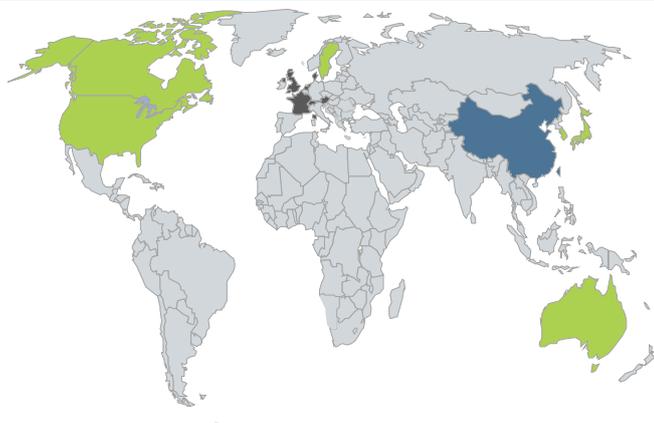


# 4E

## Benchmarking Document



Technology: Domestic Water Heaters



**Participating countries:**

Australia, Canada, Japan, Republic of Korea, Sweden, USA.

**Other funding countries:**

Austria, Denmark, France, the Netherlands, Switzerland, UK.

**Other regions covered:**

China.

## Benchmarking Report for domestic gas and electric, storage, instantaneous and heat pump water heaters

For further information refer to <http://mappingandbenchmarking.iea-4e.org/matrix> or email [operating.agent@mapping.iea-4e.org](mailto:operating.agent@mapping.iea-4e.org)

Issue date: 14 February 2017

The information and analysis contained within this summary document is developed to inform policy makers. Whilst the information analysed was supplied by representatives of National Governments, a number of assumptions, simplifications and transformations have been made in order to present information that is easily understood by policy makers, and to enable comparisons with other countries. Therefore, information should only be used as guidance in general policy - it may not be sufficiently detailed or robust for use in setting specific performance requirements. Details of information sources and assumptions, simplifications and transformations are contained within the document or the related Mapping Documents.





## Summary overview and outcomes

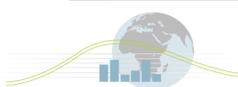
Throughout the developed world, the heating of water for domestic use is one of the largest consumers of energy in the household sector. However, water heaters vary in their type and mode of operation, the source of energy used and, potentially more than any other domestic appliance, the actual energy consumed is impacted by consumer usage patterns and ambient environmental conditions. Such complexity creates a number of challenges for policy makers seeking to understand and effectively manage water heating energy consumption. To assist policy makers in this understanding, and to highlight potential opportunities for future reductions in water heating energy consumption, the IEA's 4E Technology Collaboration Programme has developed conversion factors that have enabled this international comparison of policies currently in place to manage water heater product performance, and to benchmark the comparative resultant energy performance of water heaters available across a number of international markets. The analysis compares the policy frameworks and product performance of gas and electrical storage, electrical heat pump and gas instantaneous water heaters available in Australia, Canada, China, Japan, the Republic of Korea, Sweden, and the USA.

The specific mix of water heater types used varies considerably between countries as a result of culture, historic practice, existing infrastructure and energy source availability. Not surprisingly, the specific policy frameworks developed and deployed by policy makers vary significantly depending on these local conditions. However, in the majority of countries, at least some product types have mandatory and/or voluntary product performance standards in place with these requirements tending to fall into two broad categories:

- Product specific: Typically individual aspects of product energy consumption are limited, e.g. minimum requirements are placed on the efficiency of the water heating process or the rate of heat loss during water storage;
- Technology neutral: Specific levels of water heating service are defined, with an associated maximum energy consumption assigned to that level of service irrespective of technology deployed.

In practice, almost all regulatory regimes deploy a hybrid of the two approaches. For example, until regulatory transition currently underway, the USA specified a generic set of hot water service requirements for almost all water heaters, but applied differing minimum performance standards for each water heater type delivering that service. Even where 'pure' technology neutral standards are deployed, the specific service requirements selected often favour one or more particular product type(s). However, it is interesting to note that some of the best performing products across international markets have resulted from alternate policy interventions. For example:

- In Japan, the Top Runner programme does set mandatory performance requirements but, rather than setting minimum requirements for individual products, future product performance targets are based on a category/application-specific weighted average value of shipments from manufacturers. This has led the Japanese heat pump water heater market to be being dominated by some of the best performing products in the





world. Australia also has some very high performing heat pump models apparently drawn into the market by emissions-based white certificate schemes in some States.

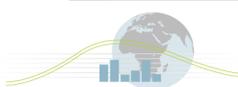
- Korea has a high proportion of the best performing instantaneous water heaters despite the Korean minimum performance standard not being particularly challenging. This may be a spin-off from the aggressive advertising promoting condensing boiler systems spilling over into a consumer demand for condensing instantaneous water heaters which are then easily identifiable via the Korean energy label.
- The North American ENERGY STAR programme is encouraging premium performance products across all water heater types.

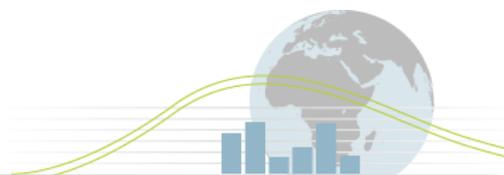
Given the range of policy deployed, and the specific local conditions, it is not surprising that no one country has the best performing products across all water heater types. However, for all countries, there is potential to make savings across almost all water heater types. The magnitude of the savings potential varies but in some cases it is very large. For example, savings of over 1 MWh per year per product are available to policy makers in Canada simply by moving the market towards the more efficient gas storage water heaters already available locally. Even for electric storage water heaters where manageable losses are limited, savings of 100 to 200 kWh/year per product are available to policy makers in most countries. Within the context of the total annual energy consumption of water heaters, such savings might appear insignificant. However, savings of this magnitude are often sought for other products (e.g. refrigerators) and could be achieved simply by eliminating the worst performing products from the market with no apparent loss of service to the consumer.

There are, however, much larger potential savings available from moving *between* types of water heater. On a delivered energy basis, and at the reference conditions used, water heater types providing similar levels of service have annual energy consumptions of:

- Air sourced heat pumps: 1.1 – 2.0 MWh;
- Direct electrically heated storage: 4.4 - 5 MWh;
- Gas instantaneous: 6.2 - 6.5 MWh;
- Gas storage: 6.0 - 7.7 MWh.

Hence, to take the most the most extreme example, a switch from the worst performing gas storage water heater to the best heat pump model would reduce annual energy consumption by almost 7 MWh per water heater. However, traditionally, policy makers have been reticent in pursuing policies that would drive switching of product type, even where technology neutral policy measures have been deployed. But recently, the technology neutral labelling of the water heaters in the EU clearly has such technology switching as a long term goal. Further, the transition in regulatory requirements currently under way in the USA appears to be moving towards technology neutrality based on primary energy. For water heaters above 208 litres in the USA, it appears the likely impact will be to drive electrically heated water heaters to heat pump technology, and gas storage water heaters to condensing efficiencies. Not only is this likely to yield significant energy savings in the US market, it is also likely to stimulate the introduction of a large number of higher efficiency gas storage and electric heat pump products into the broader market. If this is the case, such products (or similar derivatives) may become more widely available internationally and present policy makers elsewhere with more options for managing their own markets.





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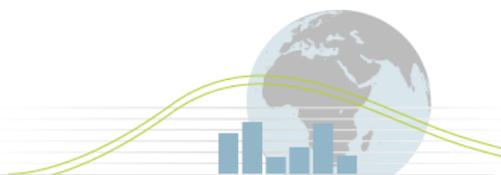


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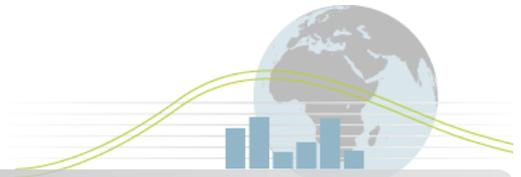
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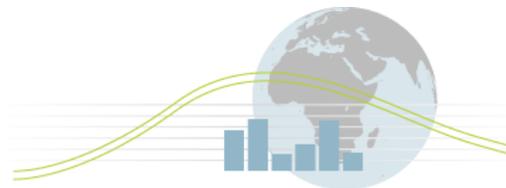




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## 1 Introduction

Throughout the developed world, the heating of water for domestic use is one of the largest consumers of energy in the household sector. Consequently, for an extended period, policy makers have sought effective mechanisms to manage this consumption. However, the water heaters available vary in their type and mode of operation, the source of energy used, and whether the products have additional functionality beyond simple water heating, e.g. provision of domestic space heating. Further, potentially more than any other domestic appliance, consumer usage patterns and ambient environmental conditions have a major impact on water heater energy consumption, and these variations have differing impacts depending on the type of water heater in use.

