Heat Pump Water Heaters:

Summary and Comparison of International Test Standards

June 2013

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Summary

The heat pump is one of the most energy efficient technologies for heating water for household use. Energy efficiency is a key point in product advertising and marketing, and important for the policymakers who manage energy labelling and minimum energy performance standards (MEPS) programs.

There are major differences between the existing test standards (also called 'test procedures' or 'test methods') for heat pump water heaters. As a result, manufacturers have to undertake different tests for each economy where they sell their products. This inhibits trade, adds to product cost and slows the development of the global heat pump water heater market.

This project analyses current standards and test methods, with the aim of developing proposals for internationally-comparable energy efficiency test methods, metrics and efficiency classes for use in future efficiency policy measures.

The project is being undertaken in the following stages:

1. A survey and analysis of existing test standards for heat pump water heaters;
2. Preparation of a draft Interim Report on the above, for a workshop discussion with international technical experts, which took place in Beijing in April 2013;
3. Finalisation of the Interim Report following comments;
4. Development of guidelines for internationally-comparable test methods;
5. Dissemination of the project findings and deliverables through targeted mailings and an international workshop to be held in Coimbra, Portugal on 10th September 2013.[1]

The present document is the Final Interim Report under Task 3 above.
It summarises the main elements of the existing test standards, presents conclusions regarding the standards and makes recommendations for the general direction of the next phase of the project.

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[1] The meeting is to be held in association with the 7th International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL); see http://www.eedal-2013.eu/?q=node/28

Selected terminology and definitions

Add-on	See *stand-alone*
All-in-one	See *unitary*
Auxiliary heating	A secondary source of water heating in a heat pump water heater (e.g. a resistance element)
COP	Coefficient of performance: thermal energy imparted to hot water (or delivered by the water heater) divided by electricity supplied to the water heater, under specified conditions. COP is calculated in different ways in different test standards.
DB	Dry bulb (temperature)
Domestic hot water	Water heated for the purpose of household washing, bathing and cooking
Draw-off	A withdrawal of hot water from the tank during testing or actual use (may be specified in either volumetric or energy units)
EF	Energy Factor (in USA and Canada tests) – equivalent to *COP*
Europe	The countries which are members of the European Union *or* the countries whose standards bodies are members of the European Committee for Standardization (CEN)[2]
HPWH	Heat pump water heater
Humidity	A measure of the moisture content in the air. Humidity is commonly specified as relative humidity, or as a combination of DB and WB temperatures.
Hybrid heat pump	A heat pump water heater with auxiliary heating
Integral	A model where the heat pump, in-tank heat exchanger and storage tank are designed to work together and to be sold together, even if the parts can be separated.
MEPS	Minimum Energy Performance Standard
Model	A design that is manufactured in multiple *units*, every one of which has (or is intended to have) the same energy efficiency and operating characteristics
RH	Relative humidity – a measure of moisture content in the air relative to the maximum moisture carrying capacity at the specified DB temperature
Sanitary water	See *domestic hot water*
SCOP	*Seasonal COP*: A weighted average of COP values to reflect the energy efficiency of a water heater over a typical operating year
Split	A complete HPWH system with tank, where the components are not all housed in the same cabinet
Stand-alone	HPWH compressor unit sold without a storage tank
Standby energy	Energy used when compressor is not running (eg for controls, pumps etc). compensate for standing heat loss
Standing heat loss	Energy lost from hot water during periods when there is no draw-off (as distinct from the energy consumed to compensate for this energy loss).
Static operation	Energy used by compressor during non-draw periods to compensate for standing heat loss
Tapping	See *draw-off*
Unit	A single specimen of a model
Unitary	A HPWH with the compressor, evaporator, condenser and water tank housed in the one cabinet or assembly
WB	Wet bulb (temperature)

[2] Members of CEN are: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland*, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway*, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland*and United Kingdom. (*these countries are not members of the EU).

1 Overview of the Project

This project was commissioned by the Collaborative Labelling and Appliance Standards Program (CLASP), the Australian Department of Climate Change and Energy Efficiency (DCCEE), the Korea Testing Laboratory (KTL) and the International Copper Association (ICA), on behalf of the Asia-Pacific Economic Cooperation (APEC) Collaborative Assessment of Standards and Testing Methods (CAST) initiative and the Super-efficient Equipment and Appliance Deployment (SEAD) Initiative of the Clean Energy Ministerial.

It is being undertaken by George Wilkenfeld & Associates, Energy Efficient Strategies and Thermal Design (Australia) and Waide Strategic Efficiency (United Kingdom).

Its objectives are to analyse current standards and test methods to evaluate the energy efficiency of heat pump water heaters and to prepare proposals for internationally-comparable energy efficiency test methods, metrics and efficiency levels, for use in future efficiency policy measures.

1.1 Background

Heat pump technology is a far more energy efficient way to use electricity to heat water than traditional electric resistance technology. Heat pump water heaters collect energy from the ambient air, water or the ground, and transfer it to water in an insulated storage vessel. The electricity is used in the motor that drives the refrigeration compressor (although some units also have backup resistance elements for periods of high hot water demand or when the external conditions make normal heat pump operation difficult).

In principle, the technology is the same as that used in mainstream refrigeration and air conditioning equipment, although the operating conditions are somewhat different. This report is concerned with HPWHs that collect energy from the ambient air, since these are the types which are most commonly traded internationally.

While heat pump water heaters have been available for several decades, they are becoming more popular as buyers increasingly factor energy efficiency into purchasing decisions, due to rising electricity prices and awareness of the need to reduce greenhouse gas emissions from energy use.

Heat pump water heaters – and their components – are manufactured in many countries and are widely traded internationally. The most complex elements are the compressors and their controllers. These may be purchased by local assemblers, who add the cabinet, evaporator, condenser, expansion valve, heat transfer fluid, hot water storage tank and regulation system that make up a complete heat pump water heater.

Complete refrigeration units (which look like the outdoor units of split air conditioning systems) are also widely traded. Local suppliers may sell these with hot water storage tanks to make a complete water heater, or sometimes sell refrigeration units on their own for connection to existing water heaters. Complete ‘unitary’ or ‘all-in-one’ systems, where the refrigeration unit and the water heaters are housed in the one factory-built assembly, are also widely traded.

In practice there are many ways to design and assemble HPWHs, with different refrigerant fluids (e.g. R134a, R410a, R744/CO_2), operating pressures, heat exchanger characteristics, water storage volumes, heat losses and control strategies. The choice of refrigerant fluid determines the design of most of the other components, so this is a primary design decision.

The energy efficiency in operation will depend on how these complex design factors interact with:

- The usage patterns – the amount of hot water drawn off daily, and the interval between draw-offs, which is important because heat pumps can have a lower reheating rate than electric resistance elements under certain conditions;
- The climatic conditions – some designs and some refrigerants operate better at different ambient temperatures and at different humidity conditions. HPWHs are likely to be at their lowest efficiency in the coldest season, when the total hot water demand may be at its peak;
- The presence of frost and the means for dealing with it – frost build-up on the evaporator surfaces (which collect energy from the ambient air) inhibits air flow and heat transfer, so units designed to operate under conditions of low temperature and high humidity must employ de-icing strategies such as the use of resistance elements, reversal of the refrigerant flow or the hot water flow, all of which carry an energy penalty; and
- The energisation profile – some designs can operate satisfactorily under tariffs where the hours of supply are restricted, while others require continuous supply.

Energy-efficiency is not the only requirement of HPWHs. They must also give a satisfactory supply of hot water without the user having to wait an unacceptable time for reheats between draw-offs, and they need to be durable and quiet. Some designs trade off energy efficiency for functionality, e.g. by relying excessively on resistance element boosting.

The energy-efficiency advantage of HPWHs over other forms of water heating is their main selling point, so manufacturers have an incentive to claim the highest possible level of efficiency (usually expressed in terms of ‘Coefficient of Performance’, or COP). Several economies have developed tests to measure the COP, so that manufacturers can report values on a consistent basis and their claims can be independently verified. Some of the test standards incorporate other tests such as noise and the ability to deliver specified volumes of hot water over specified periods.

The present study has identified six (6) national standards as well as the European standard. Two of these (Canada and the USA) are virtually identical, but the rest – Australia/New Zealand, China, Japan and Korea (draft) – differ so much that the results reported under one standard give little indication of the efficiency of the same water heater tested under a different standard.

This makes it very difficult for regulators in different economies, and almost impossible for buyers, to compare performance claims made for products tested to different standards. Without internationally comparable test methods, the consequences are that:

- HPWHs will have to be tested under the methods of test in use in every economy to which they are exported; or

- Potential buyers will be confused by different efficiency and performance claims made under different test methods and at different operating conditions.

Either outcome would inhibit trade, add to product cost and act as a constraint on the development of the global heat pump water heater market. It will also inhibit the development and marketing of highly efficient products.

The ideal way to avoid this would be to adopt a single common method of test. In June 2013, TC86/SC6 of the International Standards Organisation (ISO) agreed in principle to develop a new test standard for heat pump water heaters.[3] However, this will take some time to develop, given the need to address different climate zones, levels of hot water use and draw-off patterns. Furthermore there is no guarantee that an ISO test, whenever finalised, would be adopted in all the countries which have pre-existing test standards, so the problem of multiple test standards may persist for some time.

Based on previous experience, the most promising and achievable objective in the medium term would be to work towards an internationally *consistent* approach to HPWH testing. The foundation of this would be a common method of testing for basic performance, e.g. the COP to heat up water from cold, under one or more standard ambient conditions in the laboratory.

The data from these physical tests could possibly be used on their own to indicate product COP under a limited range of conditions. Alternatively, a specified subset of physical parameters could be accepted as the basis for performance modelling and simulation under conditions not actually tested in the laboratory.

This would enable economies to use the common physical test results to determine (or at least approximate) a model's performance under local conditions anywhere in the world. At the least, this would enable COP values to be reported to a common metric in each market, for energy labelling purposes. Ideally the method would also be sufficiently reliable so regulators could use it to assess whether a model meets MEPS, in economies where MEPS are in force.

Intending exporters and local regulators could determine the energy rating of products in each market using the simulation model accepted in that market, without conducting additional physical tests.

It is likely that physical tests alone will not deliver sufficient information to allow comparison of products under normal conditions of use in different regions, and that that some modelling or computer simulation will also be necessary. While modelling involves some complexities, the principles of HPWHs operation are well understood (with the exception of the control strategies, which appear to vary substantially amongst manufacturers). A number of sophisticated models exist that could be used to form the basis of an accurate and internationally agreed approach to performance simulation.

Additional levels of convergence would be achieved if:

- a single simulation model or approach were accepted in all markets; and

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[3] ISO TC86/*SC6 Testing and Rating of Air-Conditioners and Heat Pumps* agreed at its meeting on 14 June 2013 to develop a test standard for air source heat pump water heaters. The scope of the standard is currently being determined – whether to cover the domestic water heating task only or the possibility of a space heating task as well (see Section 2.2.1 *Duty and Capacity* in the present report),

- there were agreed thresholds and classifications for levels of energy–efficiency (eg COPs under defined conditions that might be accepted for MEPS, and COPs that define 'higher-efficiency' product).

The development of a roadmap to these objectives relies on a detailed understanding of the current methods of physical HPWH testing and simulation currently in use, planned or advocated, of the differences between them and of their potential points of convergence. This is the objective of the present study.

1.2 Project Stages

This project is being undertaken in the following stages:

1. A survey and systematic analysis of existing test standards for heat pump water heaters;
2. Preparation of a draft Interim Report on the above,
3. Presentation of the draft Interim Report to a Workshop of invited experts and stakeholders in Beijing, China on 12th April 2013 in association with the 41st meeting of the APEC Expert Group on Energy Efficiency and Conservation (EGEEC);
4. Completion of the Interim Report after comments (the present report);
5. Development of guidelines for internationally-comparable test methods and efficiency class definitions for heat pump water heaters, that take into account variations in climate, draw-off patterns and other factors, and which can be considered by policy makers and efficiency program developers in setting MEPS and categorical or endorsement labels; and
6. Dissemination of the project findings and deliverables through targeted mailings and an international workshop to be held in Coimbra, Portugal on 10th September 2013.[4]

For stage 5, this project is drawing on the data from a series of physical tests on heat pump water heaters being undertaken by the Korea Testing Laboratory (KTL). The project implementers are grateful to KTL for their kind assistance and cooperation for this project.

1.3 Interim Report

The present document is the Interim Report under Task 4 above. It summarises the main elements of the existing test standards, using a consistent evaluation framework developed for this project.

Part 2 of this report analyses the existing HPWH test standards in detail.

Part 3 presents our conclusions regarding the standards and makes recommendations for the general direction of the next phase of the project. It also poses a number of questions to stakeholders, on which responses were invited up to the end of May 2013.

Appendix A summarises the main aspects of each existing test standard. Appendix B has some details of the KTL testing programme. [continues]

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[4] The meeting is to be held in association with the 7th International Conference on Energy Efficiency in Domestic Applians and Lighting (EEDAL); see http://www.eedal-2013.eu/?q=node/28

2 Analysis of Test Standards

2.1 Coefficient of Performance (COP) - the Key Metric

The key energy efficiency advantage of heat pump water heaters (HPWHs) is their ability to transfer more energy to the hot water than the amount of electricity they consume, because some of the energy is extracted from the ambient heat source (usually air, water or the ground).

The energy imparted to the water divided by the electrical energy consumed is generally called the Coefficient of Performance (COP) or the Energy Factor (EF).[5] For water heaters both COP and EF are dimension-less quantities, because the numerator and the denominator are calculated in energy units.

