filling and heat-up. After the heat source cuts out, the water heater enters another zero-load stabilization period for 12 hours. The 24-hour load profile is applied after this second stabilization period. Following the 24-hour load profile is another 12-hour zero-load re-stabilization period. The filling/heat-up and stabilization stages are applied only to storage water heaters. The energy consumed during the stabilization periods is used to account for any energy surplus or deficit during the 24-hour measurement cycle. Figure 1 shows a schematic of the test cycle.

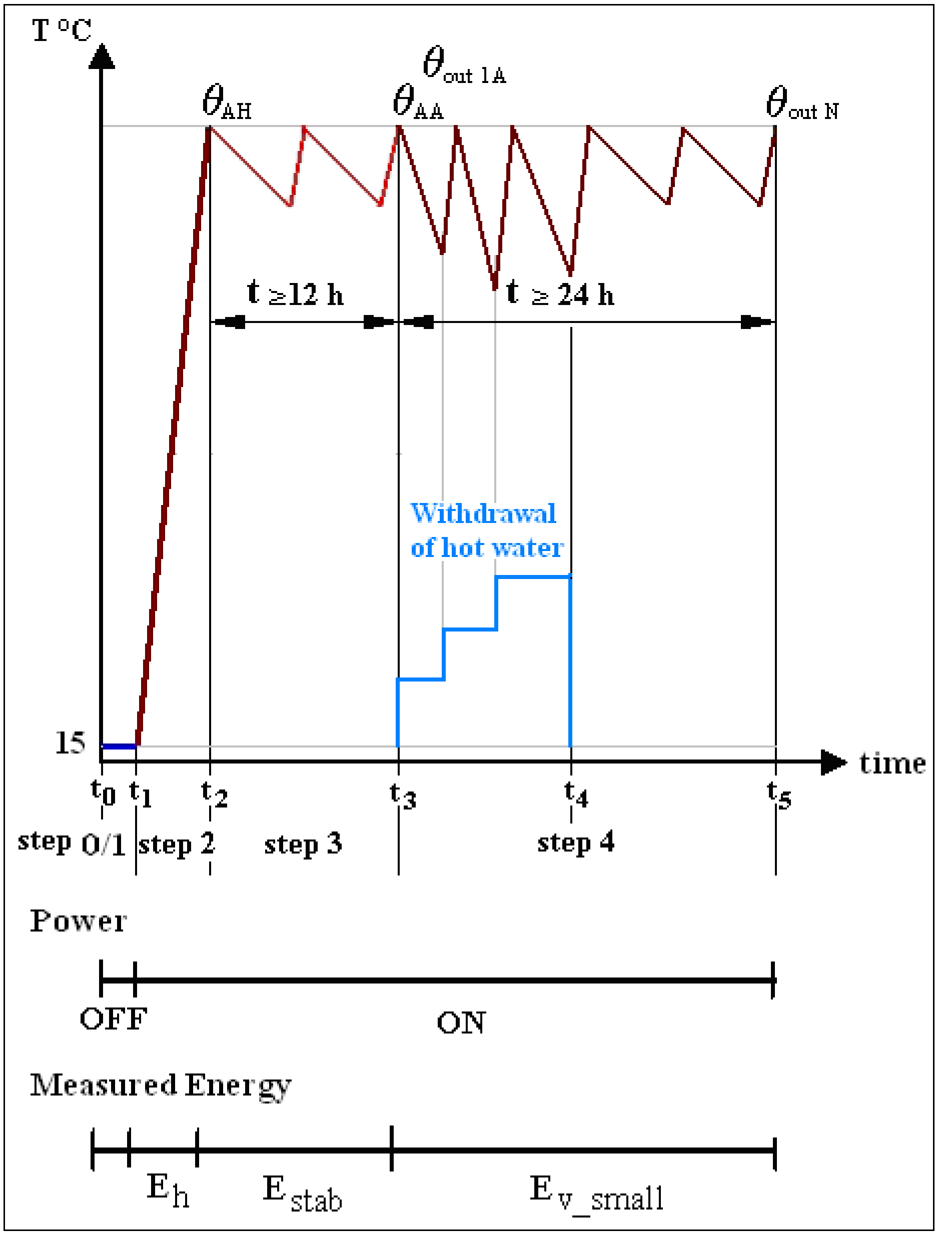

Figure 1. Schematic of EU test cycle for water heaters. [22]

Following the on ecodesign philosophy, a water heater's energy efficiency is calculated as the ratio of the useful energy provided by the water heater as hot water to the energy required for its generation. The testing pattern represents a peak situation, *e.g.*, weekends. On average daily field use is expected to be only 60% of the indicated hot water energy specified in the test procedure. To calculate the average annual heat load, a factor of 0.6 (60%) is applied for 366 days [22]. The energy required also takes into account hot water distribution losses and waste heat recovery.