Unsurprisingly, developing effective strategies for the management of water heater energy consumption has proved challenging, and the strategies deployed vary significantly between jurisdictions. Regulatory and voluntary performance requirements range from minimising the energy consumption of individual water heater types to managing consumption through broadly technology neutral standards under specific operating conditions, and almost every combination in-between. When combined with differing test methodologies for the various water heater types, this has made the comparison of water heater performance challenging on the national level, and yet more so between countries.

Nevertheless, given their significant contribution to household energy consumption, policy makers continue to seek enhanced understanding of the comparative performance of water heaters to enable improved management of water heating energy consumption. Further, policy makers are seeking comparisons beyond their national markets to highlight potentially successful policy options and technological developments that they may adapt to local circumstances and/or to identify opportunities and risks that may arise from products arriving in their markets from elsewhere.

To provide policy makers with such information, this Benchmarking Report seeks to compare the performance of storage, instantaneous and heat pump water heaters available in a number of national markets by type, between type and by energy source. The report also seeks to outline the primary regulatory interventions in each jurisdiction and, where possible, provide an analysis of the associated improvements in the energy performance over the 2000-2015 period.

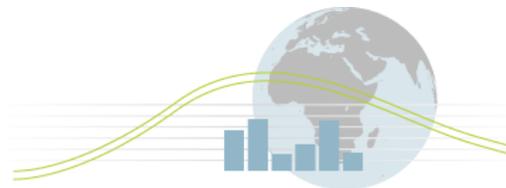
The products and regulatory policies compared are those recently available in Australia, Canada, China, Japan, the Republic of Korea, Sweden, and the USA.

The benchmarking has been undertaken as part of the Mapping and Benchmarking activities of the IEA's Efficient End-Use Electrical Equipment (4E) Technology Collaboration Programme. Water heaters are the sixteenth product to be compared internationally, with the results of all analyses available on the 4E website<sup>1</sup>.

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<sup>1</sup> <http://mappingandbenchmarking.iea-4e.org>





## 1.1 Important cautions

Water heaters are complex products that are often designed for individual markets where very specific test and regulatory regimes are in place. These test methods can differ by product type within a particular jurisdiction, and vary between jurisdictions. Very little empirical information is publicly available on how the various types of water heaters designed for these specific markets and regulatory regimes perform under alternative conditions. Therefore the normalisation process developed for comparing products of different types, and available in different jurisdictions, has notable limitations. Further, some of the data available for the analysis is limited in terms of market coverage and/or the performance criteria recorded for individual models. Hence, readers are strongly encouraged to make themselves familiar with the limitations and cautions contained within:

- Section 2.2.2: Overall approach to analysis and results presented;
- Section 2.3: Data sets analysed and reliability of normalised product performance data and regulatory requirements;
- Annex 1: Summary description of the normalisation process for minimum and premium performance requirements;
- Individual country Mappings which detail limitations of original data sets and any data set-specific manipulations undertaken <sup>2</sup>;
- The separate standalone document: *'Development of Conversion Factors and Overall Approach for International Comparisons of Water Heaters'* <sup>3</sup>.

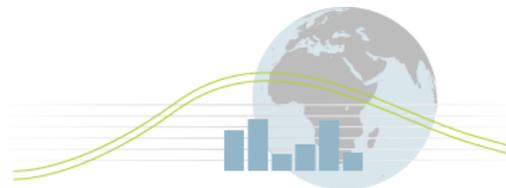
In particular, the normalised performance values for any *individual* model should be treated with caution and should be viewed within the context of the wider data set to which it belongs. Further, due to specific issues with data limitations and/or the normalisation process, significant additional uncertainty relates to normalised results for heat pump products for all countries, for Swedish storage water heaters, and the normalised regulatory performance requirements for the EU.

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<sup>2</sup> Individual Country Mappings are available for Australia, Canada, China, Japan, the Republic of Korea, Sweden, and the USA at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>

<sup>3</sup> Available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>





## 2 Benchmarking objectives, scope and approach to analysis, data sources and cautions

### 2.1 Objectives of the Benchmarking analysis

This analysis seeks to provide policy makers with:

- An outline of the primary policies implemented in each country analysed and, where possible, an indication of any associated improvements in the energy performance over the period 2000-2015;
- Information on the comparative performance by type, and between types, of a broad range of water heaters available in a number of national markets.

### 2.2 Scope and approach to analysis

#### 2.2.1 Scope

The analysis is limited to water heating products that<sup>4</sup>:

- Are primarily for use in the household environment (as defined at the individual country level);
- Have a primary water heating only function, i.e. excluding space heating functionality;
- Are closed systems with integrated water heating, i.e. excluding remote boiler and vented systems;
- Have gas or electric as their primary energy source.

As shown in Figure 1, a number of types of electric and gas water heaters are analysed in the Benchmarking. Insufficient data was available for the accurate analysis of electric instantaneous water heaters, and no data was available for analysis of gas heat pumps. Therefore comparisons are limited to electric storage and electric heat pumps, and gas storage and gas instantaneous water heaters. Comparisons of product performance are made on a 'delivered energy' basis due to the significantly different energy supply mixes in individual countries.

#### 2.2.2 Overall approach to analysis and results presented

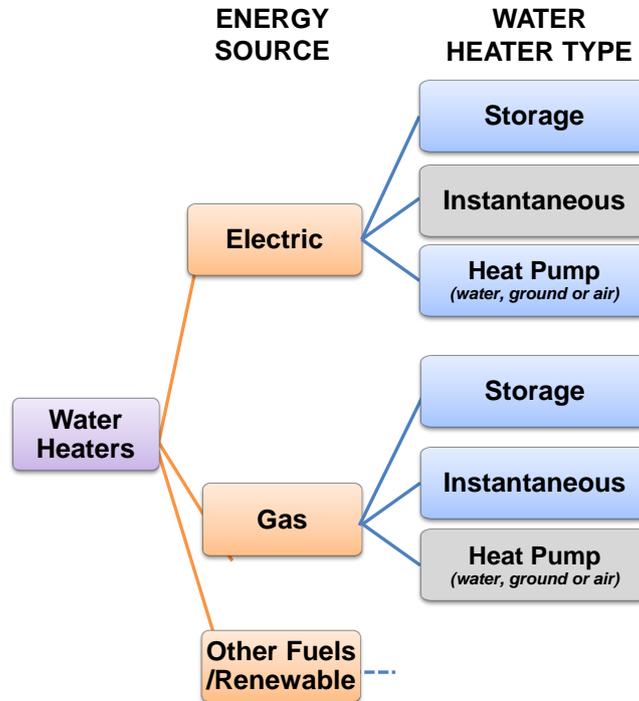
##### 2.2.2.1 Comparisons of water heater product performance

Figure 2 shows the simplified energy flows and average energy consumptions for storage water heaters across a range of volumes<sup>5</sup>. Depending on the country, the ambient conditions and hot water service specified in local test methods/regulatory requirements, the actual energy consumption for individual water heaters will vary significantly, and these variations become more pronounced between water heater types.

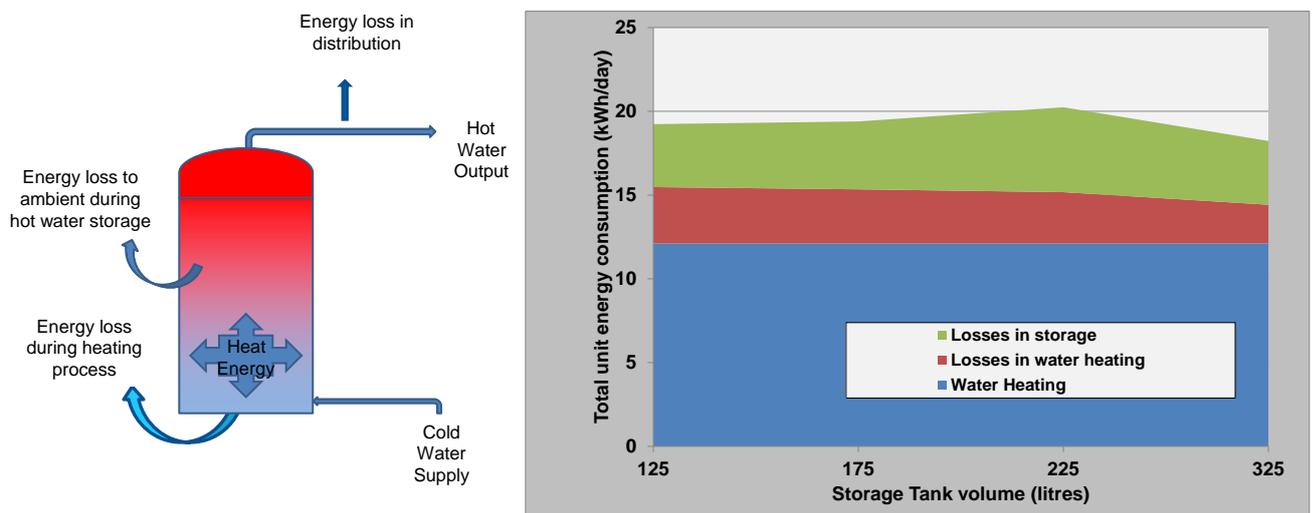
<sup>4</sup> To maintain comparability of product performance a number of additional exclusions have been applied to some data sets, e.g. the exclusion of storage water heaters with more than one tank. Where these exclusions are specific to an individual data set, details are included in the Mapping document for the country concerned (all national Mapping documents are available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>). Where the exclusion is more generalised, this is highlighted in the overall approach (refer to Section 2.2.2), or in the document text relating to the specific analysis being undertaken.



