# 9. WATER HEATING APPLIANCES

## Overview of the product

Water heating appliances cover an extremely diverse range of product types that are used primarily for domestic hot water, space heating or a combination of both end uses together.

In the case of domestic hot water, hot water is used for purposes such as showers, baths and personal hygiene (ablution), washing of cooking and eating utensils and general cleaning purposes (including clothes washing).

In the case of space heating, heated water is usually distributed via a hydronic pipe system (loop) to provide heating via radiators that are placed around the dwelling – their output is controlled as required. This section does not cover larger scale central heating systems that supply multiple households or commercial buildings. It does not cover district heating systems.

Water heating appliances are a mainstream product in developed economies and most developing economies. A huge range of energy technologies are typically used for this purpose including:

- Electric resistive heating (storage and instantaneous)
- Electric heat pump (storage)
- Gas with storage (commonly methane, LPG or other gas variants)
- Gas instantaneous (little or no storage) (commonly methane, LPG or other gas variants)
- Solar thermal systems of various types (storage), often with supplementary boosting which may be integrated (in tank) or separate (external)
- Oil fired storage systems
- Solid fuels systems including wood and other biomass sources (storage).

The most common configurations are:

- Storage systems – where water is heated and stored in an insulated tank or vessel for use as required – heat can be added using any of the above technologies. Within the storage type, there are displacement water heaters (where the heated water is supplied directly for use and cold water displaces the used hot water and is subsequently heated) and heat exchange types (where incoming cold water is heated using stored heat in a vessel and a heat exchanger which is then supplied as hot water). Displacement water heaters can be closed (mains pressure or low pressure) or open (vented with feed tank and falling water level).
- Instantaneous systems – where hot water is generated on an as required basis and where little or no hot water is stored - typically very high power inputs are required to meet the hot water demand and these are usually limited to gas systems and in a few cases three phase electric resistive systems.
- Circulation systems – where hot water is pumped in a loop (usually for space heating) and the temperature in the hot water loop is maintained by a water heating appliance. Circulation systems may or may not have a storage tank associated with them.
- Combination systems – where more than one of the above systems are combined, typically for combined domestic hot water and space heating.

Water heating appliances are extremely diverse around the world and in most regions systems tend to be design for and adapted to local requirements, conditions and available fuels. In many regions products are designed and manufactured locally. The international trade in water heating appliances is moderate to small. There is a large range of regulatory requirements for both safety and energy efficiency.

## Comparison of energy performance test procedures

### *Key parameters to consider for efficiency testing and measurement*

In the most simplistic sense, the efficiency of water heating appliances can be defined as the energy output (hot water) over the energy input (external energy sources).

For energy sources such electricity, gas and oil, determination of the energy input is relatively straight forward. For other energy sources such as solid fuels and various solar systems, determination of energy input can be complex and can vary from test to test due to the variable nature of the energy source.

Determination of energy output is usually defined as the additional energy to heat the water from cold to a defined temperature multiplied by the volume of water delivered. For circulating systems, the energy output is defined as the temperature rise multiplied by the volume of flow.

However, the fundamental problem for water heating appliances is that the overall energy consumption and the associated energy efficiency of the appliance is strongly affected by the hot water consumption assumed for the measurement and the conditions under which it is measured. Many of these factors are non-linear and very complex. Many are associated with regional climatic factors. Some of the key parameters that affect energy consumption and efficiency of water heating appliances include:

- Heat losses from storage systems, including ambient temperatures and hot water storage temperatures
- Conversion efficiency during operation (electric, gas and oil systems) of storage systems
- Conversion efficiency during operation of instantaneous gas systems under different output temperatures and flow rates (modulating systems)
- Start-up losses for instantaneous systems
- Energisation profile for electric storage systems (continuous versus limited duration tariffs)
- Changes in cold water variations temperatures throughout the year
- Typical changes in solar radiation input levels and ambient temperatures for solar systems and heat pump systems throughout the year (on an hourly basis)
- Hot water demand varies by time of day, day to day and by season by household and, on average, by region (on an hourly basis).

The most significant factors that affect overall energy consumption for each of the major types of water heating appliance are:

- Heat losses from storage systems tend to remain fairly constant, so lower hot water demand appears to have a much lower task-efficiency than higher hot water demand.