Distribution losses are those heat losses that occur between the water heater and the point where the hot water is used. These losses reduce the rated energy efficiency of a water heater. The farther the water heater is installed from the end-uses of hot water, the greater the distribution losses. To approximate the impact of the likely installation location of a water heater, reference distribution losses are made dependent on the type of air intake, physical size and load profile of the water heater. If the water heater does not consume a fossil fuel, the air-intake is "none," and the distribution losses are low. If the water heater is fossil fuel fired and takes its combustion air directly from outdoors through a dedicated duct, the air intake is "room-sealed"; otherwise it is "open." An open air intake water heater is assigned the highest distribution losses. Physically larger water heaters and water heaters capable of meeting higher load profiles also have high distribution losses.

Waste heat recovery accounts for the space-heating benefits of the heat lost from a water heater located indoors. The heat recovery parameter is the assumed fraction of the waste heat from the water heater that is considered beneficial. The assigned heat recovery parameter, which ranges from 0% to 32%, depends on the energy source (electric or fossil fuel), the size of the water heater, and how noisy the water heater is.

In keeping with the life cycle assessment philosophy of ecodesign, the different types of energy used by the water heater are converted to source energy. A water heater's measured electricity use is increased by the EU average of the amount of primary energy used to provide the end-user with one unit of electricity. A conversion factor of 2.5 is used in the test procedure..

International Organization for Standardization

The ISO has no test procedure for conventional water heaters. Part of four of the ISO test procedures for solar water heaters characterizes system performance by means of component tests and computer simulation. Some parts are relevant to testing conventional water heaters [23]. The procedure sets out a method of evaluating the annual energy performance of heated water systems using a combination of test results for component performance and a mathematical model to determine performance based on annual load cycle. The mathematical model recommended to evaluate the annual energy performance of the water heating system is the TRNSYS program. Many of the values used in the test procedure, such as temperatures or draw patterns, are not specified in the standard. They are to be specified by the certification or incentive program that references the standard.

The test procedures for determining the thermal capacitance of a water heater tank and the heat loss of the water heater are contained in Annex B, Store Performance. The thermal capacitance test involves measuring the temperature of the water drawn from the tank.as it is purged all energy. The heat loss test is an exteneded cool-down period to determine how fast the water in the tank loses energy to ambient air. The ISO standard references the Australian standard for gas water heaters for determining thermal efficiency, startup heat capacity, and maintenance energy use (make-up for standby losses). As noted above, at this time the Australian standard is also being revised.

Comparing Current Efforts

Table 3 summarizes the differences among current and proposed test procedures for residential hot water heaters. The table helps illustrate the difficulties involved in comparing or attempting to harmonize test procedures for water heaters.

Table 3: Comparison of ASHRAE, EU, and Australian water heater test procedures.

	ASHRAE 118.2 (and DOE)	**European Union**	**Australia/New Zealand AS/NZS 4552.2 (draft)**–Minimum energy performance standards for gas water heaters; **AS/NZS4552.3**–Energy consumption test methods for gas water heaters; **AS/NZS 4234:2008**–Heated water systems: calculation of energy consumption
Status	Being revised	Awaiting adoption by European Council	AS/NZS 4552.2 in draft form; AS4552.3 to be published 2011; 4234:2008
Scope	Residential water heaters	Sanitary water heaters	Gas water heaters
Scope limits	2–120 gallons, <75 kBtu/hr & <2gallons, <200 kBtu/hr	Provides drinking or sanitary hot water	For storage: ≤50 megajoules (MJ)/hr (47.4 kBtu/hr); for instantaneous ≤250 MJ/hr (236.9 kBtu/hr) (AS/NZS 4552.2)
Type of test	24-hour simulated use test	24-hour simulated use tests	Parameter determination followed by energy use calculation using TRNSYS
Number of draw patterns	1	10	Multiple depending on location and time of year (AS/NZS 4234:2008)
Daily load	64.3 gallons	0.345–93.52 kWh (1.177–319.1 kBtu)	37.67 MJ (200 L water from 15.0–60.0 °C) (AS/NZS 4552.2)
Number of draws	6	3 to 30	8 for Australia, 10 for New Zealand; (AS/NZS 4234:2008)
Flow rate	3 gpm	2–96 liters/min. (0.53–25.4 gpm)	Varies by location and time of year (AS/NZS 4234:2008)