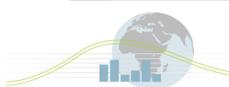
**Figure 1: Types of water heater analysed and the associated energy sources**  
*(Analysis is limited to water heaters using gas and electricity as their primary energy source. Insufficient data was available to analyse products shown in grey)*

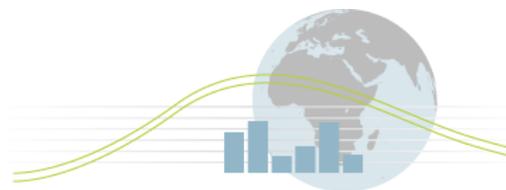


**Figure 2: Conceptual graphic of the energy flows in an unvented storage water heater<sup>5</sup>**



<sup>5</sup> Energy consumptions/losses based on an average of all unvented gas and electrical storage water heaters analysed when delivering a 12.113 kWh/day in 39 equal sized draws under 'normalised' conditions.





However, conceptually, the energy flows are *similar* for all water heater types. Consequently, by adopting a specific draw profile, a fixed set of ambient conditions and, where necessary making some limited assumptions, it is generally possible to compare the energy used to deliver that specific hot water service under generic local conditions. Subsequently, it is possible to transition to alternative draw profiles and/or ambient conditions. Thus, a methodology has been developed for the IEA 4E which allows such transitions and facilitates the comparisons of different water heater types at both the national and international levels. The generic approach for these conversions (termed normalisation) is detailed in the standalone document '*Development of Conversion Factors and Overall Approach for International Comparisons of Water Heaters*'<sup>6</sup>.

Figure 3 A-D provides a graphical representation of the results from each step of the process for electric water heaters; moving from the very different energy consumption values declared under local requirements to the (broadly) similar values under normalised Benchmarking reference conditions.

By adopting this approach:

- Individual **Country Mappings**<sup>7</sup> have been developed which, for each country analysed, provide:
  - Unit energy consumptions for individual water heater models as *declared* under the local requirements/test methods *for that type* of water heater. These declared values are presented in comparison with minimum and/or premium energy performance requirements in that country;
  - Unit energy consumptions for individual water heater models under a set of conditions that, as closely as possible, mirror local requirements across water heater types, thus enabling direct comparisons at the national level of water heaters of differing types;
  - Details of any manipulations and assumptions for each data set necessary to enable direct product comparisons.
- This **Benchmarking Report** has been developed which provides:
  - International comparisons of the energy performance of individual water heater types under normalised conditions;
  - Similar international comparisons of the performance of water heaters across all types of water heaters.

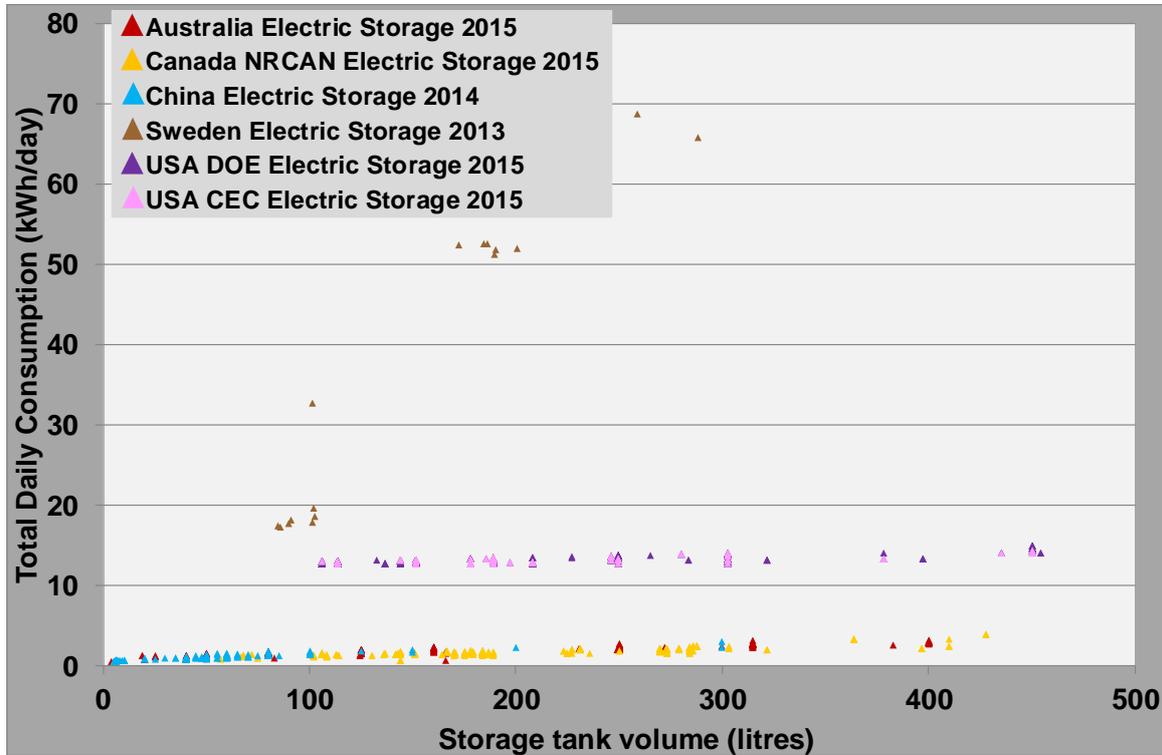
<sup>6</sup> Available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>

<sup>7</sup> Individual Country Mappings are available for Australia, Canada, China, Japan, the Republic of Korea, Sweden, and the USA at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>

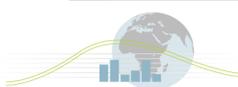
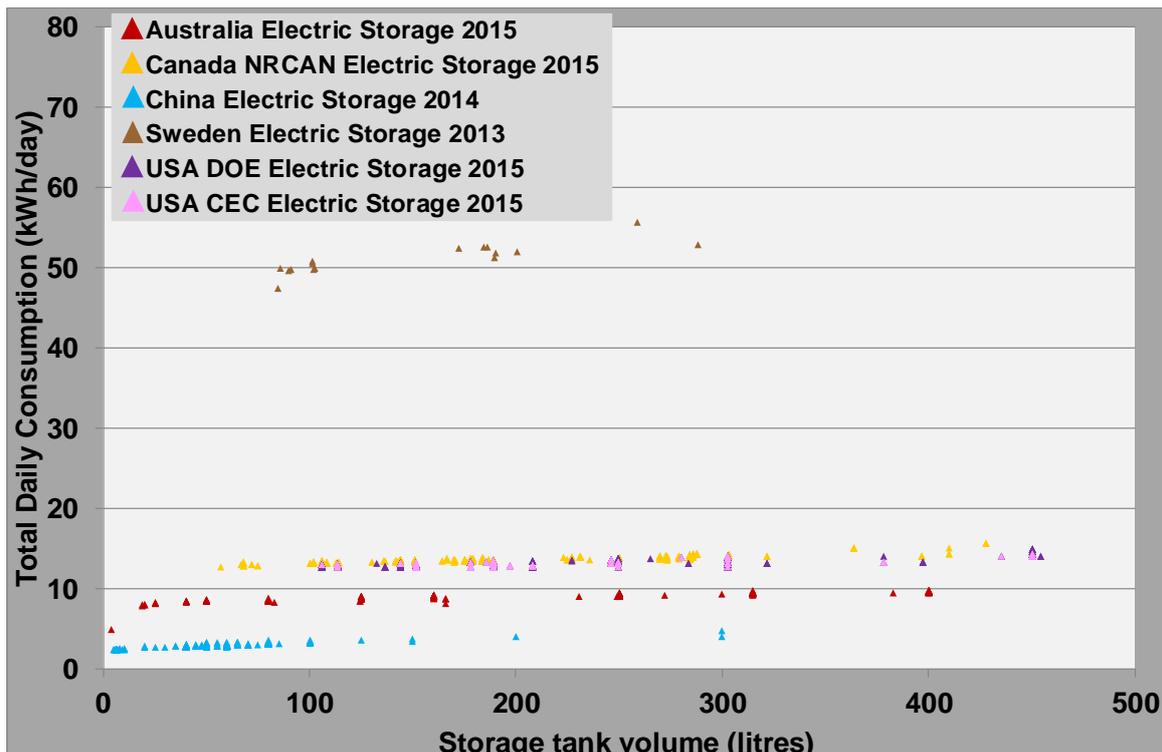