- Heat losses per start for instantaneous systems mean that the number of separate hot water events per day can affect the overall efficiency. Otherwise they are less affected by total hot water demand.

- The overall efficiency of heat pump systems tends to be much less sensitive to hot water demand than standard storage systems (impact of heat loss is reduced through greater operating efficiency).

- Solar based systems use less boost energy under a lower hot water demand when compared to a higher hot water demand. Solar input is usually highest when the hot water demand is lowest and vice versa so there can be a seasonal mismatch in demand and supply for solar systems, which means that boost energy usually highly seasonal.

- Actual solar input, ambient air temperatures and cold water temperatures vary by time of day, day to day and by season by region – this affects all systems to some extent, but especially solar and heat pump systems.

### *Overview of the international test method*

In general terms, international standards for water heating appliances are poor or nonexistent.

The IEC has a standard for electric storage water heaters IEC 60379 *Methods for measuring the performance of electric storage water-heaters for household purposes*. This standard was published in 1987 and has not been revised in recent years and is now withdrawn. The standard only provides for determination of heat loss for electric storage water heaters and the approaches and methods specified are not globally applicable nor in line with best practice.

The only other international standards of interest are a series of ISO standards which were initially developed for solar systems but which have the potential to be adapted for other water heater technologies. The relevant standards are:

ISO 9459-1:1993 - *Solar heating -- Domestic water heating systems -- Part 1: Performance rating procedure using indoor test methods*

ISO 9459-2:1995 - *Solar heating -- Domestic water heating systems -- Part 2: Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems*

ISO 9459-5:2007 - *Solar heating -- Domestic water heating systems -- Part 5: System performance characterization by means of whole-system tests and computer simulation*

Part 1 and Part 2 standards are relevant only for solar thermal water heaters.

Part 5 is a standard that uses a statistical means of correlating detailed performance data for solar water heaters. It is very complex and the instrumentation to collect the required data is extremely expensive. The standard requires the use of software that is propriety and there is no public documentation on the underlying calculations used by this software. Publication of this standard was not supported outside of Europe. It has now been adopted by Europe for some energy efficiency requirements.

In contrast to Part 5, an alternative approach to simulation of solar water heater performance is being developed:

ISO/CD 9459-4 - *Solar heating -- Domestic water heating systems -- Part 4: System performance characterization by means of component tests and computer simulation*

Part 4 sets out a testing approach to determine the performance characteristics of key components of water heaters that can then be used in the simulation of energy consumption under a wide range of conditions. The component data is measured using defined testing approaches, depending on the water heater type. The measured component data is then put into an open source thermodynamic simulation model called TRNSYS (A TRaNsient SYstems Simulation program), which was developed by the University of Wisconsin, Madison and has been in use internationally for over 20 years. TRNSYS can be used to simulate performance hot water systems (including solar systems) and is also used in the simulation of the thermal performance of buildings and their associated equipment, including control strategies, occupant behaviour, alternative energy systems (wind, solar, photovoltaic, hydrogen systems). This standard completed the committee draft (CD) stage in mid 2009.

### *Adequacy of the international test method*

IEC60379 is not used to any extent and the methods specified are out of date and not robust. The standard is now withdrawn. Its use is not recommended.

ISO9459 Part 1 and Part 2 related to indoor and outdoor testing of solar thermal water heaters. These standards are applicable to these specific product types by are not relevant to other types of water heating appliances.

ISO9459 Part 5, as noted above, is very complex, expensive to apply and relies on proprietary software. Specifying its use is considered to be overly onerous by some experts.

ISO9459 Part 4, which is still under development, could provide a sound basis for dealing with all types of water heating appliances. While it has been primarily developed for solar water heaters (which are perhaps the most complex of all water heating appliances), the approaches can be applied to all water heating types. Key characteristics of each water heater component are determined under defined measurement conditions and these components are then combined to simulate overall performance for any set of operating conditions using the open source TRNSYS thermal simulation software. Any operating conditions (e.g. climate, temperatures, solar input) can be selected and any user related hot water profile (hourly, daily, monthly) can also be used as a simulation input in order to determine overall energy consumption and energy efficiency.