	ASHRAE 118.2 (and DOE)	European Union	Australia/New Zealand AS/NZS 4552.2 (draft)–Minimum energy performance standards for gas water heaters; AS/NZS4552.3–Energy consumption test methods for gas water heaters; AS/NZS 4234:2008–Heated water systems: calculation of energy consumption
Draw type	10.7 gallons	1: sum energy after reaching useful temperature (Tm); 2: sum all energy, must reach peak temperature (Tp)	6 minutes each, flow rate adjusted to match fraction of daily load (AS/NZS 4234:2008)
Delivery temperature	135 °F	Tm = 25–45 °C (77–113 °F); Tp = 40–55 °C (104–131 °F)	45 °C minimum in section 3.5.2; 60 °C in Appendix C -(AS/NZS 4234:2008)
Logging interval	5 seconds	1 second	1/4 second tankless; 1 second storage; 1 minute standby (being considered)
Internal temperatures	6	No	1
Gain/loss	Calculate from internal temperatures	Pre- and post-test stabilization	Calculate from one internal temperatures
Discharge	No	No	From temperature-pressure relief valve as water expands during heating
Includes: Source energy multiplier	1	2.5	1
Distribution losses	No	Yes	No
Smart controls	No	Yes	No
Wasted water	No	No	Yes
Solar	No	Yes	Yes (AS/NZS 4234:2008)
Heat pump water heater	Yes	Yes	Yes, solar-boosted (AS/NZS 4234:2008); air source to be added

	ASHRAE 118.2 (and DOE)	**European Union**	**Australia/New Zealand AS/NZS 4552.2 (draft)**–Minimum energy performance standards for gas water heaters; **AS/NZS4552.3**–Energy consumption test methods for gas water heaters; **AS/NZS 4234:2008**–Heated water systems: calculation of energy consumption
Combination unit	No	No	Excluded (AS/NZS 4552.2)
Outcomes: Primary rating	Energy factor (EF)	Energy efficiency	Annual energy consumption (AS/NZS 4552.2)
Recovery	Recovery efficiency	No	Recovery efficiency for storage; Steady-state efficiency tankless;
Standby	Standby heat loss coefficient	Standing loss	Maintenance energy
Startup energy	No	No	Yes
Wasted water	No	No	Yes

Bibliography

[1] U.S. Department of Energy, "Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters; Final Rule," 2010. http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/htgp_finalrule_fedreg.pdf

[2] U.S. Department of Energy, "10 CFR Part 430. Energy Conservation Program for Consumer Products: Test Procedure for Water Heaters; Final Rule," *Federal Register*, vol. 63, p. 22, May 11 1998.

[3] U.S. Department of Energy, "Energy Conservation Program for Consumer Products: Test Procedures for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters," 2010. http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/tp_nopr_waterheaters_2010-08-30.pdf

[4] ASHRAE, "ASHRAE/ANSI Standard 118.2-2006, Method of Testing for Residential Water Heaters," in 2006.

[5] P. Waide and L. Harrington, "Opportunities for Success and CO2 Savings from Appliance Energy Efficiency Harmonisation (draft)," CLASP June 2010.

[6] ASHRAE, "ASHRAE/ANSI Standard 118.1-2003, Method of Testing for Rating Commercial Gas, Electric and Oil Service Water Heating Equipment," in *ASHRAE*, 2003.

[7] M. J. Hewett, "Inside ASHRAE Standard 155P: A New Measure of Commercial-Boiler-System Performance," *BSE*, p. 9, June 2005.

[8] University of Wisconsin-Madison College of Engineering's Solar Energy Lab, "A TRaNsient SYstems Simulation Program, TRNYSYS 17." vol. 2011. http://sel.me.wisc.edu/trnsys/index.html

[9] C. C. Hiller, "New Hot Water Consumption Analysis and Water-Heating System Sizing Methodology," *ASHRAE Transactions*, vol. 104, 1998.