**Figure 3: Stages in Mapping and Benchmarking process (electric water heaters)**

**A: Locally declared values: Energy consumption values displayed as declared under national test conditions for each water heater type**

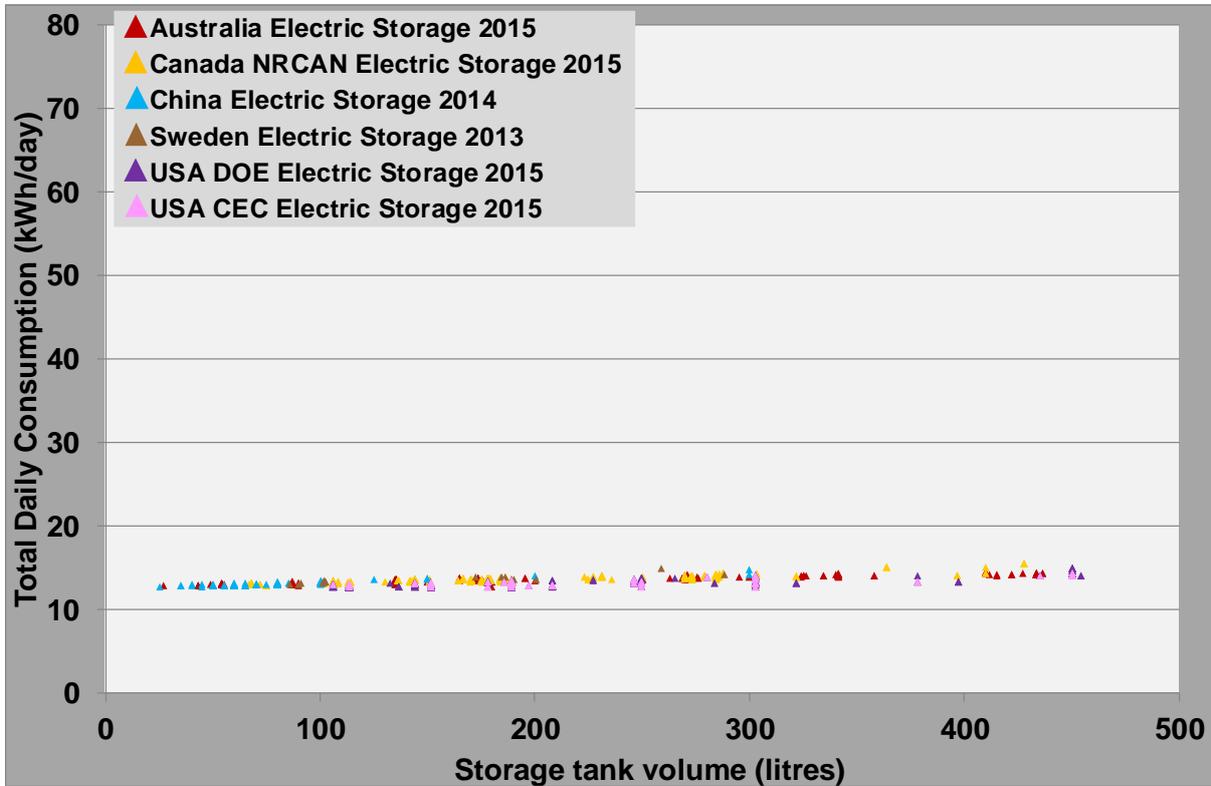


**B: Generic local conditions: Energy consumption values converted to generic local conditions, i.e. to be comparable with other water heater types under local conditions by adopting a generic set of temperature and draw-off conditions in line with those used across water heaters at the national level**

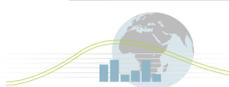
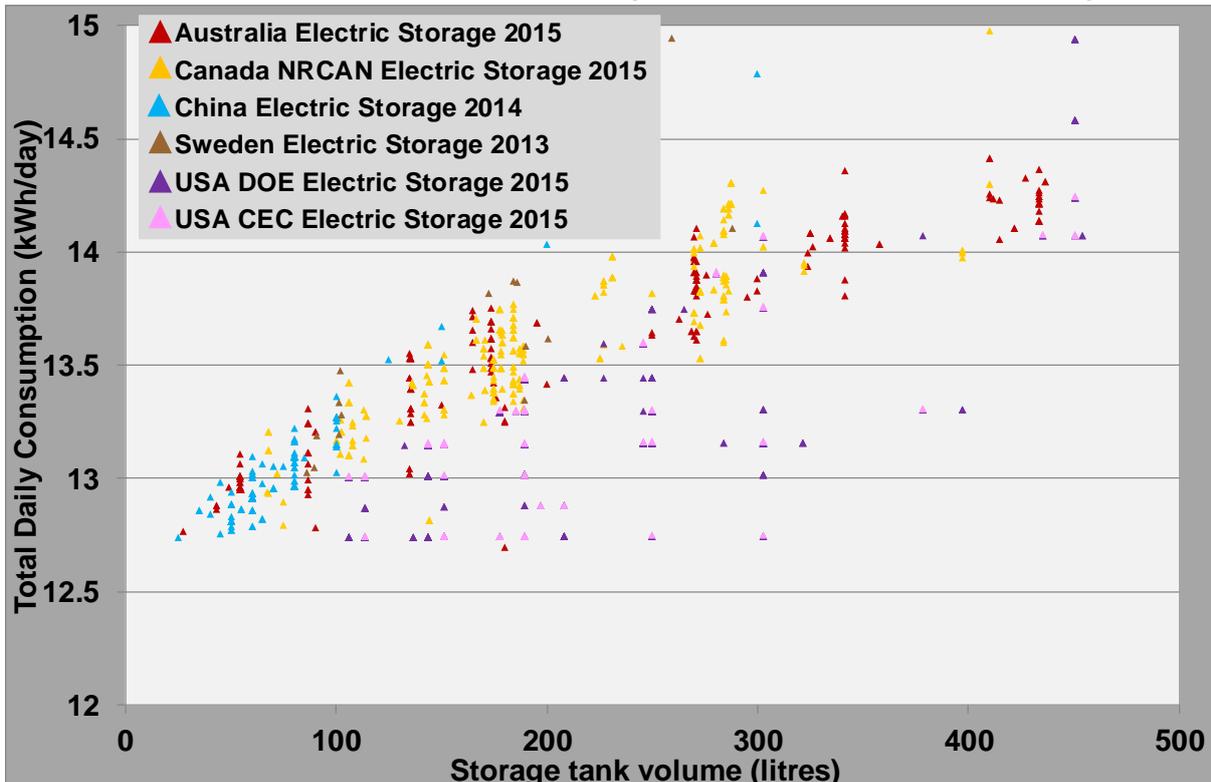




*C: Normalised reference conditions: Energy consumptions normalised to the benchmarked reference conditions, i.e. to be comparable with other water heater across international borders*



*D: Normalised reference conditions – rescaled: Energy consumptions normalised to the benchmarked reference conditions but with the y-axis rescaled to assist visual comparisons*





In line with previous 4E Benchmarking Reports, to minimise any distortion in reported product performance introduced by the normalisation process, the reference conditions to which normalisation occurs are aligned to those in the country/region supplying the largest number of data sets, in this case the USA. Hence, in general, product performance has been normalised to the operating conditions and draw profile defined in the USA test and regulatory requirements in place prior to July 2014<sup>8</sup> as shown in Table 1. Where individual pieces of analysis are based on other conditions, this is made clear in the associated text<sup>9</sup>.

**Table 1: Reference conditions used in the normalisation process**

Variable	Benchmarking Reference Condition
Total hot water delivered per day	12.113 kWh/day
Number of draws per day <sup>10</sup>	39 draws of equal size over an 18 hour period
Cold water temperature	14.44 °C
Hot water delivery temperature	57.22 °C
Average ambient temperature – internal	19.72 °C
Average ambient external temperature	21.8 °C

### 2.2.2.2 Alignment of products capable of providing similar service

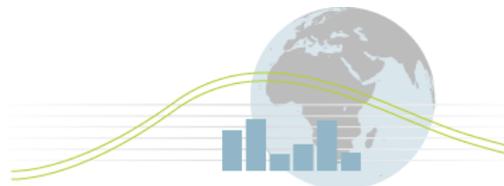
Following normalisation, comparison of the performance of products of the same type can be undertaken directly on a like-for-like basis. For example, the total energy consumption of storage water heaters can be compared simply by plotting total energy consumption relative to product volumes, thus providing direct comparisons of storage water heaters of any individual volume with other storage water heaters of the same volume.<sup>11</sup>

<sup>8</sup> On 11 July 2014, the US Department of Energy released a revised test procedure for residential and commercial water heaters. However, all data from the USA used in this analysis is based on declarations prior to the introduction of the new test methodology. For full details refer to the USA Mapping available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>

<sup>9</sup> Where additional assumptions have been widely necessary to enable comparison, these are detailed in the *Overall Approach*. Details of any assumptions and required data manipulations for individual data sets are included in the national Mapping relevant to that data set. All these documents are available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>

<sup>10</sup> Note the number of draws per day differs from the six specified in the USA regulatory requirements. However, the value selected is equivalent to 3.2 draws of equal size per kilowatt hour of water delivered (rounded up to an integer value) over an 18 hour period. This value more accurately represents the typical consumer usage patterns across the countries from which data was analysed and results in a more realistic projection of the comparative energy used by the varying water heater types under normal operating conditions.