### *Regional differences in products and testing approaches*

Water heating appliances are incredibly variable at a regional level. They tend to be locally or regionally produced and designed to fit very specific requirements of design and construction within the residential and small commercial sector. To some extent, house design and construction, climate and the availability of different fuels (and their prices) have had a strong influence on water heating appliance designs. Even within a country, there is a diverse range of available products. Climate and fuel availability can be very highly variable within a country.

It is hardly surprising that there is a huge divergence in testing approaches for water heaters at a country and regional level. This has occurred because:

- There have been no suitable international test methods.
- There is a huge diversity in water heater types, designs and configurations at a country level.
- It is self evident that climatic factors will have an influence on water heater energy consumption, especially for solar types, and most test methods are unable to deal with these factors in a generic manner.

- Typical hot water usage and demand is highly variable at a country level, and most test methods are unable to deal with hot water usage in a generic manner.

The most common approach to determine energy efficiency for water heating appliances is to define a relevant “task” (hot water supply profile) for the determination of energy consumption and therefore efficiency. In order to get a representative and relevant value, it is also necessary to specify local operating conditions and in some cases climatic factors. Many of these parameters vary substantially through the year and across regions, so understandably there is substantial divergence at a regional level.

For electric storage water heaters (using resistive heating elements) there are some common approaches in some regions to the measurement of standing heat losses for regulatory purposes. There are a number of differing details in the determination of heat loss values (especially with respect to storage temperatures, ambient temperatures and test period), but the results can be broadly compared if sufficient test details are known.

The reason that the heat loss approach is sometimes used for these systems is that the conversion efficiency of a resistive element is close to 100% (usually in the range 95% to 98%) and therefore the main difference between different storage water heaters is the standing heat loss (as the hot water used is more or less supplied at 100% efficiency), so hot water usage becomes irrelevant in a comparative sense for these types of systems. However, the hot water usage profile will affect the measured heat loss if the element is not continuously energised (e.g. overnight of off peak controlled tariffs). The heat loss approach may not be suitable where a comparative total energy consumption value is required for a defined task (the heat loss measurement can be used in a simulation of total energy consumption under defined conditions and hot water delivery, but a range of other details regarding the water heater design and construction are needed to do this with accuracy).

### *Comparability of regional testing approaches*

As all regions have used their own local requirements for the rating and testing of water heating appliances, there is virtually no alignment and comparability of test data, as all values are obtained under different conditions and different hot water supply profiles. The divergent approaches have been implemented to keep test requirements locally relevant. At this stage there is no possible approach to covert data between different test procedures.

Where data on heat losses is known for electric storage water heaters that use electric resistance elements, the results can be broadly compared if sufficient test details are known to make adjustments to the measured test values.

### *Subjective assessment of the level of international harmonisation for testing*

There is virtually no global harmonisation regarding testing of water heating appliances. Within the major regional blocks (e.g. Europe, North America) there are uniform approaches for some product groupings, but these have been specifically developed to reflect local usage profiles and climatic conditions. These approaches cannot be readily adapted to other regions in their current form. Even within regions, coverage of different product types is patchy.

### *Prospects and key directions for international harmonisation of testing*

The current situation for water heating appliances is fairly bleak. There are many different product types and most are complex in their design and operation. Water heater energy consumption is heavily affected by hot water demand, which is highly variable at a regional level, and by many climatic factors, which are also very variable.

While there is not really any harmonisation regarding heat loss measurements for electric storage water heaters that use resistive heating elements, there is some level of comparability of the underlying test approaches for these products. However, many countries are moving to limit their use or even ban them due to their relatively high electricity consumption. Therefore focusing on harmonisation of heat loss testing for these types of products is not likely to be very productive in terms of a global effort.

Any global approach to harmonisation of testing needs to be able to deliver a range of very specific outputs in order to be acceptable:

- Ability to deal with a wide range of hot water usage profiles (e.g. time of day, day to day variations, seasonal variations).
- Ability to take into account a diverse range of climate related conditions including ambient temperatures, cold water supply temperatures and solar related parameters where necessary (e.g. heat pump and solar systems).
- Well defined, accurate and reproducible quantification of key product characteristics.
- Combining of all of these parameters to accurately estimate energy consumption under any given conditions through simulation.

Achieving all of these objectives is a significant challenge. Get such an approach accepted internationally is perhaps an even bigger challenge.