Conventional electric resistance water heaters cannot by definition have a COP over 1.0, because all of the heat imparted to the hot water comes from an electric resistance element. A well-designed HPWH should have a COP significantly higher than 1.0. However, HPWHs are relatively complex systems, so testing and predicting their performance is not straightforward. The overall energy efficiency can vary with the following:

- the local climate where it is installed;
- the temperature of the cold water supplied to the HPWH and of the hot water produced;
- the performance of the heat pump/heat transfer system (compressor, evaporator, condenser and other components);
- the heat loss of the storage tank;
- the quantity of hot water drawn off each day;
- the quantity and duration of each draw and the time intervals between draws;
- the thermostat settings and the control strategy; and
- the energisation profile, e.g. whether the heat pump can run at any time or whether it cannot run at certain times due to a restricted (off-peak) tariff.

The same HPWH can give very different COP values according to how it is tested and how the results are calculated from the measurements. Some test standards only measure the COP during the period when the unit first heats the water from cold, some take into account the COP during a series of physical draw-off and reheating cycles, and some take into account the energy used to maintain the hot water at storage temperature during periods when no hot water is being drawn off.

Therefore the COP values reported under one test procedure cannot be directly compared with those reported under another. A further complication is that some methods report COPs under the tested physical conditions only, while others report a 'seasonal' value that is weighted according to how performance is expected to change over the year, as ambient conditions and inlet cold water temperatures vary. This weighted value is often called the 'Seasonal COP' (SCOP) value.

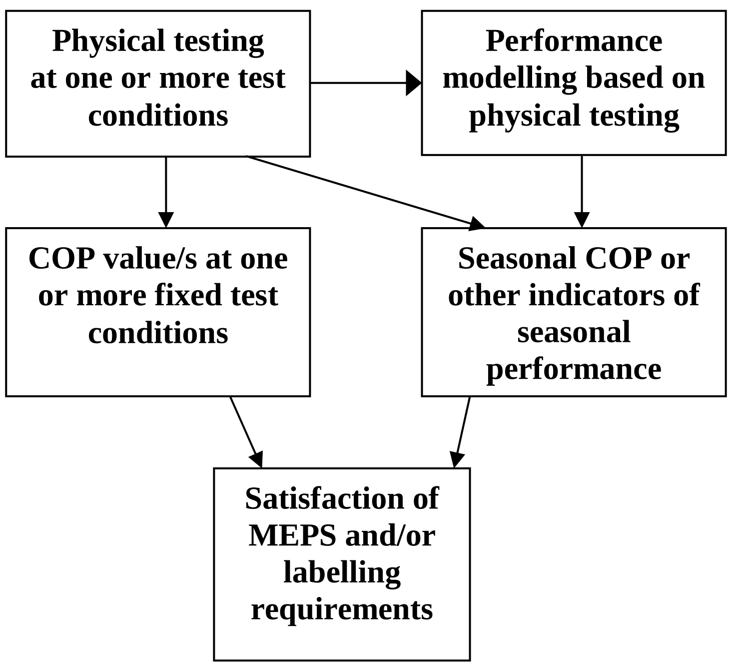
[5] COP can be measured over different time scales – instantaneously during the heating process, during the entire cycle of heating water from cold to hot, or over a longer period during which hot water is drawn off and more cold water is heated. The term EF usually means the last of these cases.

There are currently two main approaches to determining the performance of HPWHs (see Figure 1):

1. Using physical testing alone to establish the main performance characteristics of a unit, either in order to report them (whether in a test report only or on an energy label) or to check whether they meet a given minimum energy performance standard (MEPS); and
2. Using physical testing to determine the key performance characteristics of a unit so that computer modelling is possible for a wide range of usage patterns and operating conditions. The modelling results are then reported and used to give the unit its energy rating and to check whether it meets MEPS.

At present the only known use of the second approach in public policy is the Australian and New Zealand (AS/NZS) standards, where the results of the physical tests described in AS/NZS 5125 are used to model seasonal performance using the procedure in AS/NZS 4234. The other standards reviewed in this report all derive COP or SCOP values from physical tests alone.

Figure 1 Typology of HPWH test standards



The COP values determined by testing may be used by the manufacturer or distributor to advertise the product, to demonstrate that it meets minimum legislated levels of efficiency or to demonstrate that it meets certain qualifications, such as the right to be labelled ‘Energy Star’ compliant or to qualify for financial rebates. In all cases, suppliers have a strong commercial incentive to claim the highest possible COP or SCOP values for their products.

Where manufacturers have to undertake tests using different standards so they can export a particular model to different countries, it is common for the most favourable of the COP values obtained to be reported in advertising, unless there is a legal requirement in the importing economy that all COPs have to be reported to a specified test standard or condition.

Table 1 gives an overview of the HPWH test standards in use and under development (that were identified for the present project) and the programs and purposes for which they are currently used. The details of each test standard are set out in Appendix A.[6]

Table 1 Overview of standards, MEPS and labelling for heat pump water heaters

Country/Economy Test Standard (a)	**Physical testing**	**Derivation of COP/SCOP**	**Requirements in standard itself (g)**	**Requirements outside standard (h)**
Australia & New Zealand (b)	No draw-off (e)	Seasonal Performance modelled (but not reported as SCOP)	Proposed - MEPS, labelling standard under development	Voluntary – eligibility under Renewable Electricity Act
Canada (c)	Draw-off	EF calculated	Proposed – will impact HPWHs from April 2015	Voluntary – Energy Star endorsement energy label
China	No draw-off	COP calculated	Yes	No known program for HPWHs
Europe (b)	Draw-off	COP calculated	No	Voluntary – Top Ten endorsement Proposed – mandatory energy labelling and MEPS
Japan	Draw-off	SCOP calculated	No	TopRunner standards
Korea (d)	No draw-off	COP calculated	No	No known program for HPWHs
USA (c)	Draw-off	EF calculated	Proposed – will impact HPWHs from April 2015	Mandatory – EnergyGuide label Voluntary – Energy Star endorsement energy label

(a) See detailed descriptions in Appendix A. (b) Standard officially applies to two or more economies. (c) Separate standards but essentially the same test (d) In draft – not yet published. (e) No draw-off during testing. Load patterns are simulated in seasonal performance modelling. A revision of the test standard is under way. It is planned to include draw-off tests for the purpose of determining minimum energy performance (MEPS) levels. (g) Where energy labelling and/or MEPS are included in the standard itself, so that products failing to meet those requirements are considered non-compliant with the standard. (h) Where laws or regulations state that a product must be tested using a given standard, but any MEPS and/or labelling requirements are in the regulations, and so can be altered without changing the test standard.

[6] The Thailand building regulations specify that heat pump water heaters installed in new buldings of greater than 2,000m^2 (including condominiums) shall have a minimum COP of either 3.5 (if the hot water delivery temperature is 50°C) or 3.0 (if the hot waer deoliver temperature is 60°C). The cold water supply and air temperature are boith stated to be 30°C, but no other details of the test are given (Thailand 2009).

2.2 Test Standard Parameters

2.2.1 Product Classification and Configuration

The HPWHs within the scope of this project are those in which the vapour compression cycle is driven by an electric motor-powered compressor. Any refrigerant fluid may be used (although China Standard GB/T 23137–2008 has special construction requirements for CO_2 units due to their high operating pressures). While all the standards under consideration agree on this point, they define and classify products according to different criteria. The following is a preliminary list.

Heat source

- Ambient air source – either non-ducted (ie free air flow around the evaporator) or ducted (where the evaporator is installed inside a building – see EN16147)
- Ambient water source
- Ambient earth source (usually transferred to the heat pump via a liquid circulated through pipes buried or drilled into the ground)
- Waste heat from an industrial or space heating process.

Configuration

- Unitary (refrigeration unit and water storage tank in the one cabinet)
- Split – heat pump connected to tank by refrigerant lines, condenser inside water tank
- Split – heat pump connected to tank by water lines, condenser housed in same cabinet as evaporator. This configuration may be designed as
    - single pass ('one time') – water heated to desired temperature in one pass; and
    - multi-pass ('circulated') – water heated to desired temperature in stages.

Duty and Capacity

The aspect of HPWHs that is the subject of this project is the capacity to provide 'domestic' or 'sanitary' hot water, i.e. water at the temperatures and in the quantities needed for the typical washing, bathing and cooking needs of a single household.

Some HPWHs may be defined as 'commercial' in that they can provide larger quantities of hot water or at a higher temperature. However, the criteria are not always clear. China Standard GB/T 21362–2008 defines a 'Commercial & Industrial' HPWH as one with 'nominal heating capacity of 3000W and above'. Many HPWHs sold to the residential market have a far greater heating capacity. Furthermore, some domestic HPWHs can be easily adapted for commercial use by adding multiple storage tanks.

Some HPWHs are also designed to provide hot water for space heating purposes (under-floor coils or radiators) as well as sanitary hot water. European Standard EN 16147:2001 states that:

> Testing procedures for simultaneous operation for domestic hot water production and space heating are not treated in this standard. In this standard the basis of the measurements are the daily EU-Reference-Tapping-Cycles defined in the mandate

M/324. Presently there is no standard fixed for daily cycles for the space heating mode.

Auxiliary Heat Source

Some HPWHs have an auxiliary heat source, usually an electric resistance element, which can supplement the vapour compression cycle for periods of high hot water demand or take over the heating task entirely if the vapour compression cycle is unable to operate (e.g. under frost or very low external temperature conditions).

The operation of the auxiliary heater may be automatic or consumer-activated. For user-selectable heat sources, the setting for the tests is not always clear. For example, it may be possible to switch the element on for the tests of hot water delivery and reheat times, but switch it off for the tests of energy-efficiency. While this would be misleading, not all test standards explicitly prevent this.

'Smart' Controls

Water heaters are now being designed with control logic that can adapt the operation of the water heater to the pattern of household hot water use. For example, if the controller observes that hot water demand is concentrated at a certain time of day it can adapt reheat times to minimise heat loss or to make use of cheaper electricity rates (assuming that there is a capability for the water heater to have tariff times programmed into it, or to monitor them in real time).

The proposed European regulations for the energy labelling of water heaters (including HPWHs) allows models with 'smart controls' to obtain a rating one grade higher than would be indicated by energy efficiency alone (EC 2013). It defines 'smart control' as 'a device that automatically adapts the water heating process to individual usage conditions with the aim of reducing energy consumption'.[7]

While 'smart' controls may enable a water heater to reheat at times when electricity tariffs are lower use, and so reduce running costs, they complicate energy efficiency testing because the water heater may behave differently after 'learning' the draw-off patterns used in the first stages of a test (see Appendix A6).

Impact of Configurations

The way in which HPWHs are defined varies significantly between standards (see Table 2). This means that products which are grouped together for testing under one standard may need to be separately tested under a second standard, because of some design difference that may not even be defined under the first standard. Furthermore, some product types may not even be testable under other standards - because there is no provision for them. For example, the European Standard EN16147 does not appear to provide for the testing of a unitary HPWH designed to be installed outside, whereas this product type common in Australia.[8]

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[7] Some new water heaters have the capability to change their mode of operation (ie to turn off, reduce load or turn on) in response to signals sent from the utility or other 'remote agent'. This is a separate capability that does not impact on energy consumption or energy-efficiency.

[8] The test conditions in Table 5 of EN16147 specify 20ºC ambient temperature for the storage tank but 7ºC 'outside air'. These conditions can only be maintained if the units are separated.

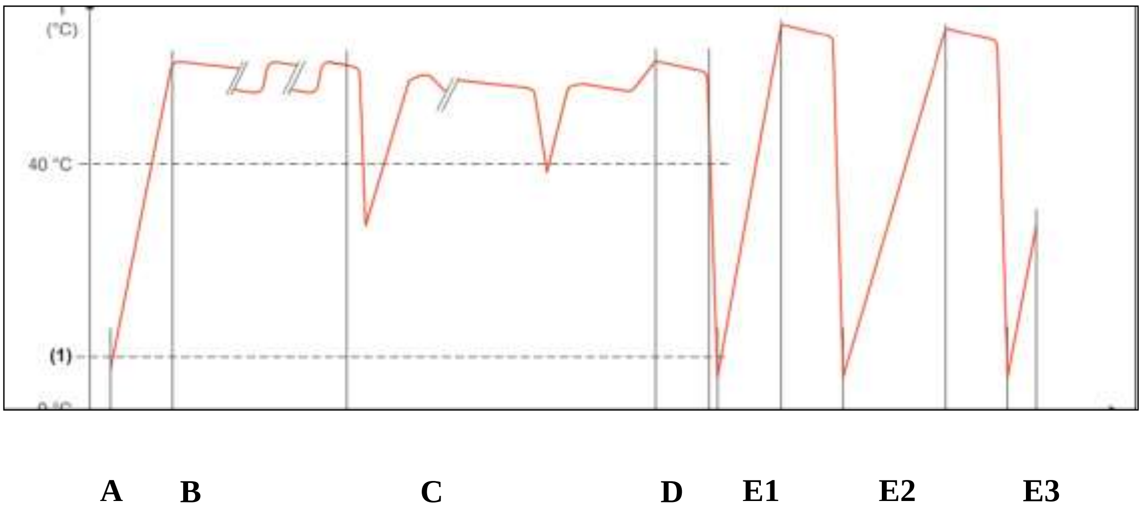
2.2.2 Physical Energy Performance Testing

The number, type and settings of physical tests to be performed may depend on the HPWH's heat source, configuration, duty and capacity, and whether it has an auxiliary heat source. The most detailed physical energy tests involve all of the following stages (illustrated as a sequence in Figure 2, adapted from EN16147):

A. heating up period
B. determination of 'standby' (or 'static operation') energy to compensate for heat loss while the hot water is untapped
C. hot water 'tapping' or draw-off sequence
D. maximum quantity of water that can be drawn off at a usable temperature
E. tests to determine useful ambient energy operating range.