<sup>11</sup> It should be noted that this approach does not alleviate all comparative issues. In particular, while the analysis tool used automatically filters out products unable to service the defined daily water heating requirements, the approach ignores the *capability* of products of the same type to deliver levels of hot water service significantly higher than the reference conditions chosen for benchmarking. For example, a 300-litre and a 600-litre direct electric storage water heater should both be able to service the hot water requirements defined in the Benchmarking reference conditions. Further, the efficiency of water heating of both products will be similar at around 98%. However, with identical levels of insulation, the heat loss from the water stored in the 600-litre model will almost certainly be higher than the heat loss from the 300-litre model simply due to the greater tank surface area of the larger capacity product. Hence the 600-litre model will need to expend more energy in maintaining the water at target storage temperature and consequently will have a reported lower overall efficiency (energy embodied in hot water supplied/energy input) than that for the 300-litre model. This is indeed correct at the specified Benchmarking conditions, but the 600-litre product is *capable* of servicing significantly higher daily hot water demands and, at these higher service levels, the model's overall efficiency levels would



However, such comparisons become more complicated for water heaters of different types where the typical characterisation of an ability to service a demand varies. To use a simple example, storage water heaters are typically marketed based on storage tank volume, while instantaneous water heaters are typically marketed on their ability to supply hot water at a specific flow rate. Therefore there is no direct equivalent metric by which to compare product performance.

Under specific and well defined service conditions, such ‘equivalence’ can be arrived at through measures such as the ‘first hour delivery capacity’ used in the USA and the recent requirement for manufacturer self-declaration of predefined service levels in EU. However, these comparative measures are not consistent between countries, where defined at all, and cannot reliably be transposed to the Benchmarking reference conditions as part of the normalisation process. Therefore, an alternate approach has been developed for comparison of products capable of delivering broadly equivalent service. While recognising the demand for hot water is very climate and culturally dependent, a simplistic assumption has been made that the distribution of service demands for hot water will be broadly similar in all countries. Further, it is assumed that the distribution of products available in the market will mirror the distribution of service demands.<sup>12</sup> Thus, by analysing the distributions of the storage volumes and flow rates of products available in the differing markets (refer to Annex 2), and aligning the peak average volumes and flow rates for each type, products delivering broadly equivalent levels of service fall within the ranges shown in Table 2. Hence, these volume and flow rates are used when comparing products of differing types.

**Table 2: Estimated size/capacity of water heaters of different types delivering equivalent levels of service**

Product Type (comparative metric)	Estimated Product Equivalence			
<i>Electric and Gas Storage Water Heaters (volume in litres)</i>	100	200	300	400
<i>Air Source Heat Pumps (volume in litres)</i>	180	280	380	480
<i>Electric and Gas Instantaneous (flow rate in litres/minute)</i>	10	15	20	25

### 2.2.2.3 Comparisons of minimum and premium performance requirements

In addition to the comparisons of product performance, a summary analysis of minimum and premium performance standards has been undertaken. As with individual products, in order to compare the prescribed performance requirements from the differing countries, it is necessary to normalise to the reference Benchmarking conditions. In a number of cases the normalisation may follow the same methodology as used for products. However, where

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be notably higher as the heat loss during storage would be proportionately lower in comparison to the energy embodied in the hot water supplied. To some extent this limitation to the analysis is alleviated in inter-product type comparisons where products of similar service levels are compared. However, care should be taken when comparing products of the same type with significantly different performance capabilities.

<sup>12</sup> This approach is simplistic as, beyond consumer preference and demographics, there is a wide range of other factors influencing products available in national (and local) markets ranging from physical limitations to the size or type of product that can be deployed (e.g. limited space for storage water heaters), to the availability of energy sources (e.g. no access to gas supplies). However, given the limited data available to the analysis, the simplistic approach described is the only apparent practical option to estimate equivalence of service between product types.





national requirements are defined based on maximum energy consumption for a defined load profile, normalisation becomes more complex. An approach has been developed to deal with this issue and is summarised in Annex 1, but it should be noted that this approach has significant uncertainties and normalised performance requirements derived in this way should be treated with caution. In particular, the normalised performance requirements for all products in the EU and for Australian instantaneous water heaters should be treated as illustrative only.

Where comparisons are made of the performance requirements for products of different types, the volume and flow rates defined in Table 2 are again used as the basis for 'equivalent service'.

## 2.3 Data sets analysed and reliability of normalised product performance data and regulatory requirements.

### 2.3.1 Sources, sizes and age of data sets

Analysis was conducted on the performance of approximately 10,000<sup>13</sup> individual water heater models available in the Australian, Canadian, Chinese, Japanese, Korean, Swedish, and United States markets. A summary of the sources and sizes of data set analysed by each type of water heater is given in Table 3. Figure 4 shows a graphical representation of years for which model data is available in each data set. While these graphics are simple summaries, they do highlight the differences in the sizes of the various data sets and illustrate that in some cases (particularly Sweden) analysis is limited by the overall number of models for which data is available. Further, even where data sets appear to be quite large, where the total models are spread over a number of years, the number of models in any particular year may be limited.<sup>14</sup>

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<sup>13</sup> Table 3 shows approximately 20,000 individual product records from all data sources. However, in a number of markets all models were not necessarily unique (e.g. where a particular product had some attribute that did not affect the product performance it necessitated two model numbers to be recorded, e.g. product colour or position of fittings). Similarly, where more than one data set was available for a specific country, individual models may be common to both data sets (e.g. the US DoE federal register and products registered under ENERGY STAR). Less frequently models *that could be identified* as identical appear in data sets from more than one country. Consequently it is estimated that approximately 10,000 unique water heater models were analysed.

<sup>14</sup> Further details of content source and other information on data sets are provided in the individual country Mappings available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>

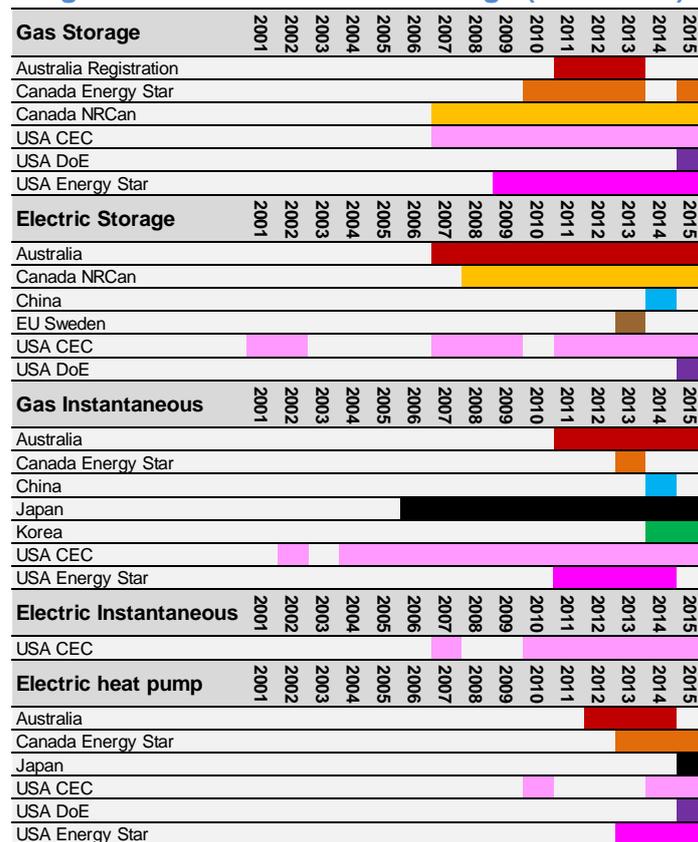




**Table 3: Summary of sources and sizes of data sets analysed by water heater type**

Product Type	Country	Source	Product Level Records
Electric storage	Australia	Energy Rating National Register	488
	Canada	Federal Register	584
	China	Market Survey/National Product Register <sup>15</sup>	595
	Sweden	Confidential	16 <sup>16</sup>
	USA	Department of Energy (DoE)/ California Energy Commission (CEC)	1373/1370
Gas storage	Australia	Energy Rating National Register	84
	Canada	Federal Register/ENERGY STAR	1712/190
	USA	DoE/CEC/ENERGY STAR	3428/4223/734
Gas instantaneous	Australia	Energy Rating National Register	158
	Canada	ENERGY STAR	104
	China	Market Survey/National Product Register <sup>15</sup>	338
	Japan	Ministry of Economy, Trade and Industry (METI)	356
	Korea	KEA National Register	2823
	USA	CEC/ENERGY STAR	1705/374
Electric instantaneous	USA	CEC	194
Electric air source heat pump	Australia	Energy Rating National Register	136
	Canada	ENERGY STAR	190
	Japan	Ministry of Economy, Trade and Industry (METI)	230 <sup>17</sup>
	USA	DoE/CEC/ENERGY STAR	171/107/119

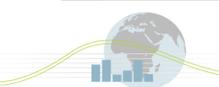
**Figure 4: Periods of data coverage (2001-2015)**

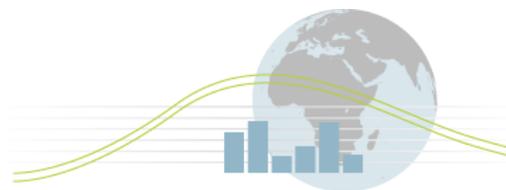


<sup>15</sup> Data from China gathered through capture of data from the four largest national retailers and cross referenced to the National Register administered by the China National Institute of Standardisation (CNIS).