[10] Japan Industrial Association of Gas and Kerosene Appliances, "TS S 0003:2010, Measurement method of thermal efficiency for domestic gas and oil water heater under standard usage mode," Japanese Standards Association, 2010. http://www.webstore.jsa.or.jp/webstore/Com/FlowControl.jsp?lang=en&bunsyoId=TS+S+0003%3A2010&dantaiCd=JIS&status=1&pageNo=0

[11] Standards Australia, "AS/NZS 4692.2:2005, Electric water heaters - Minimum Energy Performance Standard (MEPS) requirements and energy labelling ", 2005.

[12] Standards Australia, "AS/NZS 4692.1:2005, Electric water heaters - Energy consumption, performance and general requirements ", 2005.

[13] Gas Appliance and Equipment Energy Efficiency Committee, "Gas Water Heater Comparative Testing Round-Robin 2005/06," 2006. http://www.energyrating.gov.au/library/pubs/200612-wh-round-robin.pdf

[14] L. Harrington, "Gas Water Heaters: New Test Method," Melbourne, presentation May 2007. http://energyrating.gov.au/pubs/2007-wh-harrington.pdf

[15] Council of the European Communities, "Council Directive 92/75/EEC of 22 September 1992 on the indication by labelling and standard product information of the consumption of energy and other resources by household appliances." vol. 75: Official Journal of the

European Union, 1992, p. 4. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:191:0029:0058:EN:PDF
[16] European Parliament, "Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 establishing a framework for the setting of ecodesign requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC of the European Parliament and of the Council." vol. Directive 2005/32/EC: Official Journal of the European Union, 2005, p. 30. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:191:0029:0058:EN:PDF
[17] European Parliament and the Council of the European Union, "Directive 2009/125/EC of the European Parliament and of the COUNCIL of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast)." vol. Directive 2009/125/EC: Official Journal of the European Union, 2009, p. 26. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:285:0010:0035:en:PDF
[18] R. Kemna, M. v. Elburg, W. Li, and R. v. Holstein, "Eco-Design of Water Heaters: Task 1 (Draft Final) Report- Definition, Test Standards, Current Legislation and Measures," Van Holsteijn en Kemna (VHK), Draft Final July 2 2007.
[19] European Commission, "Working documents on ecodesign and energy labelling of water heaters and hot water storage tanks of June 2010, Notes," 2010. http://www.eceee.org/Eco_design/products/water_heaters/notes_wd_23June2010
[20] European Commission, "Working document, Draft Commission communication in the framework of the implementation of Commission Regulation (EC) No …/… implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for water heaters and hot water storage tanks, and of the implementation of Commission Delegated Regulation (EU) No …/… implementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of water heaters and hot water storage tanks," 2010. http://www.eceee.org/Eco_design/products/water_heaters/WD_transitional_testing_calculations_19July2010
[21] European Commission, "Working document on possible Ecodesign Energy labelling and Installation requirements for Boilers and Water Heaters," 2008. http://www.eceee.org/Eco_design/products/water_heaters/2008_02_29_working_document_boilers.pdf
[22] European Commission, "Annex IV on Eco-design implementing measures for dedicated water heaters. Draft v2," 2008. http://www.eceee.org/Eco_design/products/water_heaters/Annex_IV_8July08
[23] International Organization for Standardization, "Draft International Standard ISO/DIS 9459-4 Solar heating — Domestic water heating systems — Part 4: System performance characterization by means of component tests and computer simulation," 2010, p. 74. http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=41695

Appendix 1 – Load profiles for testing water heaters from proposed EU ecodesign regulations for water heaters