Not all test standards include all of these stages, and some also include other (non-energy) performance and safety tests and requirements. Some standards include multiple sequences of energy tests under different operating conditions, including conditions which induce frosting on the evaporator (see Table 3).

Figure 2 Typical stages in HPWH testing



Ambient temperature and humidity

The temperature and humidity at the evaporator is one of the main determinants of the performance of an air-source HPWH, because the evaporator collects the heat from the ambient air and transfers it into water. The less heat in the ambient air, the harder it is to concentrate. Some HPWH designs and some refrigerant fluids will operate well at low ambient temperatures, while others operate better at higher temperatures.

Humidity is also a major factor. At higher temperatures, humidity assists the performance of a heat pump by transferring latent heat to the evaporator. If cold air temperature is accompanied by high humidity the evaporator surfaces can 'frost' or ice up. The ice will form an insulating barrier that inhibits heat transfer and air flow. At high humidity (90% or more), frosting begins to appear at 1ºC to 2ºC ambient air temperature. Modelling performance at these conditions is not usually possible, as a number of non-linear effects come into play, so physical tests under frosting conditions are usually necessary if the product is intended for use in these conditions.

Every test standard specifies the ambient temperature and humidity for at least one test condition (the humidity condition may be expressed as either Relative Humidity or Wet Bulb temperature, but these are interchangeable). The more conditions at which a HPWH is tested, the greater the confidence that it will perform well under different climate conditions in use.

Of the existing HPWH test procedures analysed, the Australian/New Zealand standard has the greatest number of test conditions, specifying four mandatory test conditions and one additional 'low temperature' test for products that the manufacturer claims are 'suitable for low ambient temperature operation without auxiliary boosting'. The Chinese standard uses up to four conditions. The Canadian, USA and European standards each use a single test condition.

There is some indication that a single test condition may not be sufficient to indicate the performance of heat pumps which may be sold across a wide geographical area. The Northwest Energy Efficiency Alliance (NEEA) in the USA has published a supplementary test (at an ambient of 50°F or 10°C) for HPWHs intended for sale in that region (NEEA 2011). For the purposes of its proposed energy labelling program, the European Commission has added two extra test conditions to the single test in EN16147 (EC 20913).[9]

Instrumentation and Heat-up

It is relatively easy to measure the amount of electricity supplied to a HPWH over a given time the period, but more difficult to measure the amount of energy effectively transferred to the water, and of this how much is available for drawing off as hot water and how much is lost. If more measuring instruments are used, measurement tolerances are tightened and/or the frequency of readings is increased, then it is possible to gain a better understanding of how energy flows through the water heater, and it becomes easier to replicate the test results.

Table 3 shows that the Australian and New Zealand, Canadian and USA test standards require 6 sensors to be inserted into the tank at precise locations, while the Chinese and European test standards do not specify a number or a location, making repeatability more difficult. The Japanese and (draft) Korean test standards focus on measurement of the water temperatures at the inlet and outlet of the water heater during draw-offs.

Most HPWHs have a variable thermostat that determines the temperature at which heating stops. The Australian and New Zealand standard specifies that HPWHs be tested at the maximum setting, whereas the other standards specify a fixed temperature – as low as 50°C in the Korean test (unless the manufacturer states otherwise) to 65°C for CO_2 refrigerant units in the Chinese test, and more than 65°C in the Japanese test. In the European standard, temperature is set according to the manufacturer's instructions.

Tapping

The tapping or draw-off schedules represent a major difference between tests (see Table 4). The range is from no tapping at all (China and Korea), one draw repeated 6 times (Canada

[9] It is understood that EN16147 will be revised to match the EC 2013 Ecodesign Regulation.

and USA), and multiple combinations of tapping schedules and ambient conditions (Japan and Europe). The present versions of Australian and New Zealand standards do not use a physical tapping load, but account for tapping in seasonal modelling.

Some standards specify a single flow rate for all tappings, while others apply lower flow rates to smaller-volume draws and a higher flow rate to higher-volume draws. The flow rate for tapping can have a significant impact on performance, because high flow rates will cause the water in the tank to mix or 'de-stratify', so the temperature of water drawn off at the top will be lower.

The inclusion of a tapping load in a standard can have several objectives:

- to collect data on how the water heater responds to a typical draw, so that this can be used in further calculations or modelling;
- to test the extremes of performance (eg how much hot water it can deliver in a single draw and how quickly it can recover to a useful temperature); and
- to simulate performance in actual use.

As household hot water use is highly variable, there is no guarantee that any given tapping pattern (or pattens) will be statistically representative of actual use in a given population of households even in the one country, let alone between countries.

Heat loss and Standby

The in-use energy efficiency of a HPWH depends on its ability to retain heat as well as to heat water from cold. Some test procedures measure the energy required to maintain the stored water at the maximum temperature when there is no draw-off. This is influenced by both the heat loss of the tank and the energy-efficiency of the heat pump at what is usually its least efficient operating point.[10] The Australian and New Zealand test does not determine heat loss in this way, but cross-refers to a separate standing heat loss test (AS/NZS 4692.1).

2.2.3 Other Requirements

A HPWH may be energy-efficient but may reheat very slowly, so determining its delivery capability is important. The quantity of hot water which a HPWH can supply over a given time period depends on both its storage volume and the rate at which it reheats.

Draw-off tests can measure delivery capability directly, and can also account for temperature drop by discarding hot water when it falls below a specified temperature (which differs between tests). The Australian and New Zealand standard cannot directly test delivery, but the simulation based on the test results does model when the flow would drop below specified limits.

The Chinese, European and Japanese standards include further requirements, beyond those strictly related to performance and energy efficiency. These include:

[10] The terms 'standby', 'static operation' and 'standing heat loss' are used to mean different things in different standards, and not always clearly defined.

- Testing the air-tightness of the refrigeration system using a leak detector;
- Pressure-testing the water tank (both static and pulse pressure tests);
- Noise testing in an anechoic chamber;
- Testing the durability of the packaging;
- Water contamination;
- Corrosion resistance to salt spray;
- Durability of the external finish; and
- Safety (electrical safety, flammability etc.).

Finally, a number of standards include requirements for permanently marking products with key design and performance characteristics.

Table 2 Terminology for product configurations

	Configuration	**Australia & NZ** AS/NZS5125	**USA** CFR430	**Canada** CSA-C745-03	**China** GB/T23137/21362	**Europe** EN16147	**Japan** JISC9220-2011	**Korea** Draft (KSB ****)
1	HP and tank in same casing (a) – location of installation not specified	Integral	Heat pump water heater with storage tank – integral	Not directly defined, but test accommodates	Packaged type	ND	Single package	Single package
2	HP and tank in same casing – indoor tank location	ND	ND	ND	ND	Factory-made units which can be ducted on airside	ND	ND
3	HP and tank separate but supplied together – linked by water lines	ND	Heat pump water heater with storage tank – separated	ND	Split type	ND		Split type
4	HP and tank separate but supplied together – linked by refrigerant lines	Integral ('condenser integral to tank')	Heat pump water heater with storage tank – separated	ND	Split type	Split Heat Pump – outdoor heat exchange	Split	Split
5	HP sold separately – may be linked to any storage tank by water lines	Stand-alone heat pump	HPWH without storage tank (also called 'Add-on')	Not directly defined, but test accommodates	Not directly defined, but test accommodates	ND	Split	Split
6	Recirculating stand-alone heat pump	Requires recirc-ulation to reach final storage temp.	ND	ND	Circulated heating HPWH	ND		ND
7	Once-through stand-alone heat pump	Delivers water at final storage temp in one pass	ND	ND	One-time heating HPWH	ND		ND
8	Static heating HPWH	ND, but probably all of types 1-5	ND, but probably all of types 1-5	ND, but probably all of types 1-5	Water flows past heat exchanger by natural convection	ND		ND
9	Off-peak product	ND	ND	ND	ND	Meets tapping pattern between 0700 and 2200 without external energy supply	Meets tapping pattern between 0700 and 2200 without external energy supply	ND
10	Ability to heat water for hydronic space heating	No	No	No	No	Possible but only domestic hot water production tested	ND	Possible but only domestic hot water production tested
11	Special configurations or designations	Suitable for low ambient temperature without boosting	ND	ND	ND	With 'smart control' to adapt to individual usage conditions	With 'Intermediate holding tank' for bath recirculation	ND

ND = Not specifically defined in this standard, but not necessarily excluded. (a) Refrigerant condenser may be in or on the tank, or there may be separated by water circulation lines but within the same casing.

Table 3 Summary of Test Conditions for Heat Pump Water Heater Test Methods

Parameters	**Australia & NZ** AS/NZS5125	**USA** CFR430	**Canada** CSA-C745-03	**China** GB/T23137/21362	**Europe** EN16147	**Japan** JISC9220-2011	**Korea** Draft (KS B ****)
Scope (brief)	Heat pump (air source)	Electric storage 76L to 454L, Heat pump to 24A single phase 250V	Electric storage 76L to 454L, Heat pump to 24A single phase 250V	23137 – domestic 21362 – comm./ind Air and water source	Heat Pump – air water or brine source, domestic HW only	Household air source heat pump (HFC or CO_2) with tank	Air source heat pumps for hot water and space heating, with or W/O tank
Test Chamber	Wooden platform and walls	Wooden platform and walls	Wooden platform and walls	Not stated	Avoid direct radiation	Insulated chamber (calorimeter)	Insulated chamber (calorimeter)
Ambient Air Test Conditions (TC)	TC1 <10°C TC1 80% to 90% RH TC2 18°C to 20°C TC2 60% to 70% RH TC3 30°C to 35°C TC3 30% to 40% RH TC4 30°C to 35°C TC4 55% to 65% RH Low temperature (LT) for products claimed suitable for low temperatures 0°C to 2°C, RH >= 90%	19.7°C ±0.5°C (67.5°F) 49% to 51% RH	19.7°C ±0.5°C (67.5°F) 49% to 51% RH	Nominal 20°C ±.0.5°C ** WB 15°C (RH 59% @ 20°C) Maximum DB 43°C WB 26°C Auto-defrost DB 2°C WB 1°C Low temperature DB -7°C WB -8°C Variable	Evaporator 7°C WB 6°C (RH 86.8%) Tank (indoor) 20°C	TC1 (mid season) DB 16°C ± 1K WB 12°C ± 0.5K TC2 (summer) DB 25°C ± 1K WB 21°C ± 0.5K TC3 (winter) DB 7°C ± 1K WB 6°C ± 0.5K	Standard DB 7°C WB 6°C Severe Cold Zone DB -15°C WB NS
Air flow	0.25 to 0.5 m/s	Not stated	Not stated	< 0.5 m/s	< 1.5 m/s	Not stated	ISO5151 Annex A/C/D
Cold Water Supply	TC1, LT <10°C TC2 <15°C TC3, TC4 <25°C	14.4°C±1°C (58°F)	14.4°C±1°C (58°F)	15°C ±.0.5°C Nom 29°C Max 9°C Others	10°C ±0.20K	TC1 17°C ± 2K TC2 24°C ± 2K TC3 9°C ± 2K	Low 15°C±0.15 K Midum 30°C±0.15 K High 40°C±0.15 K
Control Setting	Maximum	57.3°C ±3K (135°F ±5°F)	57.3°C ±3K (135°F ±5°F)	55°C ±0.5°C	Nominally 55°C (temperature rise 45K)	Normal ≤65°C (Winter hot >65°C) (Sanitary = max)	Manufacturer's instructions (nominal 50°C)
Water Pressure	Not specified	275kPa to rated	275kPa to rated	Not specified	Not specified		≤ 343 kPa
Installation	Manufacturer's instructions. Piping be as short as practicable (where	Installed in accordance with manufacturer's instructions.	Installed in accordance with manufacturer's instructions.	Installed in accordance with manufacturer's instructions.	Installed in accordance with manufacturer's instructions	Installed in accordance with manufacturer's instructions.	Installed in accordance with manufacturer's instructions.

Parameters	**Australia & NZ** AS/NZS5125	**USA** CFR430	**Canada** CSA-C745-03	**China** GB/T23137/21362	**Europe** EN16147	**Japan** JISC9220-2011	**Korea** Draft (KS B ****)
	applicable)				(excluding optional accessories).		
Tanks Sensors	6 equal volumes	6 equal volumes	6 equal volumes	Not specified	Not specified #	Inlet and outlet only #	Inlet and outlet only
Daily Drawoff Volume	None (heat up only)	243.4L	243.4L	None (heat up only)	5 from S=36L to XXL=420L ***	Standard 455.7 L (40°C) Small 278.0 L (40°C)	None
Daily Drawoff Pattern	No physical tests (a) seasonal modelling	6 × 40.6L at 1h	6 × 40.6L at 1h	None	Complex (24 hour) (11 to 30)	Complex (24 hour) (51 and 31)	None
Drawoff energy	No physical tests – seasonal modelling	43.7 MJ	43.7 MJ	Not applicable	7.5MJ to 87.9MJ	See separate table	Not applicable
Drawoff Flow rate	Not applicable	11.4 L/min	11.4 L/min	Not applicable	4 or 10 L/min	5 or 10 L/min	Not applicable
Heat Loss	AS/NZS4692.1	Standby part of test	Standby part of test	Test Method for Thermal Insulation Performance (heat and cool down)	Not directly measured, but included in standby power input	To be confirmed	Not directly measured
Performance tests included	Low ambient temperature performance	First hour rating (volume for temperature drop of 13.9K) Volume	First hour rating (volume for temperature drop of 13.9K) Volume	Max operating Auto-defrost Min operating Low temperature Design and construction Noise Volume for 10K drop	Heat up test Standby power (heat loss) Max temp and hot water delivery (40°C) Operating range Safety	Safety Various performance Design and construction	Safety Material Structure Performance for Space heating Performance for sanitary water supply Seasonal COP Noise
Test Point Period	Consists of the period of time where the mass weighted average tank temperature changes by 5 K to 5.5 K	Water draw off with normal water heater operation until the heat source cuts in, stop the draw and wait until the maximum mean tank temperature is achieved					

NS = not specified. # In some cases, sensors are located at 40mm spacing to calculate residual heat. (a) A revision of the test standard is under way. It is planned to include draw-off tests for the purpose of determining minimum energy performance (MEPS) levels.