<sup>16</sup> Data from Sweden is based on tests conducted in 2013 which predate the current regulations. Hence, the products tested were not required to comply with any specific product performance requirements. However, tests were conducted in line with the current regulatory requirements.

<sup>17</sup> This is the total number of Japanese heat pump records submitted, although a smaller number (49) were actually analysed due to a significant number of products having functionality beyond the scope of the comparisons (e.g. multiple storage vessels).





### 2.3.2 Original data quality, impact of the normalisation and the grading of resulting outputs

Significant efforts were made by all participants to obtain information on the performance of products within their national markets, and to ensure the integrity of the data supplied. However, inevitably the specific nature of each data set is different. For example, the content may differ either in the product attributes captured during original data collection, or in the method of capture, e.g. compulsory product registration as products originally enter a market compared with somewhat less comprehensive surveys of the actual products sold within a market in a particular year.<sup>18</sup> Further, the manipulation required to firstly align, and then normalise data sets introduces additional uncertainty into the comparability of results.

In an effort to assist readers in understanding the degree of confidence that may be placed in individual input data and results, the IEA 4E has developed a system for 'grading' the outputs associated with individual data sets, and the comparability of those outputs with outputs from data sourced elsewhere. The grading system developed to provide a measure of the confidence or reliability of analysis and particular outputs is based on an appraisal of the type and quality of the initial data input, and the degree to which any consequential manipulations are *likely* to have degraded the reliability of the original data and/or the comparability of outputs with those of other countries. While expert opinion is used to formulate the specific grading allocated to individual data sets or outputs, this expert opinion is formed based on a consistent framework outlined in Annex 3.

Based on the grading system outlined above, each output used in this report has been allocated a 'robust', 'indicative' or 'illustrative' grading as summarised in Table 4.

**It is strongly recommended that readers familiarise themselves with the gradings allocated to each output to ensure they have an understanding of the degree of confidence they may place in individual outputs and associated observations.**

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<sup>18</sup> Although even product registration databases have problems associated with whether a registered product actually entered the market, and the longevity of that product's time in the market.





**Table 4: Summary of grading of Mapping, Benchmarking and regulatory requirements**

Country	Product Type	Mapping	Benchmarking	Mandatory and Voluntary Regulations
Australia	Heat Pump	Robust	Indicative	Not Applicable
	Electric Instantaneous	Robust	Indicative	Not Applicable
	Electric storage	Robust	Indicative	Indicative
	Gas storage	Robust	Indicative	Indicative
	Gas Instantaneous	Robust	Indicative	Indicative
Canada	Heat Pump	Robust	Robust	Robust
	Electric storage	Robust	Robust	Robust
	Gas storage	Robust	Robust	Robust
China	Electric storage	Robust	Indicative	Indicative
	Gas Instantaneous	Robust	Indicative	Illustrative
Japan	Gas Instantaneous	Robust	Robust	Robust
	Heat Pump	Indicative	Indicative	Illustrative
Korea	Gas Instantaneous	Robust	Robust	Robust
Sweden	Electrical Storage	Illustrative	Illustrative	Illustrative
USA CEC	Electric Instantaneous	Robust	Indicative	Not Analysed
	Heat Pump	Robust	Robust	Not Analysed
	Gas Instantaneous	Robust	Indicative	Not Analysed
	Gas storage	Robust	Robust	Not Analysed
	Electric storage	Robust	Robust	Overall
USA DoE	Electric Instantaneous	Indicative	Indicative	Robust
	Gas storage	Indicative	Indicative	Robust
	Heat Pump	Indicative	Indicative	Not Applicable
USA ENERGY STAR	Gas Instantaneous	Robust	Indicative	Indicative
	Gas storage	Robust	Robust	Robust
	Heat Pump	Robust	Indicative	Robust





### 3 Comparisons of minimum and premium performance requirements

Despite the heating of water being one of the largest consumers of energy in the household sector, the difficulties in effectively characterising and regulating water heating product performance in a meaningful way are amply demonstrated by the relatively late introduction of performance requirements in most countries.<sup>19</sup> As can be seen from Figure 5, for the vast majority of countries, performance requirements of any kind were not introduced until at least 2000 and, in many cases, later than 2010.<sup>20</sup> This contrasts with other major domestic energy using products, such as refrigerators, where most countries/regions had introduced minimum performance requirements by the end of the 1990s.

Figure 5 also illustrates that the types of water heater covered by performance requirements vary significantly, with the two extremes being the EU and the USA that have performance requirements spanning almost all water heater types, and Korea where only gas instantaneous products have mandatory performance requirements. However, with the exception of China,<sup>21</sup> this broadly reflects the prevalence of product types used in those particular markets, for example over 90% of water heater only products in Korea are gas instantaneous water heaters,<sup>22</sup> while the EU and the USA have a much broader mix of all product types in use.<sup>23</sup>

<sup>19</sup> While the scope of this analysis is limited to regulatory interventions on minimum product efficiency, it is important to note that a wide range of policies is in place seeking to positively influence the efficiency of water heaters available in the market, and to encourage consumers to select more efficient models and/or types. For example, all countries included in this analysis have water heating labelling of some kind, although specific product coverage and regulatory nature (voluntary, mandatory, etc) vary considerably. In addition, policy interventions extend far beyond (and often pre-date) such regulatory requirements and include direct and indirect product subsidies (including white certificates), mass communications programmes, product selection tools, etc. While non-comprehensive, details of some of these additional policies are given in the individual country Mappings, and a selection are detailed in the two water heating reports issued by CLASP.

<sup>20</sup> On 11 July 2014, the US Department of Energy released a revised test procedure for residential and commercial water heaters. However, all data from the USA used in this analysis is based on declarations prior to the introduction of the new test methodology and so performance requirements based on this new test methodology are excluded from the analysis. For full details refer to the USA Mapping available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>

<sup>21</sup> Currently China has mandatory performance requirements for only electric storage and gas instantaneous water heaters, reflecting the historic structure of the market. However, a much wider range of water heaters is now becoming widely used and proposals for the introductions of technology neutral standards have recently been released.

<sup>22</sup> The 90% reflects water heater only products. Overall the water heater market in Korea is dominated by combination systems which heat water and supply underfloor heating.

<sup>23</sup> More detail on the prevalence of individual product types by market can be found in the individual country Mappings and in the 'Summary Characterisation of 4E Participant Water Heater Markets', all available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>





**Figure 5: Date of introduction and revision of minimum and premium product performance requirements**

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
<b>All types</b>																										
Sweden (via EU regulations)																										
<b>All gas types</b>																										
Australia																										
<b>Gas storage</b>																										
Canada																										
USA DoE																										
USA/Canada ENERGY STAR																										
<b>Gas Instantaneous</b>																										
China																										
Japan																										
Korea																										
USA DoE																										
USA/Canada ENERGY STAR																										
<b>Electric Storage</b>																										
Australia																										
Canada																										
China																										
USA DoE																										
<b>Heat pump</b>																										
Japan																										
USA ENERGY STAR																										

♣symbol indicates dates of revision/required compliance

As highlighted previous, the regulatory frameworks (i.e. the test method, draw profiles where specified, and resulting performance requirements) vary enormously and continue to evolve. This is amply demonstrated by Figure 6 which shows how all product performance requirements have evolved over time (as specified under local conditions<sup>24</sup>); the more legible Figure 7 shows the same information but includes only a limited number of draw profiles from the EU (where the variety of permissible hot water draw profiles distorts the previous graphic); and Figure 8 which shows the same information but only for the most recent performance requirements in each country.

<sup>24</sup> In some cases slight modifications have had to be made to local declarations to enable inclusion on a single graphic. For example, where regulations only specify a heat loss rate for storage tanks, this has been assumed to be steady state for 24 hours. Similarly, for gas units where only a water heating efficiency rate is specified, the local equivalent draw profile has been used (or where no local equivalent draw profile, the reference load profile is used).