	3XS			XXS			XS			S			
	Qtap	F	Tm	Qtap	F	Tm	Qtap	F	Tm	Qtap	F	Tm	Tp
h	kWh	l/mn	ºC	kWh	l/mn	ºC	kWh	l/mn	ºC	kWh	l/mn	ºC	ºC
7:00	0.015	2	25	0.105	2	25				0.105	3	25	
7:05	0.015	2	25										
7:15	0.015	2	25										
7:26	0.015	2	25										
7:03	0.015	2	25	0.105	2	25	0.525	4	35	0.105	3	25	
7:45													
8:01													
8:05													
8:15													
8:25													
8:03				0.105	2	25				0.105	3	25	
8:45													
9:00	0.015	2	25										
9:30	0.015	2	25	0.105	2	25				0.105	3	25	
10:00													
10:30													
11:00													
11:30	0.015	2	25	0.105	2	25				0.105	3	25	
11:45	0.015	2	25	0.105	2	25				0.105	3	25	
12:00	0.015	2	25	0.105	2	25							
12:30	0.015	2	25	0.105	2	25							
12:45	0.015	2	25	0.105	2	25	0.525	4	35	0.315	4	10	55
14:30	0.015	2	25										
15:00	0.015	2	25										
15:30	0.015	2	25										
16:00	0.015	2	25										
16:30													
17:00													
18:00				0.105	2	25				0.105	3	25	
18:15				0.105	2	25				0.105	3	40	
18:30	0.015	2	25	0.105	2	25							
19:00	0.015	2	25	0.105	2	25							
19:30	0.015	2	25	0.105	2	25							
20:00				0.105	2	25							
20:30							1.05	4	35	0.42	4	10	55
20:45				0.105	2	25							
20:46													
21:00				0.105	2	25							
21:15	0.015	2	25	0.105	2	25							
21:30	0.015	2	25							0.525	5	45	
21:30	0.015	2	25	0.105	2	25							
21:45	0.015	2	25	0.105	2	25							
Qref	0.345			2.1			2.1			2.1			

	M				L				XL			
	Qtap	F	Tm	Tp	Qtap	f	Tm	Tp	Qtap	f	Tm	Tp
h	kWh	l/mn	ºC	ºC	kWh	l/mn	ºC	ºC	kWh	l/mn	ºC	ºC
7:00	0.105	3	25		0.105	3	25		0.105	3	25	
7:05	1.400	6	40		1.400	6	40					
7:15									0.105	3	25	
7:26												
7:03	0.105	3	25		0.105	3	25					
7:45					0.105	3	25		4.420	10	10	40
8:01	0.105	3	25						0.105	3	25	
8:05					3.605	10	10	40				
8:15	0.105	3	25						0.105	3	25	
8:25					0.105	3	25					
8:03	0.105	3	25		0.105	3	25		0.105	3	25	
8:45	0.105	3	25		0.105	3	25		0.105	3	25	
9:00	0.105	3	25		0.105	3	25		0.105	3	25	
9:30	0.105	3	25		0.105	3	25		0.105	3	25	
10:00	0.105	3	25									
10:30	0.105	3	10	40	0.105	3	10	40	0.105	3	10	40
11:00	0.105	3	25						0.105	3	25	
11:30	0.105	3	25		0.105	3	25		0.105	3	25	
11:45	0.105	3	25		0.105	3	25		0.105	3	25	
12:00												
12:30												
12:45	0.315	4	10	55	0.315	4	10	55	0.735	4	10	55
14:30	0.105	3	25		0.105	3	25		0.105	3	25	
15:00	0.105	3	25									
15:30	0.105	3	25		0.105	3	25		0.105	3	25	
16:00	0.105	3	25									
16:30	0.105	3	25		0.105	3	25		0.105	3	25	
17:00	0.105	3	25									
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
21:30												
21:45												
Qref	5.845				11.655				19.070			

	XXL				3XL				4XL			
	Qtap	f	Tm	Tp	Qtap	f	Tm	Tp	Qtap	f	Tm	Tp
h	kWh	l/mn	ºC	ºC	kWh	l/mn	ºC	ºC	kWh	l/mn	ºC	ºC
7:00	0.105	3	25		11.2	48	40		22.4	96	40	
7:05												
7:15	1.820	6	40									
7:26	0.105	3	25									
7:03												
7:45	6.240	16	10	40								
8:01	0.105	3	25		5.04	24	25		10.08	48	25	
8:05												
8:15	0.105	3	25									
8:25												
8:03	0.105	3	25									
8:45	0.105	3	25									
9:00	0.105	3	25		1.68	24	25		3.36	48	25	
9:30	0.105	3	25									
10:00	0.105	3	25									
10:30	0.105	3	10	40	0.84	24	10	40	1.68	48	10	40
11:00	0.105	3	25									
11:30	0.105	3	25									
11:45	0.105	3	25		1.68	24	25		3.36	48	25	
12:00												
12:30												
12:45	0.735	4	10	55	2.52	32	10	55	5.04	64	10	55
14:30	0.105	3	25									
15:00	0.105	3	25									
15:30	0.105	3	25		2.52	24	25		5.04	48	25	
16:00	0.105	3	25									
16:30	0.105	3	25									
17:00	0.105	3	25									
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	
21:30												
21:45												
Qref	24.53				46.76				93.52			