Some of these heat pump test methods appear to draw on air conditioner test methods such as ISO5151. Some specify a calorimeter for testing. The air temperatures are similar to some air conditioner temperatures (eg GB/T (China) and USA ambient conditions are similar to ISO5151 indoor heating (and outdoor minimum cooling), EN (Europe) and JIS are the same as ISO5151 H1 outdoor heating conditions, Korea Low temperature and Cold Zone ambient temperatures for space heating tests are the same as ISO5151 outdoor heating conditions (H2 and H3 respectively).

** Under GB/T23137 heat pump water heaters with CO_2 refrigerant have different operating conditions as follows:

- Inlet water 17°C ±1K
- Outlet water 65°C ±2K
- Air dry bulb 16°C ±1K, air web bulb 12°C ±0.5K (RH=62.8%)
- Additional safety and construction requirements are included.

*** In EN16147, there are several drawoff patterns (called tappings) as follows:

- There are about 10 different drawoff event types specified, each with its own energy drawoff and flowrate (4 or 10 L/s)
- There are 5 drawoff patters described: Small, Medium, Large, X Large and XX Large made up of standard events
- Small – 11 events, 2.1 kWh (7.56 MJ), nominally 36 litres at 60°C equivalent
- Medium – 23 events, 5.845 kWh (21 MJ), nominally 100.2 litres at 60°C equivalent
- Large – 24 events, 11.655 kWh (41.96 MJ), nominally 199.8 litres at 60°C equivalent
- X Large – 30 events, 19.07 kWh (68.65 MJ), nominally 325 litres at 60°C equivalent
- XX Large – 30 events, 24.53 kWh (88.31 MJ), nominally 420 litres at 60°C equivalent
- For many of the event types, volume delivered is not counted until a specified temperature rise is reached.

For JIS C 9220-2011, there is a series of complex drawoff patterns as follows:

- Hot water delivery temperatures are specified as 40°C -2K +0K (even though storage temperature is higher)
- There are 4 different drawoff types: wash basin, kitchen, bath, shower.
- Flow rates for wash basin and kitchen is 5L/min. Flow rates for bath are 10-15L/min and shower is 10L/min.
- Wash basin and kitchen events are generally less than 5L, a few to 25L, shower 20L or 50L, bath 180L
- Standard household and Small household profiles are specified by 3 seasons
- Standard winter - 51 events, 16.276 kWh (58.594 MJ), nominally 455.74 litres at 40°C equivalent (cold water 9°C)
- Standard intermediate - 51 events, 12.076 kWh (43.473 MJ), nominally 455.74 litres at 40°C equivalent (cold water 17°C)
- Standard summer - 51 events, 8.401 kWh (30.242 MJ), nominally 455.74 litres at 40°C equivalent (cold water 24°C)
- Small winter - 31 events, 9.927 kWh (35.737 MJ), nominally 277.96 litres at 40°C equivalent (cold water 9°C)
- Small intermediate - 31 events, 7.365 kWh (26.515 MJ), nominally 277.96 litres at 40°C equivalent (cold water 17°C)
- Small summer - 31 events, 5.124 kWh (18.445 MJ), nominally 277.96 litres at 40°C equivalent (cold water 24°C)
- Some systems have a heat exchange facility that allows reheating of bath water – for these types, some heat exchange load is added onto the based events specified.

Korean standard has additional outdoor conditions for testing for space heating to evaluate SCOP (seasonal coefficient of performance):

- Standard DB 7°C and WB 6°C, hot water inlet 40°C (loop), outlet 45°C (same as hot water production except 15°C inlet, 50°C outlet).
- Low temperature DB 2°C and WB 1°C, hot water inlet 40°C (loop), outlet 45°C.
- Cold Zone DB -7°C and WB -8°C, hot water inlet 40°C (loop), outlet 45°C.
- Severe Cold Zone DB -15°C and WB N/S, hot water inlet 40°C (loop), outlet 45°C (same as hot water production except 50°C outlet (inlet temperature under consideration)).

Table 4 Draw-off schedules

Standard	Number of schedules, names	Number of Draws	Daily load KWh/day in hot water	Daily load MJ/day in hot water	Average MJ/draw	Annual load GJ/yr in hot water	Supply temp limits (below which draw discarded)
Australia & NZ AS/NZS 5125:2011	N/A (a)	N/A	N/A	N/A	N/A	Modelled	N/A
AS/NZS 4234	1	8	6.25 to 15.8 varies with season	22.5 to 57 peak winter, varies with season	Varies with season	Modelled	45°C
Canada CSA C745-03:2003	1	6	12.1	43.7	7.28	15.95	
China GB/T 23137–2008	N/A	N/A	N/A	N/A	N/A		N/A
China GB/T 21362–2008	N/A	N/A	N/A	N/A	N/A		N/A
Europe EN 16147:2011	S	11	2.10	7.56	0.69	2.76	N/A
	M	23	5.85	21.15	0.92	7.72	N/A
	L	24	11.66	41.95	1.75	15.31	N/A
	XL	30	19.07	68.65	2.29	25.06	N/A
	XXL	30	24.53	87.55	2.92	31.96	N/A
Japan JIS C 9220:2011	Std Winter	51 (56) *	16.276	58.594 (62.714)	1.149	Complex seasonal calculation interpolating measured values and specified days at 1K temperature increments	40°C
	Std Intermediate	51 (56) *	12.076	43.473 (46.533)	0.852		
	Std Summer	51 (56) *	8.401	30.242 (32.103)	0.593		
	Small Winter	31 (34) *	9.927	35.737 (37.471)	1.153		
	Small Intermediate	31 (34) *	7.365	26.515 (27.799)	0.855		
	Small Summer	31 (34) *	5.124	18.445 (19.221)	0.595		
Republic of Korea Under development	N/A	N/A	N/A	N/A	N/A		N/A
USA CFR-430	1	6	12.1	43.7	7.28	15.95	Draw terminates when temp falls by 13.9°C from nominal storage temp of 57.2°C (ie to 43.3°C)

* JIS C9220-2011 specifies some additional events associated with a heat exchange facility to reheat bath water. These events and the energy associated with them have been included in the total values shown in brackets. (a) A revision of the test standard is under way. It is planned to include draw-off tests for the purpose of determining minimum energy performance (MEPS) levels.

2.3 Use of Test Data

The energy efficiency metrics (COP, SCOP, EF) derived from the test standards are used in a number of ways to promote greater energy efficiency in heat pump water heating in different countries:

- Minimum energy performance standards (MEPS) included in the test standard itself. This means that a product cannot comply with the standard unless it meets those MEPS levels. The Chinese test standard is an example of this.

- Legally binding MEPS levels imposed by legislation that refers to a specific test standard. The proposed European Directive on *ecodesign requirements for water heaters and hot water storage tanks* (EC 2012) is an example of this.

- Mandatory energy labelling that refers to a specific test standard (e.g. the European *eocdesign requirements* and the US EnergyGuide label).

- Voluntary endorsement and/or labelling regimes, where participation is not legally required but has a high commercial value to product suppliers. Examples include the Energy Star labelling program in the USA, the Japanese TopRunner program and the Australian Renewable Energy Target.

As these programs are likely to drive the use of HPWH standards in future (see Table 1), they are described in the following sections. Apart from these national and international programs, many other schemes, such as energy utility rebates for the purchase of higher-efficiency heat pumps or building code requirements, also refer to the standards, either directly or indirectly (e.g. by limiting eligibility to products that meet voluntary endorsement criteria).

2.3.1 Australia and New Zealand

The Australian and New Zealand Standard AS/NZS 5125 determines COPs for HPWHs as they heat up under 5 separate test conditions. The COPs are not published on their own, but the test results are used as inputs for the modelling procedure described in AS/NZS 4234. This determines the annual electricity use of the HPWH under a range of usage and climate conditions and compares it with the notional electricity use of an electric resistance water heater performing the same water heating task.

The output value is expressed in terms of '% electricity saved' compared with the notional electric water heater, even though it could just as easily be expressed as a SCOP value. The standards have evolved to support the Federal Government's Mandatory Renewable Energy Target, which requires a certain percentage of electricity supplied to be generated from eligible renewable energy sources. HPWHs and solar-electric water heaters are declared eligible to contribute to this requirement, and the '% of electricity saved' is treated as if it were generated from a zero-emissions source.

Only models which achieve a threshold level of '% electricity saved' are eligible to benefit from the scheme. The value of the benefit is around $1,000 AUD per unit sold, so although participation is voluntary nearly all suppliers have registered their models because of the commercial advantage of doing so.

Australia and New Zealand are currently considering introducing mandatory energy labelling and MEPS for HPWHs. AS/NZS 5125 is being revised so that it can produce explicit COP values which will determine whether a model complies with the mandatory MEPS levels. These levels are to be determined after a cost-benefit analysis.

2.3.2 Canada and United States

The Canadian standard and the near-identical US test (which is published as a Federal Regulation rather than a standard) determine Energy Factors for HPWHs. At present these standards specify a minimum EF of:

0.97 - (0.00132 x Rated Storage Volume in gallons)

A 55 US gallon (208.2 litre) water heater, for example, would have to meet an EF of 0.897, which would be within the reach of a well-insulated electricity resistance storage water heater. Under CFR430 however, from 16 April 2015 electric water heaters with a Rated Storage Volume of 55 gallons or more will have to meet a minimum EF of:

2.057 – (0.00113 x Rated Storage Volume in gallons)

A 55 US gallon water heater would have to meet an EF of 1.995, which is only achievable by a HPWH. Therefore this will become the effective MEPS level for larger HPWHs, although HPWHs smaller than this will only have to meet an EF of:

0.96 - (0.0003 x Rated Storage Volume in gallons)

This means a 50 gallon HPWH would have to meet an EF of 0.945, which is not particularly challenging for a heat pump, and may in fact be achievable by a highly insulated electric storage water heater.

These are minimum efficiency levels only. The Energy Star criterion for heat pump water heaters is an EF of 2.0 or higher (EPA 2009). It is not known whether this will be revised once the MEPS levels in the US standards are raised.

2.3.3 China

The Chinese test standard GB/T23137-2008 specifies that the measured COP of air source heat pump water heaters under nominal operating conditions should be not less than 3.70 for products using ‘one time heating’ and ‘circulated heating,’ and not less than 3.40 for products using ‘static heating’ (see definitions Table 2). The tested value should be not less than 90% of the value reported by the manufacturer.

Heat pump water heaters are not currently required to be energy labelled under the China Energy Label (http://www.energylabel.gov.cn/en/index.html).

2.3.4 Europe

The standard EN16147 specifies the tests for determining COP and other aspects of performance, but does not specify minimum values for these. It does specify that if the manufacturer decides to provide information about the performance of a model it must be with reference to one of the standard draw-off schedules.

The European TopTen scheme, which is supported by agencies of the European Commission, awards 'TopTen' designation to HPWHs which achieve a COP of at least 2.3 when tested to EN16147.[11]

The Ecoredesign Directive currently before the European Commission specifies a staged implementation of ecodesign requirements for MEPS and maximum sound power level for *combination* heat pumps (ie those capable of space heating as well as water heating), but not yet for heat pump water heaters only (EC 2012a). However, a Regulation Supplementing Directive 2010/30/EU currently before the European Commission specifies the energy labelling of water heaters, including HPWHs (EC 2013).[12]

The water heater label includes the energy rating on a scale of A to G, or A+ to F. This indicates the 'water heating efficiency class' of the water heater on the declared load profile. The range of test conditions includes those on EN16147 (see Table 4) but does not actually refer to it, and adds additional test conditions beyond those in the standard:

- Two additional temperature test conditions in addition to the one in Table 3 (which the Directive calls 'average climate conditions'): 'colder climate conditions' (2°C DB/1°C WB) and 'warmer climate conditions' (14°C DB/13°C WB); and
- Three additional load profiles smaller than S (these are called XXXS, XXS and XS).

The larger the load profile, the higher the energy factor that a model must achieve to attain a given rating. The A+ to A+++ classes can only be reached by water heaters using renewable energy sources (ie either HP or solar water heaters). The energy efficiency classes above A are defined such that the classes A+/A++/A+++ correspond to a contribution of 35 %/50 %/60 % of renewable energy sources to energy consumption, compared with energy efficiency class A.