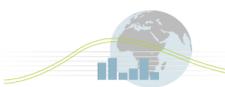
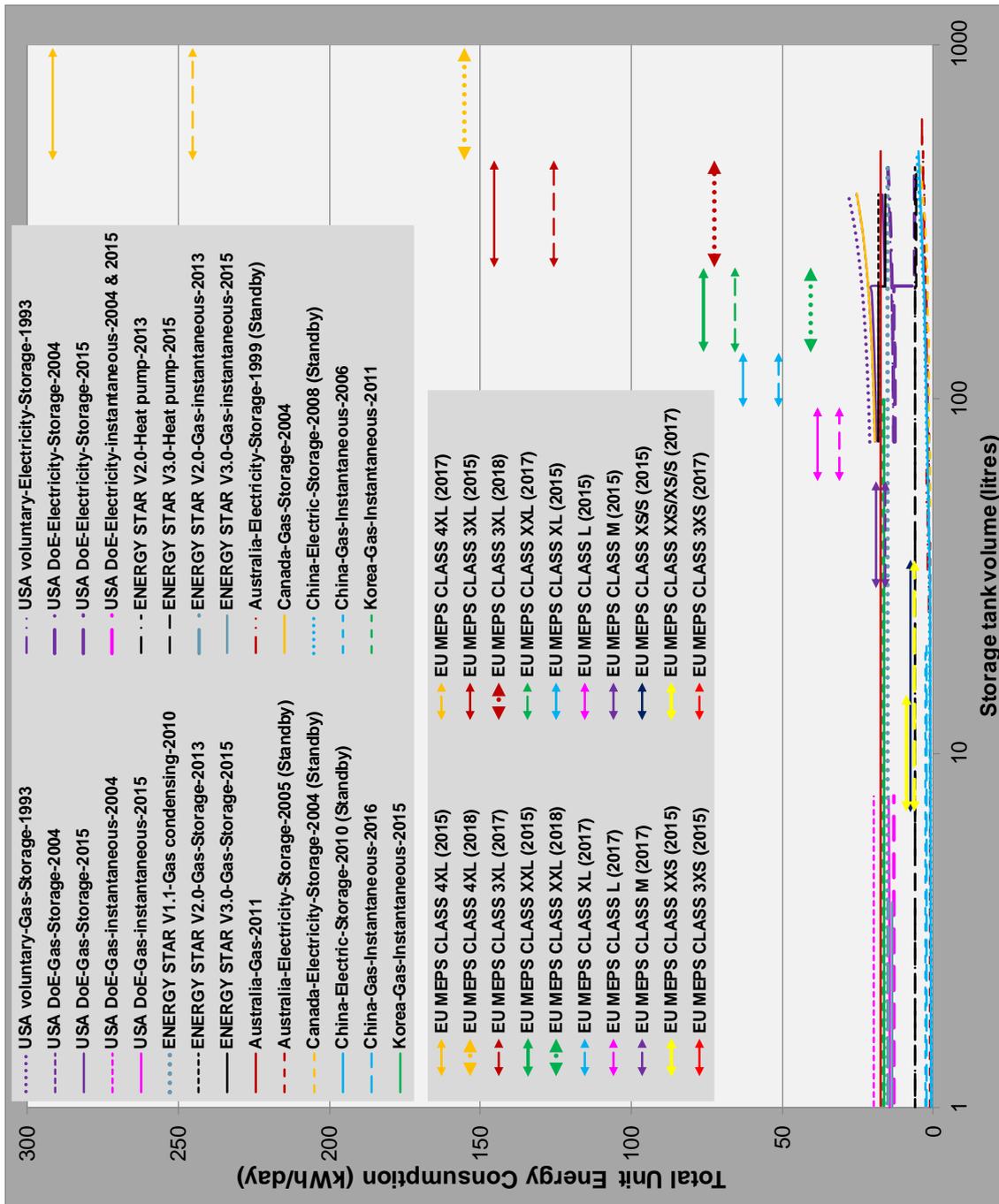




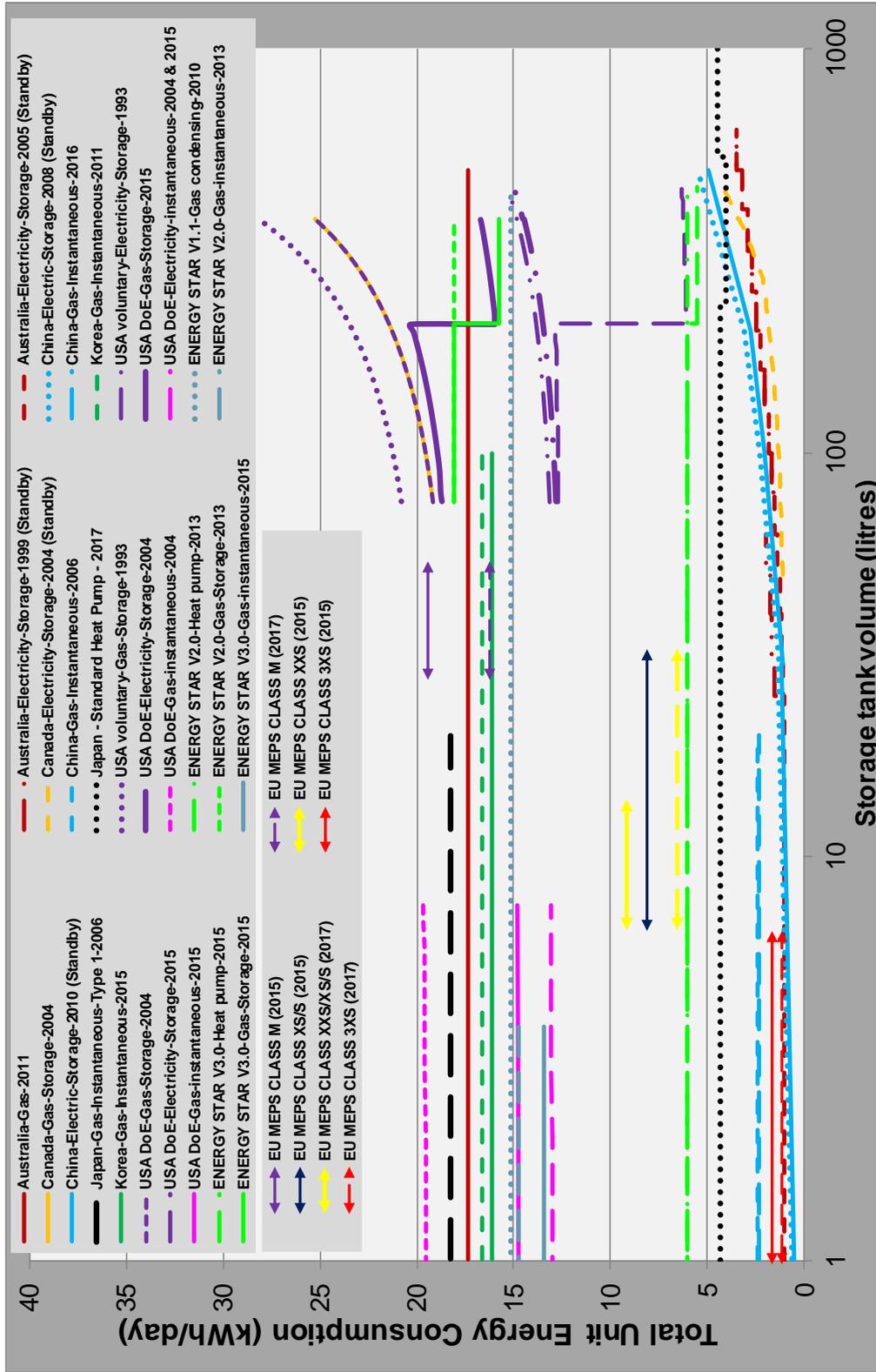
Figure 6: Current and historic product performance requirements as specified under local conditions over time<sup>25</sup>



<sup>25</sup> The EU regulations are formulated based on a series of specified draw profiles to which suppliers declare their products. For declared profiles of 'S' and smaller, a maximum storage volume is also defined for products (e.g. a maximum of 36 litres for storage water heaters declared to service draw profile 'S'). For products with draw profiles of 'M' and above, the EU places no maximum volume value. However, for storage water heaters, all profiles have a 'Requirements for mixed water at 40°C' (refer to the Sweden Mapping Document available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>). To provide a 'volume' based metric for declared profiles of 'M' and above to enable comparison with regulations elsewhere, these 'mixed water' requirements have been converted to a nominal storage volume based on a ratio of  $[(mixed\ water\ temperature - nominal\ cold\ inlet\ temperature) / nominal\ storage\ temperature]$ , i.e.  $(40-10)/65$ . However, due to differences in the likely reheat profiles implicitly assumed in the various regulations, it should be noted that the calculated EU tank volumes are likely to be larger than storage water heaters capable of supplying equivalent service from other countries.