The best prospects for achieving such a global approach appears to be ISO9459 Part 4. Although primarily developed for solar water heating systems, the approach can be adapted to suit any water heating technology. The system can estimate total system energy consumption under any given hourly hot water usage profile and any given hourly ambient conditions (including solar energy inputs).

The draft standard has just completed the Committee Draft stage. It may be several years before it is released as a published standard. The development work on this standard is being lead by the USA and Australia, however, it remains to be seen how much international support there will be for its widespread implementation. There is a potential conflict with some parties who favour the already published ISO9459 Part 5.

In order to make ISO9459 Part 4 broadly applicable to all water heating appliance designs and fuel sources, some of the approaches to determine the characteristics of key performance parameters may need to be expanded.

## Comparison of energy efficiency metrics

### *Common Efficiency Metrics and Regional Approaches*

For water heating appliances, the most simplistic approach to determining efficiency is to measure the hot water output and the energy input required to supply this energy.

However, the total energy consumption and the apparent efficiency of the appliance are strongly affected by the hot water consumption for most types. The use of stored hot water means to supply hot water demand means that any input and output calculation is much more complex and has to take into account recovery and reversion to steady state operation. The ambient conditions also affect the total energy consumption and apparent overall efficiency. For solar type systems, factors such as solar radiation and ambient conditions have a strong impact on total energy consumption.

Given this range of diverse factors, devising universal efficiency metrics can be problematic.

There are two possible objectives with respect to water heating appliance efficiency metrics. The first is to obtain a broad comparative performance value for the product. This comparison can be done locally, regionally or globally. Products compared under such an approach would all have to be treated in the same manner using standardised conditions for all of the key parameters. Energy inputs can then be directly compared.

The second possible objective is to obtain a reasonable estimate of average energy consumption of the product during normal use in order to advise consumers of the best or most efficient product for their needs. In this approach it is necessary to ensure that products are compared under typical usage conditions that are likely to be specific to a particular region or even local area.

For most water heating appliances, the biggest and most important factor is the hot water demand that has to be met by the appliance. This is likely to be quite variable by region. Even if an average value is known for a region, this will vary substantially from household to household. Even within a household, the day to day demand for hot water is likely to be highly variable. In terms of portability and flexibility, hot water demand is most usefully characterised as a distribution rather than a single average value.

One approach that is quite flexible is to develop a table of input energy for a range of defined energy outputs (ie hot water usage profiles). For example the total system energy consumption for a defined usage profile of 0MJ/day, 10MJ/day, 20MJ/day, 30MJ/day and so on could be developed (up to the maximum possible daily energy delivery). This gives total energy consumption for different usage levels (important in the determination of energy operating costs) allows the calculation of overall system efficiency. It is important to note that the variation in system energy consumption and efficiency with hot water load of each individual system could be highly diverse – some will decrease in efficiency, some will increase in efficiency, some will be roughly constant with increases in hot water load.

Requiring such data via testing at each load value would be overly onerous – the best approach is to undertake such energy consumption estimates based on simulation. It is important that such a simulation would be based on a range of key parameters that are determined by measurement in a test lab.

For systems such as solar and heat pumps, it would be necessary to undertake such a simulation for different hot water energy outputs using locally relevant climatic conditions.

For systems that use both gas and electricity (e.g. many instantaneous gas water heaters) it is important that the electricity consumption during use as well as when not in use (standby power) both be considered in the total energy consumption metric.

The most common approach already adopted to determine energy efficiency for water heating appliances is to define a relevant "task" (hot water supply profile) for the determination of energy consumption and therefore efficiency. In order to get a representative and relevant value, local operating conditions and in some cases climatic factors are also specified. In some cases, such as Europe, a number of usage levels and time of use profiles are specified.

This approach, although common, means that all data for water heating appliances is specific to a particular set of regional conditions and the defined usage condition(s). Apart from complex simulation, which is not yet fully developed, a task based approach to energy measurement is the only way to get comparative energy consumption data for different technology and fuel types. For example, the US specifies a defined hot water delivery task of 6 draw-offs totalling 243.4 litres at 1 hour intervals. 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 37.5ºC while the hot-cold water temperature differential is 42.8ºC. This test is applicable to electric storage water heaters, gas storage water heaters, oil storage water heaters and instantaneous gas water heaters. Understandably, many countries would argue that this specific task may not be relevant to their local hot water usage requirements.