Table 5 Proposed European water heating efficiency classes of packaged water heater under average climate conditions

	G	F	E	D	C	B	A	A+	A++	A+++
M	<27 %	>=27 %	>=30 %	>=33 %	>=36 %	>=39 %	>=65 %	>=100 %	>=130 %	>=163 %
L	<27 %	>=27 %	>=30 %	>=34 %	>=37 %	>=50 %	>=75 %	>=115 %	>=150 %	>=188 %
XL	<27 %	>=27 %	>=30 %	>=35 %	>=38 %	>=55 %	>=80 %	>=123 %	>=160 %	>=200 %
XXL	<28 %	>=28 %	>=32 %	>=36 %	>=40 %	>=60 %	>=85 %	>=131 %	>=170 %	>=213 %

Source : EC (2013)

[11] http://www.topten.eu/english/criteria/selection_criteria_electric_water_heaters.html&fromid=
[12] It is understood that it is to be voted on during March 2013

The HPWH energy label will also have the following information:

- A pictogram indicating the load profile on which the HPWH was tested (e.g. a single tap for a low load, a series of taps, showers and a bath for a large load);
- The noise levels (in dB) both internally and externally;
- The annual energy consumption (in both kWh/annum and GJ/annum) for each of the average, warmer and colder climate conditions (calculated in accordance with the Directive);
- A map of Europe indicating the colder, average and warmer climate zones; and
- An indication whether the HPWH is suited to operate with off peak tariffs.

2.3.5 Japan

The Japan TopRunner Program covers a wide range of products, including heat pump water heaters.[13] The program sets standards based on the best available models currently on the market, with the intention that all models must meet those levels of energy efficiency within 5 years. For HPWHs, the criteria are based on JIS 9220 (see Appendix A). The efficiency levels to be reached in 2017 are indicated in Table 6.

Table 6 Japan Top Runner target HPWH COP values for 2017

	Normal size household	Small size household
Normal climate	3.0	2.8
Cold climate	2.6	2.4

Source: METI (2012). Values above are for models with a single storage tank of <= 240 litres and no 'heat exchange' function. Other target values apply to other configurations

2.3.6 Korea

At present it does not appear that heat pump water heaters are subject to energy labelling or MEPS in Korea. It is possible this may change once the current draft test standard is completed.

[13] http://www.eccj.or.jp/top_runner/pdf/tr_heat_pump_sep2012.pdf

3. Conclusions

3.1 Comparison of Test Standards

There are many similarities between the methods of test used to determine the energy efficiency and performance of heat pump water heaters. All of them require a climate-conditioned test laboratory, and specify the ambient conditions of temperature and humidity to be maintained throughout the test. All of them involve heating the water from ‘cold’ to ‘hot’, and measuring both the electrical energy consumed by the heat pump water heater and the thermal energy added to the water.

However, the similarities end there. The testing methods are significantly different with regard to:

- The categorisation of products by types, capacities and characteristics for the purpose of selecting the range of tests to be performed;
- The precise ambient conditions to be maintained in the test room and the variability limits permitted;
- The temperature of the inlet water and the variability limits permitted;
- The draw-off patterns;
- The methods of measuring and recording the temperature and heat content of the water in the storage tank (or in some cases, the outlet water only); and
- Whether the test covers performance during heatup only, or during physical tapping and standing heat loss as well.

The way in which the data collected during physical testing is used to calculate COP, SCOP or EF values also differs significantly.

As a result of these differences, even an experienced person analysing the test results for a heat pump water heater under one method of test would have great difficulty in predicting the results that it would give under a different method of test (other than the Canadian and USA tests, which are essentially identical).

At present, it is not possible that any existing test method, other than the one specified for the purpose, can be used to demonstrate that a heat pump water heater complies with the MEPS, energy label ratings or other energy efficiency programs of a different country.

There is no single ‘best’ test method – all have their advantages and disadvantages. Some are more reproducible, in that a test in a different laboratory is more likely to get the same results. Others are better able to simulate the way that water heaters are actually used, both on a daily basis (with draw-offs) and in different climate zones. The performance of heat pump water heaters is particularly sensitive to ambient conditions, so test standards which cover more conditions are likely to replicate actual use better – but the tests are more expensive to carry out.

However, even highly detailed draw-off tests covering different daily loads and sequences do not necessarily replicate the hot water use of all households. Research on hot water use generally indicates that it is highly variable from one household to another, and in the same household over time. There is no standard draw-off sequence that could reliably represent hot water use in all economies, or even one economy for that matter.

At the same time, all hot water use is similar in that it consists of sequences of draws at irregular intervals and of different volumes and flow rates. Therefore measuring how a water heater performs over one sequence of tasks may allow its performance at other tasks or other ambient conditions to be calculated or modelled.

3.2 Proposed Approach to Harmonisation

Given the extent of the differences, it is not considered likely that the standards bodies and energy program regulators in different countries would agree to adopting a common standard, without a gradual process of confidence-building and harmonisation.

3.2.1 Direct comparison of physical tests

The first step is to identify the aspects of each test standard which lead to variations in the outcomes. The most efficient way to do this is to select a group of water heaters, conduct each method of test on them and compare the results. This has already commenced (see Appendix B).

To ensure the maximum level of data collection during this process, the highest level of instrumentation and frequency of readings should be used in all the tests.

3.2.3 Modelling and Simulation

One possible path to harmonisation is the use of a limited number of physical tests to collect sufficient data to characterize the HPWH’s attributes, so they can then be used in computer simulation to model performance under any ambient conditions and draw-off patterns – including those in the existing test standards.

This approach has already been used in Australia and New Zealand. The physical characteristics of the HPWH are measured using the test standard AS/NZS 5125:2010 *Heat Pump Water Heaters – Performance Assessment*, which has no draw-off tests. The annual energy use is then modelled, using a computer simulation program which meets the criteria in AS/NZS 4234:2008 *Heated water systems - calculation of energy consumption*. The best known of these programs is TRNSYS, although others may be used.[14]

One drawback of TRNSYS is that some of the information required for modelling (e.g. control strategy information) cannot be obtained simply by inspecting the product in the test laboratory, and must be requested from the product’s manufacturer. This raises a

[14] TRaNsient SYstem Simulation (TRNSYS) is a public domain model originally developed by the University of Wisconsin. It is an algebraic and differential equation solver typically used to simulate performance of energy systems including water heaters, heating ventilation and cooling systems and renewable energy systems.

number of serious issues for check tests, especially those done outside the economy of manufacture:

- It can introduce delays in contacting the manufacturer, requesting and obtaining the necessary information;
- The manufacturer may choose to withhold the information in order to delay the testing process; and
- It has been found that the information provide (eg on control settings) is sometimes inconsistent with the observed behaviour of the unit in the laboratory.

The most effective way to avoid these problems is to devise a method of simulation that relies solely on the aspects of design than can be observed or measured in the test laboratory without having to contact or refer to the manufacturer at all.

Such simulation methods could be used in the following ways:

1. The heat pump water heater is installed in a conditioned environment and the energy use is monitored while it heats water from cold to cut-out (with no drawoff).
2. The tank is monitored while allowed to cool down, without reheating (to calculate heat loss rate). The heatup test should be done for number of conditions (at least two, maybe four). The cool down test would only need to be done at one condition.
3. The product parameters are entered into a spreadsheet model (not TRNSYS, and not requiring any additonal data about the heat pump's refrigeration system or control strategy). This is used to model energy use - either for the standard drawoff regimes included in all HPWH standards now in use, or for any specified drawoff regime - and to produce seasonal COP values under any climate and usage profile.
4. The tester then does a physical drawoff test to replicate some or all of the drawoff regime/s modelled, and if the physical test results are consistent with the modelled results (within an allowable variance), the unit COP and SCOP values are considered to be validated for the conditions covered.

As performance under frosting conditions is nearly impossible to model, there will probably have to be a separate physical test for units intended for use in frost-prone climates.

This approach would have to exclude conditions where the heat pump supplies a space heating load as well as a domestic hot water load, since it is very difficult to standardise the magnitude of a combined load, or how it would vary in actual use (e.g. it may be better to switch off the HPWH altogether over summer and get the domestic hot water either by a resistance element or some other way - or switch the water loop so it bypasses the space heating load heat exchangers, in which case it becomes a pure domestic water heater).

3.2.2 Selected Common Test Conditions

Ideally, each economy should be able to take the results from any of the existing HPWH tests and use the simulation model to produce the results they would give if physically tested to their own standard. However, this is not likely to be realised if the modelling can only use values measurable in any competent test laboratory (ie without getting information from the manufacturer).

It is likely that agreement on a common set of basic test conditions would be required. These would be similar (but not identical) to the most common test conditions currently in use (see Table 3):

- A low-temperature test condition of 7°C DB/6°C WB – this is already included in the European, Japan and Korea (draft) standards, and would be consistent with one of the conditions in the AS/NZS standard (<10°C);
- A water temperature of 10°C for the above test;
- A warm-temperature test condition of 20°C DB/19°C WB – this is already included in the USA, Canada, and China tests, and would be consistent with one of the conditions in the AS/NZS standard (18-20°C);
- A water temperature of 15°C for the above test;
- For models designated as suitable for use in frost conditions, a test at 2°C DB/1°C WB.

No draw-off test would be necessary at these test conditions – only a heat-up test and either a static operation test (in which the compressor is allowed to run to cover heat loss from the tank) or a cool-down test (in which the compressor is switched off and the tank allowed to cool).

Each of the existing test standards already incorporates at least one of the above test conditions (or one very close to it) so only one other would have to be added. The proposed tests could be added to each existing test standard as an optional appendix, so only those manufacturers who wished to take advantage of international agreements which might streamline their trade would need to use it.

If this approach were followed, one way of building global confidence in it would be to adopt it as a screening test in the first instance. A manufacturer exporting to another economy could offer the results of the basic physical tests as a means of demonstrating compliance with the necessary requirements. If a subsequent check test using the standard of the importing economy found that a unit matched the performance which had been determined under the modelling (within stated variances) then the original result would be validated.

If the check test found that the unit did not match the claimed performance, there may be two reasons for this:

- The unit performed differently under the basic physical tests than claimed by the supplier. These tests could then be repeated to see if this is cause of the inconsistency, and if so it could be due to some manufacturing variance or fault, which the supplier could address; or

- The unit performs as claimed on the basic physical test. If so, and the modelling method was correctly applied, it must have failed to account for some aspect of the unit's performance, and so was invalid in this case. The manufacturer should then be given the option of undertaking a full test to the standard of the importing economy, to adjust the performance claims accordingly and, if necessary remove the product from that market if it fails to meet the local MEPS.

3.3 Next Steps in this Project

This project is being given access to the data from a series of tests being conducted by Korea Testing Laboratory (KTL). These are described in Appendix B. Preliminary results were presented at the first project Workshop, held in Beijing on 12th April 2013. The final results only just become available at the time of writing this Final Interim Report, and will be fully analysed in the Final Project Report[15]

After the publication of this Final Interim Report the project will proceed in the following stages:

1. The project team will assess the potential for a model that could reasonably approximate the performance of the tested water heaters using the test data from any test standard.

2. The project team will develop *guidelines* for internationally-comparable test methods that can be considered by policy makers and efficiency program developers, for use in setting MEPS and categorical or endorsement labels (it is beyond the scope of the project to fully develop such a test method).

3. The project team will prepare a final report that will be disseminated though targeted mailings and an international workshop to be held in Coimbra, Portugal on 10th September 2013.[16]

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[15] As some of the final test resuls are significantly different from the preliminary results presented at the Beijing workshop, the preliminary data and analyses have not been published in a permanent form.
[16] The meeting is to be held in association with the 7th International Conference on Energy Efficiency in Domestic Applians and Lighting (EEDAL); see http://www.eedal-2013.eu/?q=node/28

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TopTen *Selection Criteria Electric Water Heaters* (Europe) http://www.topten.eu/english/criteria/selection_criteria_electric_water_heaters.html&fromid=

Appendix A: Summary of key test standards

A1 List of Standards

Australia & New Zealand

AS/NZS 5125.1:2010 *Heat Pump Water Heaters – Performance Assessment*
AS/NZS 4234:2008 *Heated water systems - calculation of energy consumption*
AS/NZS 4692.1:2005 *Electric water heaters - energy consumption, performance and general requirements*

Canada

CAN/CSA C745-03:2003 *Energy efficiency of electric storage tank water heaters and heat pump water heaters-Third edition Update No1: 3/2005*

China

GB/T 23137–2008, *Heat Pump Water Heater for Household and Similar Uses*
GB/T 21362–2008, *Heat Pump Water Heater for Commercial & Industrial and Similar Uses*

Europe

EN 16147:2011 *Heat pumps with electrically driven compressors - Testing and requirements for marking of domestic hot water units*

Japan

JIS C 9220:2011 *Residential Heat Pump Water Heaters*

Korea

Currently developing a standard *Air source heat pump water heater for residential buildings*, to be published mid 2013.

USA

US Code of Federal Regulations Title 10, Part 430, Appendix E to Subpart B (CFR 430)
file:///C:/Documents%20and%20Settings/GLW/My%20Documents/Winword/WORK/VARIOUS/CLASP%20HP%202012/10CFR430.htm#10_CFR_430pSUBPART_B_APPENDIX_E

Air-conditioning, Heating and Refrigeration Institute (AHRI) 2013 Standard for performance rating of commercial heat pump water heaters (Draft AHRI Standard 1300) (I-P)
http://energystar.gov/products/specs/sites/products/files/AHRI%20Standard%201300.pdf

IEC

IEC60379:1987 *Methods For Measuring The Performance Of Electric Storage Water-Heaters For Household Purposes* http://www.iec-standard.com/1333.html

A2 Australia and New Zealand

Standard Reference: AS/NZS 5125
Standard Name: Heat Pump Water Heaters – Performance Assessment. Part 1: Air Source Heat Pump Water Heaters.
Standard Publisher: Standards Australia and Standards New Zealand (joint standard)
Programs or mandatory measures using this standard: Voluntary testing of the performance of electric heat pump water heaters as part of the Small-scale Renewable Energy Scheme (SRES).

Website: http://infostore.saiglobal.com/store/Details.aspx?ProductID=1444316

Related Standards:
ASNZS4692.1 Electric water heaters Part 1: Energy, consumption, performance and general requirements (heat loss only)
AS4234 Heated water systems: Calculation of energy consumption (output from AS/NZS5125 is used to calculate annual energy consumption in different climates)

Scope

This Standard specifies the test conditions and test procedures for determining the energy performance characteristics of single-circuit air source heat pump water heaters. It applies to both stand-alone heat pump water heaters and heat pumps with the condenser integral with a storage tank.

Summary of Test Procedure

The heat pump water heater is installed in accordance with manufacturer's instructions in an ambient controlled test room. The tank is filled with cold water that is less than the specified temperature for the test condition. The system is then started and allowed to operate normally until the maximum temperature is reached. This test is repeated at 3 ambient temperature conditions and two humidity levels for the warmest temperature condition (total of 4 test conditions).

Data is collected throughout the test period. Data is analysed to give the operating Coefficient of Performance (COP) for a wide range of operating conditions during the heat up phase. The test does not include any specified drawoff patterns. The data collected is then used to calculate the annual energy performance for any desired operating conditions and drawoff profile as specified in AS/NZS4234.

Test Conditions and Procedures

The heat pump is tested at four different air temperature and humidity test conditions:

Test Condition	Air Temperature	Relative Humidity
1	<10°C	80% to 90%
2	18°C to 20°C	60% to 70%
3	30°C to 35 °C	30% to 40%
4	30°C to 35°C	55% to 65%

The water temperature for each test condition is:

Test condition	Water temperature at start of test	Water temperature at end of test
1	<10°C	Maximum heat pump operating temperature
2	<15°C	Maximum heat pump operating temperature
3	<25°C	Maximum heat pump operating temperature
4	<25°C	Maximum heat pump operating temperature

The equipment shall be installed in accordance with the manufacturer's installation instructions. Piping between stand alone heat pumps and the storage tank should be as short as practicable and be insulated in accordance with the manufacturer's recommendations.

The detailed test procedure and instrument requirements are set out in Appendix A of ASNZS 5125.1:2010.

The tank is divided into 6 or more equal volume segments by virtual horizontal planes. A minimum of six tank temperature sensors shall be inserted into the storage tank. Temperature measurement sensors shall be installed inside the water heater tank such that each temperature sensor is positioned at the centroid of each of the six or more equal volume segments within the tank.

In the case of a horizontal cylinder, the sensor heights are specified as follows (where D is the internal tank diameter):

Sensor	Height of sensor
Top	0.86D
2	0.70D
3	0.57D
4	0.43D
5	0.30D
6	0.14D

For stand alone heat pumps (without an integral tank), temperature sensors shall be inserted into the supply and return lines within 300 mm of the heat pump fittings. The storage tank of a stand alone heat pump (without an integral tank) shall be mixed during testing.

If frosting of the evaporator is observed during a test, the test shall be repeated at a higher air temperature with the specified relative humidity until operating without frosting is achieved. Only data where no frosting occurs will be considered.

During the heat pump operation, one minute averages of the following variables shall be determined by recording each variable at a minimum rate of ten readings per minute:

- Air dry bulb temperature
- Air wet bulb temperature or relative humidity
- Tank core temperatures

- Water inlet temperature to the heat pump (stand alone units only)
- Water outlet temperature of the heat pump (stand alone units only)
- Electrical power input to the heat pump
- Electrical power input to the condenser water circulation pump where such a pump is separate from the heat pump

A test point period is a sequence of *N* one minute average records during which the average tank water temperature changes by 5 K to 5.5 K. A moving average 5 K interval may be used to generate a sequence of partially over lapping test points. The set of test point periods used for the *COP* and *Power* correlation shall satisfy the following distribution of test point periods:

- At least one test point period with an average tank water temperature within 5 K of the start and stop test temperatures specified
- At least three test point periods in each 10 K band in the range of the start and stop temperatures specified
- The overlap of the average tank water temperature for successive test point periods shall be less than 3 K.

The calculated values of *COP* and measured values of *Power* for all test point periods for all air test conditions shall be correlated using least squares regression of the specified non-linear functions or multiple linear regression.

COP and *Power* shall be calculated for each test point period and the standard deviation of the test data shall be determined from the calculated data.

Heat pumps are assessed for their suitability to operate in low ambient temperature conditions and are classified according to performance.

A3 Canada

Standard Reference: CSA C745-03
Standard Name: Energy Efficiency of Electric Storage Tank Water Heaters and Heat Pump Water Heaters
Standard Publisher: Canadian Standards Association
Programs or mandatory measures using this standard: Mandatory labelling and minimum energy performance standards (MEPS) for electric water heaters

Website: http://shop.csa.ca/en/canada/energy-efficiency/cancsa-c745-03-r2009/invt/27019982003/

Scope

1.1 This Standard specifies the methods for determining the energy factor for electric storage tank water heaters and heat pump water heaters.

1.2 This Standard establishes minimum energy efficiency levels for electric storage tank water heaters and heat pump water heaters.

1.3 This Standard applies to a) electric storage tank water heaters i) with volumes of 76 to 454 L (20 to 120 US gal); ii) having electric heater elements with power inputs up to 12 kW; and iii) designed to heat and store water at a thermostatically controlled temperature equal to or less than 82 ºC (180ºF); and b) heat pump water heaters that have i) a maximum current rating of 24 A; ii) a single-phase maximum voltage of 250 V; and iii) ancillary equipment necessary for the device to function.

1.4 This Standard does not apply to high-temperature water heaters.

1.5 The tests contained in this Standard are not intended to represent actual efficiencies realized in the field. Instead, these tests provide a standardized method of comparing performance.

1.6 This Standard is written in SI units. The values given in parentheses are for information only. The SI values have been calculated from the US Customary Units measurements found in the US Department of Energy publication 10 CFR, Part 430, appendix E, subpart B.

Summary of Test Procedure

With respect to the requirements for heat pump water heaters, the Canadian and US standards are essentially equivalent, so refer to US section above for details. CSA C745-03 is written and set out like a normal test procedure so is easier to follow and interpret than the US requirements.

A4 P.R. China

Standard Reference: GB/T23137-2008
Standard Name: Heat Pump Water Heater for Household and Similar Uses
Standard Reference: GB/T21362-2008
Standard Name: Heat Pump Water Heater for Commercial & Industrial and Similar Uses

Standard Publisher: National Standards of the People's Republic of China. General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China Standardization Administration of the People's Republic of China
Programs or mandatory measures using this standard: MEPS for heat pump water heaters

Scope of GB/T23137-2008 (Household)

The Standard stipulates the terms and definitions, product classification, technical requirements, test methods, inspections rules, marking, packaging, transportation, storage, etc. of the heat pump water heater for household and similar uses.

The Standard applies to heat pump water heaters for household and similar uses that are driven by the electric motor, employ the vapour compression refrigeration cycle, use air or water as the heat source and whose objective is to provide hot water. That said, this standard can still be used as a reference for heat pump water heaters of other heat sources or uses. This standard does not apply to industrial heat pump water heaters (covered by GBT21362-2008).

Summary of Test Procedure

The test method is a comprehensive standard for the design, construction and performance of heat pump water heaters. External references are made to the relevant safety standards. It also specifies specific performance measures for most parameters and has efficiency requirements included in the standard. So it covers all aspects of energy and performance as well as regulatory requirements.

The energy related tests are broken into two main parts:

1/ Energy efficiency (Clause 5.5 Performance Requirements for Heat Pump Water Heater under Nominal Operating Conditions)

- Heat Pump Heating Capacity
- Hot Water Production Capacity
- Heat Pump Heating Power Consumption
- Coefficient of Performance (COP)

The COP test does not have any drawoff pattern and effectively measures the energy to heat a tank of cold water under specified conditions (overall average value only). Some of the tests involve whole tank discharge and recovery. There are a number of test types due to the large number of types and configurations covered by the standard.

2/ Hot Water Storage Performance (Clause 5.7)

- Thermal Insulation Performance (cool down test)
- Usage Performance (hot water delivery type test)
- Water Storage Tank Capacity (volume of the storage vessel)

The standard sets performance requirements for a wide range of parameters including energy efficiency and hot water storage. There are many requirements in addition to those that cover energy related aspects.

Test Conditions and Procedures

The test operating conditions for air source heat pump water heaters are given below:

Item	Water Side		Air Side	
	Inlet Water Temperature °C	Outlet Water Temperature °C	Dry Bulb Temperature °C	Wet Bulb Temperature °C
Nominal Operating Conditions	15	55	20	15
Maximum Operating Conditions	29	55	43	26
Auto-Defrost Operating Conditions	9	55	2	1
Minimum Operating Conditions	9	55	7	6
Low Temperature Operating Conditions	9	55	-7	-8
Variable Operating Conditions	6-35	55	-7~43	-

Note: Energy performance requirements are measured under normal operating conditions above. Other conditions are specified for a range of additional performance tests. There are special conditions if CO_2 is used as a refrigerant.

The test operating conditions for water source heat pump water heaters are below:

Item	**Water Side**		**Heat Source Side**		
	Inlet Water Temperature °C	Outlet Water Temperature °C	Inlet/Outlet Water Temperature °C		
			Water Loop	Groundwater	Under-ground loop
Nominal Operating Conditions	15	55	20	15	10
Maximum Operating Conditions	29	55	30	25	25
Minimum Operating Conditions	9	55	15	10	10
Low Temperature Operating Conditions	9	55	20	15	10
Variable Operating Conditions	6~36	55	15~30	10~25	5~25

Note: Energy performance requirements are measured under normal operating conditions above. Other conditions are specified for a range of additional performance tests.

The heat pump portion of the heat pump water heater should satisfy the requirements of GB4706.32 (safety). The water heating portion should satisfy the requirements of GB4706.11 or GB4706.12 (safety).

When testing, the measured heat pumping heating capacity should not be smaller than 95% of the nominal value for heat pump heating capacity.

When testing, the measured hot water production capacity shall not be smaller then 95% of the nominal value for hot water production capacity.

When testing, the measured heat pump heating power consumption should not be larger than 110% of the nominal heat pump heating power consumption.

When testing, the measured water storage tank capacity shall not be smaller than 92% of the nominal value.

The measured COP of the heat pump water heater under nominal operating conditions should not be lower than the value stipulated in the table below. It should also not be lower than 90% of the expressed value from the manufacturer.

Heat Source Type / Heating Method	Air Source	Water Source		
		Water Loop	Groundwater	Underground Loop
One Time Heating and Circulated Heating	3.70	4.20	4.00	3.80
Static Heating	3.40	3.70	3.50	3.20

The hot water storage performance is given in the table below:

Item		Water Storage Tank Capacity/L		
		≤ 100	100~300	≥ 300
Heating Performance	Outlet Water Temperature T_2 ^oC	55		
Thermal Insulation Performance	Water Temperature after Leaving for 24h ^oC	T_2-10	T_2-8	T_2-6
Usage Performance	Hot Water Output Rate μ % (10K temp)	75%	75%	75%

For the thermal insulation test the product reaches a temperature control cutout, the power is disconnected and the water heater allowed to stand for 24 hours in controlled conditions. The temperature drop permitted is specified above.

For the usage performance the product reaches a temperature control cutout, the power is disconnected and water is drawn off at 5% of rated capacity per minute (not less than 5 litres/min). Water is discharged until the temperature at the outlet falls by 10K. The hot water output rate is a calculated weighted average mass-temperature of the discharged water (compared to 100% as the rated tank capacity volume delivered at a temperature rise of 55°C). This is a hot water delivery capacity type of test.

The tested heat pump water heater should be installed using the provided or recommended accessories and tools as per the installation stipulations of the manufacturer.

No modification or adjustment should be made to the heat pump water heater other than required for the connection of test devices and instruments.

There should be sufficient space for the air side test of the air source heat pump water heater such that the air flow field of the main machine will not change during the test. During the test, the air speed around the appliance should be as low as possible to prevent affecting the performance of the unit.

For the circulated heating heat pump water heater and the static heating heat pump water heater, the water tank of the largest capacity in the allowable range given by the manufacturer should be selected.

During the performance test, the auxiliary heat source should be disconnected from the heat pump water heater.

The standard covers a wide range of requirements in addition to energy such as:

- Structural Requirements
- Weather Resistance Requirements
- Airtightness and Pressure-Bearing Requirements
- Performance Requirements for Heat Pump Water Heater under Assessment Operating Conditions (other than normal operating conditions)
- Noise
- Packaging Requirements
- Transportation Requirements

A5 Europe (CEN)

Standard Reference: EN16147:2011
Standard Name: Heat pumps with electrically driven compressors – Testing and requirements for marking of domestic hot water units
Standard Publisher: European Committee for Standardization (CEN)[17]
Website: http://esearch.cen.eu/esearch/Details.aspx?id=7827760

Programs or mandatory measures using this standard: Energy labelling and efficiency standards for water heaters (proposed Eco-Design Regulation).[18] Regulations for heat pump water heaters and other types of hot water systems are proposed for 2014. Topten (voluntary) list of high-efficiency products.[19]

Scope

This European Standard specifies methods for testing and reporting of the rating and it specifies requirements for marking of air/water, brine/water, water/water and direct exchange/water heat pumps with electrically driven compressors connected to or including a domestic hot water storage tank. When these units are used for space heating, then EN 14511 (all parts) applies. In case of air-to-water heat pumps, this European Standard comprises only factory-made units which can be ducted on the airside. This European Standard comprises only the testing procedure for the domestic hot water production of the heat pump system.