### *Performance Issues*

Performance of water heating appliances mainly revolves around the ability of the product to meet peak hot water requirements. There are a range of secondary parameters that are also of interest.

For storage systems, the most common performance parameter is the hot water storage volume. This is usually defined as the total storage volume of the tank itself (all of which may or may not be heated). A closely related parameter is the hot water delivery capacity. This is a measure in litres or in MJ of the hot water that can be delivered in a single event. It is of most importance for electric systems as recovery boosting can take quite a long time after a full discharge (and boosting may be delayed on controlled tariffs). Common approaches are to define the water delivery within a defined temperature drop or above a defined minimum temperature floor. Hot water delivery provides an indirect measure of the level of stratification and mixing in the water heater during use – this data can be important for accurate simulation of the product during use.

Ultimately it is critical to assess the maximum hot water energy that the water heating appliance can deliver to the user – this should form the basis of any maximum capacity claim by the supplier. Possible approaches to define capacity could include:

- Instantaneous systems – MJ/hour hot water delivery (could be expressed as litres per minute at a defined temperature rise)
- Smaller storage systems - MJ/hour hot water delivery (based on full discharge and the associated recovery time)
- Larger storage system – MJ hot water delivery (based on full discharge – usually electric storage systems)

For storage systems, the amount of water discharged during heating should also be reported (this occurs as cold water is heated and expands inside the tank). Discharge can be hot water or cold water, depending where the expansion valve is fitted.

For instantaneous systems, there is an effective energy loss at start up – this is a key parameter that needs to be considered in the energy consumption of the appliance. An associated parameter is the water that is “wasted” during the start-up sequence. This is effectively the volume of water that passes through the product before any useful hot water is produced. There are a number of approaches to defining the point at which “useful” hot water is supplied – typically based on a defined temperature rise.

Other performance parameters or checks during testing that may be of interest include:

- Water leakage or discharge during operation (check for a faulty product or installation during testing).
- Gas leakage during operation (check for a faulty product or installation during testing).

- Combustion product toxicity for appliances that uses combustion for heating (this can be important as adverse (very lean) combustion can produce improved efficiency but can generate unacceptable levels of carbon monoxide).
- Rated energy input rate (power) for the appliance
- Maximum and minimum operating pressure water pressure, documentation on safety cut-out and overload systems (this is verging on safety requirements).
- Use of an anode and related maintenance requirements.

### *Comparability of efficiency metrics*

At this stage, there is almost no comparability between efficiency metrics used in different regions. This is because most metrics tend to use a defined hot water task and local ambient conditions for the determination of energy consumption and efficiency. The only exception is in the case when heat loss alone is used for electric storage water heaters that use resistive elements; in this case it is sometimes possible to compare heat loss results whenever sufficient underlying test data is available.

## Recommended directions

There is no doubt that water heating appliances present one of the biggest challenges in terms of global harmonisation of testing approaches and efficiency metrics. There is a large range of technologies, fuels and configurations in use. Many systems, such as solar and heat pumps, use ambient conditions to supply heat for the system, which makes testing slow and complex. Many products are design and made to meet local requirements, which are sometime diverse.

Not only do local climatic conditions affect the energy consumption of water heating appliances, there is also a diverse range of hot water demands across regions and even within regions. This is one of the most important factors in the determination of energy consumption and energy efficiency of these appliances.

At this stage there is no international test method for water heaters. Most regions set their own testing requirements and hot water usage parameters in a task based efficiency measurement in an attempt to reflect local usage and conditions. The differences in these conditions makes energy data non comparable across regions.

The best medium term prospect for water heating appliances is to support the development of ISO/CD 9459-4 - S*olar heating -- Domestic water heating systems -- Part 4: System performance characterization by means of component tests and computer simulation* as the basis for an international approach to water heating appliance testing and efficiency metrics. This draft standard still has some way to go before it is published, but offers a standardised approach to characterising the performance of key water heater components through testing and then combining this data to simulate total energy consumption under any local or regional climatic and usage condition.

Once finalised, a range of international metrics could be developed to allow products to be compared internationally on a fair and equitable basis.