NOTE Testing procedures for simultaneous operation for domestic hot water production and space heating are not treated in this standard. Simultaneous means that domestic hot water production and space heating generation occur at the same time and may interact. In the case of units consisting of several parts, the standard applies only to those designed and supplied as a complete package. This European Standard does not include any requirement about the quality of water.

Summary of Test Procedure

The suite of tests covered by this standard is made up of 6 components as follows:

- A: heating up period (see 6.3)
- B: determination of standby power input (see 6.4) (heat loss)
- C: determination of the energy consumption and the coefficient of performance for heating domestic water by using the reference tapping cycles (see 6.5). Different tappings in one tapping cycle (see Table 7 to Table 11 and Figure 2)

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[17] CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

[18] http://www.ecohotwater.org/

[19] Topten ('Best products of Europe') lists air source heat pump water heaters which achieve a COP of 2.3 or more when tested to EN16147:2011. Before this standard was published, the minimum criteria were stated in relation to EN:255-3:1997.
http://www.topten.eu/english/building_components/electric_water_heaters.html

- D: determination of a reference hot water temperature and the maximum quantity of usable hot water in a single tapping (see 6.6)
- E: test to determine the temperature operating range
- F: safety tests

Tests covered by A, B, C and D are of most interest to this project.

Component A is a heat up test for a tank filled with cold water. Component B is effectively a heat loss test (or maintenance test) with no hot water use for a period of >48 hours or less, if 6 on-off cycles have occurred. Component C is a series of drawoff tests where specified quantities of water are drawn off in a specified time schedule over a 24 hour cycle. Component D is a test to determine the volume of usable hot water that can be delivered at or above 40°C.

This test procedure was developed in response to a European Commission mandate to develop uniform test procedures for a range of water heater type (Mandate M/324, 27 September 2002). This mandate set out very specific requirements for Europe for new water heater test procedures including the drawoff profiles included in this standard. See ftp://ftp.cencenelec.eu/CENELEC/EuropeanMandates/m324en.pdf for more details.

Test Conditions and Procedures

The inlet and outlet temperatures of the domestic water are to be measured in the centre of the flow and as close as possible to the appliance.

The maximal permissible deviation of thermal energy for the complete tapping cycle shall be less than 5%.

For air sourced outdoor heat exchanger heat pumps, the size of the test room shall be selected to avoid any resistance to air flow at the air inlet and air outlet orifices of the test object. The air flow through the room shall not be capable of initiating any short circuit between the two orifices, and therefore the velocity of air flow at these two locations shall not exceed 1.5 m/s when the test object is switched off. The air velocity in the room shall also not be higher than the mean velocity through the unit inlet. Unless otherwise state by the manufacturer, the air inlet and air outlet orifices shall not be less than 1 m from the surfaces of the test room; this also applies to any measuring ducts.

Any direct heat radiation onto heating units in the test room onto the heat pump or onto the temperature measuring points shall be avoided.

Non ducted unit adjustable settings (ie fan speed etc) shall be set according to the manufacturer instructions.

For ducted units, the volume flow and the pressure difference shall be related to standard air and dry evaporator. The air flow rate given by the manufacturer shall be converted into standard air conditions. The air flow rate setting shall be made when the fan only is operating, at standard air conditions. The rated airflow rate given by the manufacturer shall be set and the resulting external static pressure (ESP) measured. This

ESP shall be greater than the minimum value given in the table provided, but not greater than 80% of the maximum external static pressure specified by the manufacturer.

Duct pressures for ducted systems:

Standard Capacity Ratings (kW)	Minimum External Static Pressure (Pa)[20],[21]
0 < Q < 8	25
8 ≤ Q < 12	37
12 ≤ Q < 20	50
20 ≤ Q < 30	62
30 ≤ Q < 45	75
45 ≤ Q < 82	100
82 ≤ Q < 117	125
117 ≤ Q < 147	150
Q ≥ 147	175

The heat pump shall be installed and connected as recommended by the manufacturer.

The test conditions for particular types of systems are given below:

Type of Heat Source	Heat Source Air[22] Temperature in ^{o}C (Wet Bulb in brackets)	Heat Source Inlet/Outlet or Bath[23] Temperature in ^{o}C	Range of Ambient Temperature of Heat Pump in ^{o}C	Ambient Temperature of Storage Tank in ^{o}C
Outside air heat pump (placed indoor side)	7 (6)		from 15 to 30	20
Outside air heat pump (outdoor side)	7 (6)		heat source temperature	20
Indoor air	15 (12)		heat source temperature	15
Exhaust air	20 (12)		from 15 to 30	20
Water		10/7	from15 to 30	20
Brine		0/-3	from 15 to 30	20
Direct evaporation		4	from 15 to 30	20

After the initial start up, the heat pump power supply is left on for the duration of the test.

The heat up test determines the time necessary to heat the storage quantity of water from an initial state until the first time the compressor is switched off by the thermostat sensing the water temperature in the tank.

The standby power input test (heat loss or steady state power) is determined by measuring the electrical power input over an integral number of on off cycles of the heat

[20] For equipment tested without an air filter installed, the minimum external static pressure shall be increased by 10 Pa.
[21] If the manufacturer installation instructions state that the maximum allowable discharge duct length is less than 1 m, then the required minimum external static pressure shall be 10 Pa.
[22] All air temperatures are dry bulb with wet bulb temperatures in brackets.
[23] Brine mean bath temperature for direct evaporation testing.

pump, initiated by the thermostat situated in the tank, when no hot water is drawn off. The test should be done over a period of 48 hours or less, if 6 on off cycles have occurred.

All hot water usage patterns define a 24 hour measurement cycle, within which the starting times and total energy content of each tapping are defined. There are 10 different types of hot water delivery event and each has its own flow rate and energy delivery. Smaller events have a flow rate of 4 litres per minute while larger events have a flow rate of 10 litres per minute. The 6 small hot water events count delivered energy after a temperature rise of 15K has been achieved. The cleaning and the large hot water events count delivered energy after a temperature rise of 30K has been achieved. The two dishwashing evens count hot water volume from cold but must reach a temperature rise of at least 45K during the event.

During each tapping, the tank receives cold water at a temperature of 10 °C..

At the end of the tapping cycles a test is undertaken to measure the maximum volume of usable hot water. After a thermostat cutout, hot water is drawn off at 10 litres per minute until the temperature at the outlet falls to 40°C.

This procedure is repeated at the maximum temperature setting (upper limit of use). The test is fulfilled when under the described conditions during the whole test procedure the heat pump is not shut off by a security device.

A6 Japan

Standard Reference: JIS C9220-2011
Standard Name: Residential heat pump water heaters
Standard Publisher: Japanese Standards Association (Japanese Industrial Standards)
Website: http://www.jsa.or.jp/default_english.asp

http://www.webstore.jsa.or.jp/webstore/Com/FlowControl.jsp?lang=en&bunsyoId=JIS+C+9220%3A2011&dantaiCd=JIS&status=1&pageNo=0

Programs or mandatory measures using this standard: Top Runner (new requirements commenced in 2012)

In Japan, heat pump water heaters are commonly called 'Eco-Cute' systems. 'Cute' in Japanese means hot water supply and Eco indicates 'ecological' or 'efficient.' Many heat pump water heater models use CO_2 as the refrigerant gas, giving good performance in cold winter conditions.

Scope

This standard is to be used in the design and manufacture of water heaters for hot water supply facilities primarily in the home (bathroom and kitchen). This standard covers electric vapour-compression type heat pumps that use as a refrigerant (HFC) hydrofluorocarbons or (CO_2) carbon dioxide. The heat pump system consists of air heat exchangers, a hot water tank and hot water control devices such as those defined for use in the water heater.

However, this standard does not apply to the following types:

a) where the capacity of the refrigerant circulation system is greater than 11.58 kW
b) that uses an HFC refrigerant that is either toxic or flammable combined with a temperature greater than 35°C, making the saturated vapour pressure exceed 3MPa, or alternatively if the refrigerant circulation system is equal to or greater than 19.3kW.
c) the connection refrigerant pipe, hot water storage unit and pump unit are separable; there is no water storage on the premises; or heat source other than electricity is present.

Note: The unit of pressure used in this specification refers to a gauge pressure unless otherwise stated.

Summary of Test Procedure

The water heater is placed in a calorimeter where indoor and outdoor conditions can be controlled.

The water heater is filled with cold water and allowed to operate until thermostat cutout. A specified hot water volume is drawn off and the tank is allowed to recover. This is repeated until the discharge energy is within 5% of the previous value. This indicates stable operation. Once stable operation is confirmed the test proceeds in a series of 24 hour drawoff cycles. Drawoff cycles s are specified for:

- Standard house (456 litres at 40°C) and small house (278 litres at 40°C)
- Summer, intermediate and winter seasonal test conditions. The volume drawn off is the same in each seasonal test but the cold water supply and outside air temperatures vary. This affects evaporator performance and heat loss.

An annual seasonal energy consumption is then calculated, using data from the different drawoffs and seasonal conditions.

Test Conditions and Procedures

Two main types of heat pump water heater are specified in the test:

- Systems with a heat exchange facility for reheating bathwater as well as delivering hot water ; and
- Systems without a heat exchange facility.

The water heater is generally installed in accordance with manufacturer instructions, and are tested in ‘energy efficiency mode’. In Japan, the Top Runner regulations specify that products must have an ‘energy efficiency mode’ and that manufacturers have to ship products set in this mode. However, the requirements of what is included in this mode are not clearly set out.

Many heat pump water heaters in Japan have several possible modes of operation (e.g. heavy/winter, light/summer, energy efficiency). The more advanced systems have adaptive systems that monitor hot water demand and attempt to learn the drawoff schedule from the previous days of operation. In accordance with the likely “predicted” hot water demand from past behaviour, these systems can optimise user operating costs by delaying recovery cycles until lower tariffs are available, if there is sufficient hot water remaining and if likely hot water demand will be low. These systems have electronics that can monitor hot water use, know the current time, tariff schedule and have an algorithm to assess the remaining hot water and whether recovery can be delayed until a more cost effective time.

While this type of feature has benefits for the user and is a good example of a smart appliance, it can complicate testing if the product starts to adapt to the test drawoff schedule – while the overall performance will not be greatly affected, it does reduce laboratory repeatability, which is a consideration.

The temperatures for the test are set out in the following table:

Season	Ambient air °C	Cold water inlet °C
Intermediate (TC1)	DB 16°C, WB 12°C	17°C
Summer (TC2)	DB 25°C, WB 21°C	24°C
Winter (TC3)	DB 7°C, WB 6°C	9°C

Annex A specifies the setup for testing and Annex B sets out the measurements required to measure energy consumption. Temperature sensors are located at the cold water inlet and the hot water outlet. Hot water outlet pipes are insulated.

Following the initial drawoff to establish that stable operation is reached (see above) there are a series of complex 24 hour drawoff patterns as follows:

- Hot water delivery temperatures are specified as 40°C -2K +0K (even though storage temperature is higher)
- There are 4 different drawoff types: wash basin, kitchen, bath, shower.
- Flow rates for wash basin and kitchen is 5L/min. Flow rates for bath are 10-15L/min and shower is 10L/min.
- Wash basin and kitchen events are generally less than 5L, a few to 25L, shower 20L or 50L, bath 180L
- Standard household and Small household profiles are specified by 3 seasons
    - Standard winter - 51 events, 16.276 kWh (58.594 MJ), nominally 455.74 litres at 40°C equivalent (cold water 9°C)
    - Standard intermediate - 51 events, 12.076 kWh (43.473 MJ), nominally 455.74 litres at 40°C equivalent (cold water 17°C)
    - Standard summer - 51 events, 8.401 kWh (30.242 MJ), nominally 455.74 litres at 40°C equivalent (cold water 24°C)
    - Small winter - 31 events, 9.927 kWh (35.737 MJ), nominally 277.96 litres at 40°C equivalent (cold water 9°C)
    - Small intermediate - 31 events, 7.365 kWh (26.515 MJ), nominally 277.96 litres at 40°C equivalent (cold water 17°C)
    - Small summer - 31 events, 5.124 kWh (18.445 MJ), nominally 277.96 litres at 40°C equivalent (cold water 24°C)

The hot water volumes appear to be very large because they are defined as mixed hot water that is suitable for use directly in baths or showers

The volume and energy details of the 6 drawoff patterns are shown in the table below:

Schedule name	Number of Draws	Daily load kWh/day in hot water	Daily load MJ/day in hot water	Average MJ/draw
Std Winter	51 (56) *	16.276	58.594 (62.714)	1.149
Std Intermediate	51 (56) *	12.076	43.473 (46.533)	0.852
Std Summer	51 (56) *	8.401	30.242 (32.103)	0.593
Small Winter	31 (34) *	9.927	35.737 (37.471)	1.153
Small Intermediate	31 (34) *	7.365	26.515 (27.799)	0.855
Small Summer	31 (34) *	5.124	18.445 (19.221)	0.595

* values in brackets indicate additional events and energy associated with heat exchanger function, if present. Heat exchange use increases energy delivered but not total volume of hot water delivered.

The following tables set out the drawoff profiles for the heat pump test:

- Table B.3: Standard winter, intermediate and summer drawoff for systems WITH a bath heat exchange facility;

- Table B.4: Small winter, intermediate and summer drawoff for systems WITH a bath heat exchange facility;
- Table B.5: Standard winter, intermediate and summer drawoff for systems WITHOUT a bath heat exchange facility;
- Table B.6: Small winter, intermediate and summer drawoff for systems WITHOUT a bath heat exchange facility.

The energy input, energy output and COP for each drawoff profile is then calculated from the measured test data.

Time of use tariffs are common in Japan, so there is a strong incentive to heat overnight where possible (for example, one overnight tariff is ('Denka Joze') is typically less than half the day rate). However, the hot water demand is greatest in the early evening (at least according to the test method, which is based on typical use) when tariffs are highest. So the standard has a requirement that the heat remaining in the tank be checked after the large evening drawoff to assess whether there is sufficient hot water remaining before the lower tariffs commence (this is defined as the equivalent of 100 litres of water at 40°C remaining). The unit is given some credit if recovery operation is not necessary after this drawoff.

There are two methods to determine the remaining heat energy in the tank. One is the draw off all remaining hot water and determine the stored energy by integration of temperature and flow. This can only be done at the completion of the drawoff tests. The second method, which is easier and more popular, is to measure the tank temperatures using an array of temperature sensors inside the tank at 40mm intervals to obtain an accurate temperature gradient. This allows an accurate estimate of the stored heat energy to be calculated.

There is a potential conflict in the control strategy for the water heater for systems with intelligent controls – immediate recovery ensures plenty of hot water but may end up being expensive to operate for the user. Delay of boosting should see a reduction in operating cost (where there is a lower off-peak tariff available) and perhaps a marginal improvement in overall system efficiency.

Annex C then specifies how to calculate the seasonal annual energy consumption for the heat pump water heater. There are two climate profiles: a standard climate and a cold climate. The annual performance measure for each climate essentially specifies a number of days at each average daily ambient temperature. The standard climate specifies the number of days for each daily average temperature ranging from 0°C to 30°C in 1K increments. The cold climate specifies the number of days for each daily average temperatures ranging from -9°C to 26°C in 1K increments.

The performance at each daily average temperature bin is determined by interpolation (or extrapolation) of the measured values for the three seasons tested to give an estimate of overall seasonal energy consumption. As the temperature bins are specified separately, the JIS test data can be applied to give a reasonable estimate of energy consumption under a range of different climate conditions (days by average temperature bin). However the test method covers only two hot water delivery levels (456 and 278 litres of mixed water at 40°C) so has some limitations in this respect in terms of wider applicability.

A7 R.O. Korea

Standard Reference: KS B draft
Standard Name: Air source heat pumps for hot water and space heating
Standard Publisher: Not published as yet (Korean Standards Association)
Website: http://www.ksa.or.kr/eng/

Programs or mandatory measures using this standard: (to be confirmed).

Scope

This standard applies to heat pump water heaters for household and similar uses that are driven by an electric compressor, employs a vapour compression refrigeration cycle, uses air as the heat source and whose primary purpose is to provide hot water. This standard also specifies methods of testing and reporting the energy performance characteristics of electrical driven heat pump application for sanitary hot water supply or space heating, either with a storage tank or without a storage tank.

Summary of Test Procedure

The water heater is placed in a calorimeter. The water heater is filled with cold water and allowed to operate until thermostat cutout.

The energy required to heat the water to thermostat cutout is measured. The energy available in the hot water is measured and these values are used to calculate an overall COP of the system (to be confirmed).

Test Conditions and Procedures

Note that this test procedure is based on a working draft KS standard and details are not finalised. Only a limited amount of information is available at this stage.

No air flow conditions are specified in the test standard. However, the standard makes reference to the following Annexes of ISO5151 (non ducted air conditioners):

- Annex A: Test requirements
- Annex C: Calorimeter test method
- Annex D: Indoor air enthalpy test method

Tanks temperature sensors are included on the water inlet and outlet.

The temperatures for the hot water test are set out in the following table:

Climate	Ambient air °C	Water temperatures °C
Standard	DB 7°C, WB 6°C	15°C inlet, 50°C outlet
Severe Cold Zone	DB -15°C, WB NS	Under consideration

Note: NS is not specified, nominal hot water temperature is 50°C, inlet temperature for Severe Cold Zone is under consideration.

A total for 4 test conditions are specified for space heating tests (water loop):

Climate	**Ambient air °C**	**Water loop temperatures °C**
Standard	DB 7°C, WB 6°C	40°C inlet, 45°C outlet
Low temperature	DB 2°C, WB 1°C	40°C inlet, 45°C outlet
Cold Zone	DB -7°C, WB -8°C	40°C inlet, 45°C outlet
Severe Cold Zone	DB -15°C, WB NS	40°C inlet, 45°C outlet

Note: NS is not specified.

A8 USA

Standard Reference: Code of Federal Regulations Part 430, Subpart B, Appendix E
Standard Name: Uniform Test Method for Measuring the Energy Consumption of Water Heaters
Standard Publisher: US Department of Energy (Government Printing Office)
Website: http://www.gpo.gov/fdsys/pkg/CFR-2006-title10-vol1/content-detail.html

Programs or mandatory measures using this standard: Mandatory labelling for water heaters (heat pump water heaters appear to have no specified MEPS (Energy Factor) requirements but are likely to be covered by MEPS for electric storage water heaters).

Energy Star (voluntary) endorsement program (EPA 2009).

Scope

This Standard specifies the test conditions and test procedures for determining the energy performance characteristics of all types of regulated water heaters, including gas, electric, oil and electric heat pump systems.

Heat pump water heaters are defined as having a maximum current rating of 24 amperes at a voltage no greater than 250 volts, which are products designed to transfer thermal energy from one temperature level to a higher temperature level for the purpose of heating water, including all ancillary equipment such as fans, storage tanks, pumps, or controls necessary for the device to perform its function.

Summary of Test Procedure

The heat pump water heater is installed in accordance with manufacturer installation instructions, and then placed on a constructed (and specified) plywood platform. The testing shall occur in an area that is protected from drafts.

Although a hot water delivery capacity test is specified (called first hour rating test), this is not essential except for heat pump systems, where the recovery efficiency has to be determined from this test. This is followed by an energy delivery test, consisting of 6 equal drawoffs of 40.6 litres at 1 hour intervals (totaling 243.4 litres). Standing heat losses are then determined over the remainder of the 24 hour test period. For this test the air-hot water temperature differential is 37.5°C while the hot-cold water temperature differential is 42.8°C. The Energy Factor (which is used to define the MEPS level) is determined as the ratio of the output energy (in terms of hot water delivered) to input energy during the test.

All primary temperature requirements are specified in degrees Fahrenheit with Celsius conversions shown for information.

Test Conditions and Procedures

The key elements to this test procedure are:

- Static tank capacity is determined by water volume;
- The dry bulb temperature is maintained at 19.7°C ±0.6K, and the relative humidity is maintained between 49% and 51%;
- The average temperature of the water in the storage tank is set to 57.2°C ±2.8K;
- The temperature of the water being supplied to the water heater is maintained at 14.4°C ±1.1K, throughout the test;
- Drawoff test consisting of 6 × 40.6 litre drawoffs at 1 hour intervals (total 243.4 litres) (24 hour simulated use test);
- Determination of static heat loss during remainder of 24 hour test period when there is no drawoff. (called standby losses in the test method).

Actual temperature variations in air and water temperatures are corrected to nominal values in the determination of the Modified Daily Energy Consumption (Q_{dm}).

For heat pump water heaters that use supplemental resistive heating, the electrical energy supplied to the resistive element(s) shall be metered separately from the electrical energy supplied to the appliance or to the remaining components.

Six temperature measurement sensors are required inside the water heater tank with a vertical distance of at least 100 mm between successive sensors. A temperature sensor shall be positioned at the vertical midpoint of each of the six equal volumes nodes within the tank. Nodes designate the equal volumes used to evenly partition the total volume of the tank. The sensors should be positioned away from any heating elements, anodic protective devices, tank walls, or flue pipe walls. If the tank cannot accommodate six temperature sensors and meet the requirements specified, then install the maximum number of sensors that comply with the installation requirements. Temperature sensors shall be installed either through the anodic device opening, the relief valve opening, or the hot water outlet.

If the water heater is supplied without a tank, there shall be an electric storage type water heater having a measured volume of 178 litres ±3.8 litres, with two 4.5 kW heating elements controlled in such a manner as to prevent both elements from operating simultaneously.

The test procedure also has a method to determine the recovery efficiency of heat pump water heaters through an actual drawoff test (water is drawn until the thermostat activates - first hour rating test).

The annual energy consumption of a water heater is given as 365 × Q_{dm}. The Energy Factor (EF) is the ratio of the energy in the hot water delivered to Q_{dm} (input energy) (ie an overall efficiency for the delivery of the specified hot water profile over 24 hours). Heat pumps may have an EF which is greater than 1.0, while resistive units must have an EF of less than 1.0.

Variables required to be measured, determined or declared for regulatory purposes:

- Static capacity;
- Standing heat loss kWh/24 hours (standby loss) (two different methods);

- Modified Daily Energy Consumption;
- Energy Factor;
- Annual energy consumption.

Structure of US Department of Energy Code of Federal Regulations

All regulatory requirements in the USA are published by the Government Printing Office. Energy conservation standards for many products are published under:

Title 10 – Energy

Subchapter D – Energy Conservation

Part 430 - Energy Conservation Program For Consumer Products

- Subpart A - General Provisions
- Subpart B - Test Procedures
- Subpart C - Energy and Water Conservation Standards
- Subpart D - Petitions To Exempt State Regulation From Pre-emption; Petitions To Withdraw Exemption of State Regulation
- Subpart E - Small Business Exemptions
- Subpart F - Certification and Enforcement

Appendix B. KTL Test Series

Background

Korean Testing Laboratory (KTL) is developing a Korean standard method of test for heat pump water heaters. As part of the project it is applying a number of test methods to a small group of heat pump water heaters, and making the results available for the present CLASP project.

Models tested

KTL is testing three air source heat pump water heaters:

	Model A	Model B	Model C
Configuration	Unitary	Stand-alone (split)	Stand-alone (split)
Power supply	220-240V, 50 Hz	220-240V, 50 Hz	415V, 50 Hz (3-phase)
Refrigerant	R134a	R407c	R407c
Storage volume (litres)	190	200	200
Compressor power	0.7 kW	2.8 kW	4.5 kW
Electric resistance element	2.0 kW (switchable)	None	None
Economy of Manufacture	China	China	Korea

Standards used

1. Europe - EN 16147:*2011 Heat pumps with electrically driven compressors - Testing and requirements for marking of domestic hot water units*
2. Australia/New Zealand - AS/NZS 512:2010 *Heat Pump Water Heaters – Performance Assessment*
3. USA - US Code of Federal Regulations Title 10, Part 430, Appendix E to Subpart B (CFR 430)
4. Japan - JIS C 9220:2011 *Residential Heat Pump Water Heaters*
5. Korea - Draft: *Air source heat pump water heater for residential buildings*

Each test method has a set of different ambient conditions, test procedures and draw-off (tapping) patterns (AS/NZS 5125 has no draw-off at all).

Variations to test procedures

In order to maximise the value of the KTL testing, it was requested that additional instrumentation be added to the water heaters and additional data collected during the tests, to allow more in-depth analysis of the results. The following variations were requested:

1. Include and record tank temperatures using an array of 6 temperature sensors as specified in AS/NZS 5125 Clause A3.2. Some test methods only use a single sensor or a pair of sensors close to the tank centre. These do not give sufficient

information about the total energy stored in the tank and how this changes over time. An array of sensors has to be used for the AS/NZS 5125 tests, so it is proposed that these be left in place for all tests, in addition to any other tank sensor locations that may be required by the other test methods.

2. Record data at 1 min intervals or shorter. While this frequency of data collection is usually no problem for modern test laboratories, some test methods may not specify such a recording interval. A uniform data recording interval for all tests will make the data more useful and will allow direct comparisons to be made across the different test methods.

3. Data recording during heat up phase: AS/NZS 5125 requires the tank to be filled with cold water and the water heater is operated until it reaches its maximum operating temperature. Some of the test methods being investigated may not require measurement of the water heater operation from cold until thermostat cutout (some commence the formal test after the tank temperature has stabilised and the drawoff pattern commences). The cold water temperatures, ambient temperatures and temperature settings may be different for each test method and these requirements should be followed for the relevant test method. However, it is requested that, at the start of the relevant test, the tank is filled with cold water, data recording is commenced immediately and then the water heater is switched on only after at least 60 min. The water heater is then allowed to operate in accordance with the relevant test method. This will provide data that is equivalent to AS/NZS 5125 data for the specific test method but which otherwise may not be routinely recorded.

4. Cool down data: For at least one test condition for each of the national test standards being undertaken (preferably the condition with the coldest ambient temperature, if there is more than one ambient temperature specified), allow the unit to operate after the completion of any drawoff pattern for at least 3 thermostat cycles (eg for the US test method, which concludes with 18 hours of no drawoff, these measurements could be conducted immediately at the end of the 24 hour test method). At a thermostat cutout, turn off the power and continue to record the tank temperatures (while maintaining the relevant ambient conditions) until the average tank temperature falls at least 10K (note that this may take as long as 48 hours for an extremely well insulated tank, but usually this will be 15 to 30 hours). This test is being undertaken in lieu of a standard heat loss test (which is separately specified in AS/NZS 5125) and should provide the effective conductivity of the water heater shell.

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