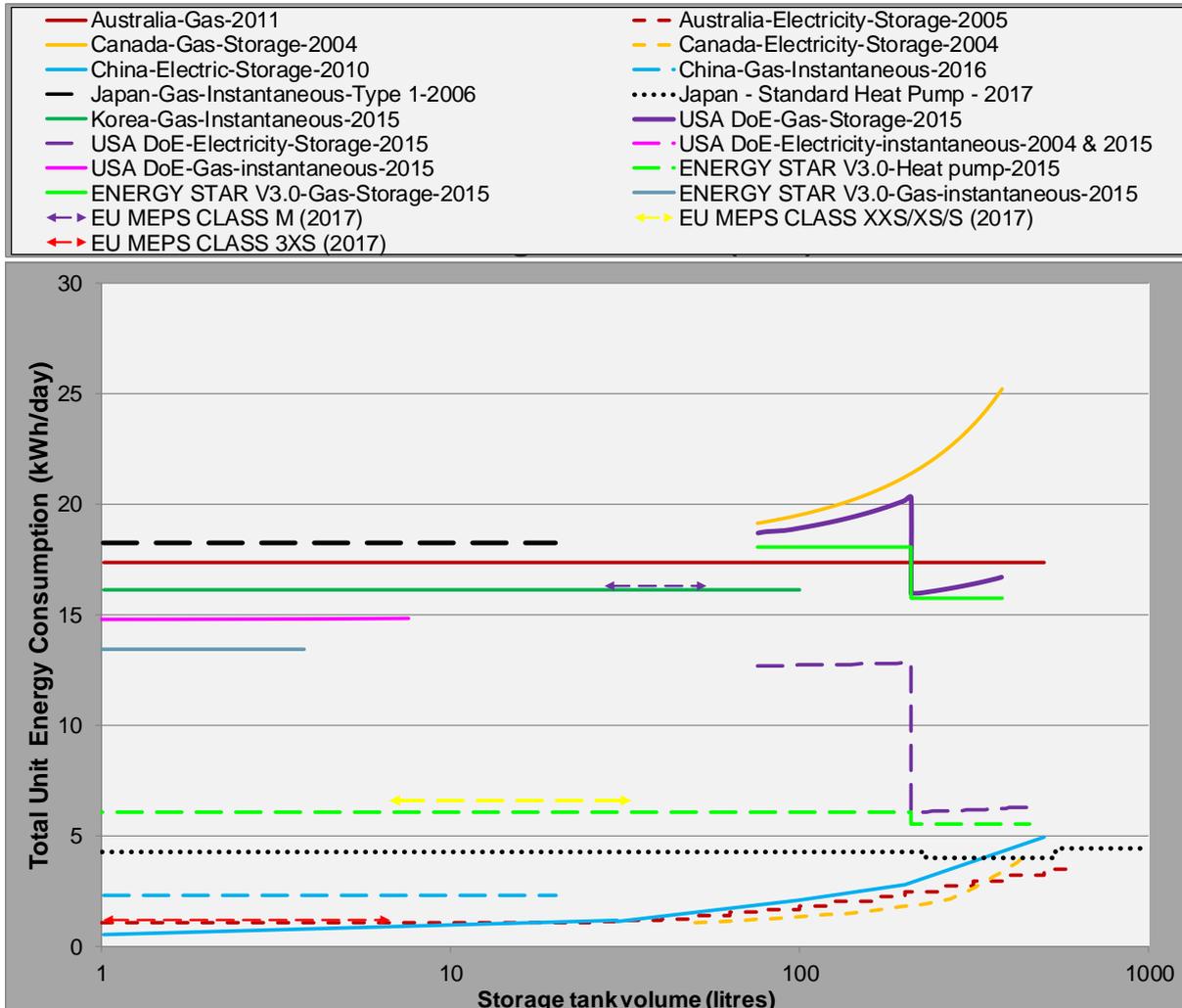


Figure 7: Current and historic product performance requirements as specified under local conditions over time (limited EU profiles<sup>25</sup>)





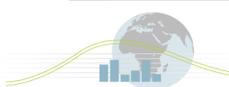
**Figure 8: Most recent product performance requirements (all water heater types) as specified under local conditions (limited EU profiles<sup>25</sup>)**



While Figure 6 to Figure 8 show the great variations in performance requirements, in themselves they do little to illuminate how the requirements differ. However, a degree of clarity can be brought by examining only the most recent regulations for gas and electric storage water heaters.

As Figure 9 demonstrates, Australia, Canada and China have broadly similar performance requirements for electrical storage water heaters, all based on heat loss as a function of volume (or a direct equivalent), although under differing hot water and ambient air temperatures. No restriction is placed on the electrical heating efficiency, although this must be measured and reported in Canada. However, for the equivalent gas storage water heaters:

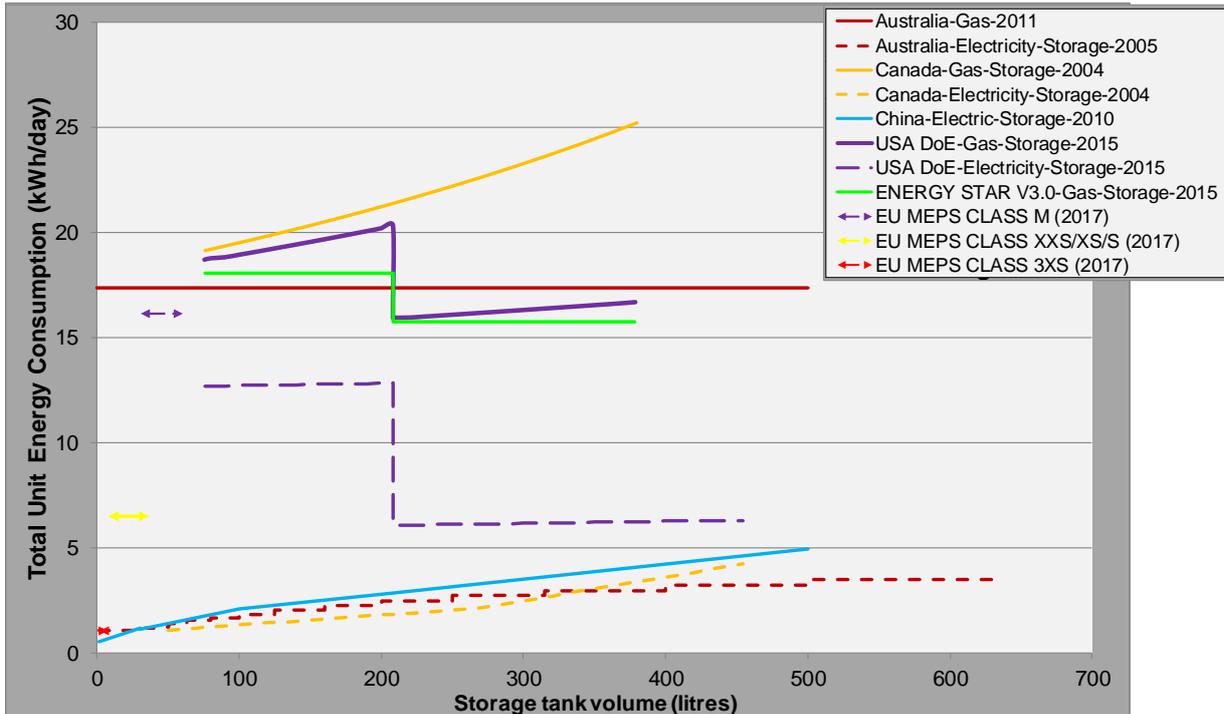
- Canada uses a defined daily draw profile with maximum energy consumption as a function of volume; the draw profile is harmonised with the USA and performance requirements are aligned with those in the USA in 2004.





- Australia has a defined draw profile with fixed maximum daily energy consumption irrespective of tank volume; this maximum daily consumption is aligned with that for gas instantaneous units.
- China currently has no regulation of gas storage water heaters.

**Figure 9: Most recent performance requirements (gas and electric storage water heaters only) as specified under local conditions (limited EU profiles<sup>25</sup>)**

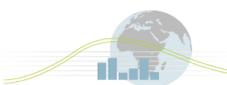


Conversely, for *all* water heater types, the USA (federal DoE regulations and the voluntary ENERGY STAR<sup>26</sup>) define a specific draw-off profile, but then assign differing performance requirements depending on product type. In this case a stepped function at 55 gallon (208 litre) storage capacity for both gas and electrically heated units, although at notably different daily energy consumption requirements. For electrical storage models, this step function requires performance levels that can only be met by electric heat pump units for all ENERGY STAR qualified and federally regulated products above the threshold. Similarly, both gas storage and instantaneous water heaters above the threshold will be required to be condensing units.

The recently introduced EU requirements also use a range of allowable draw profiles with minimum performance requirements attached to each. However, these draw profiles are completely energy source/product type neutral.

Hence, the strategies deployed for managing energy consumption in individual countries vary significantly and, in this form, still may not be compared directly given the differing test methods/ambient conditions, draw profiles and performance metrics used. However, by

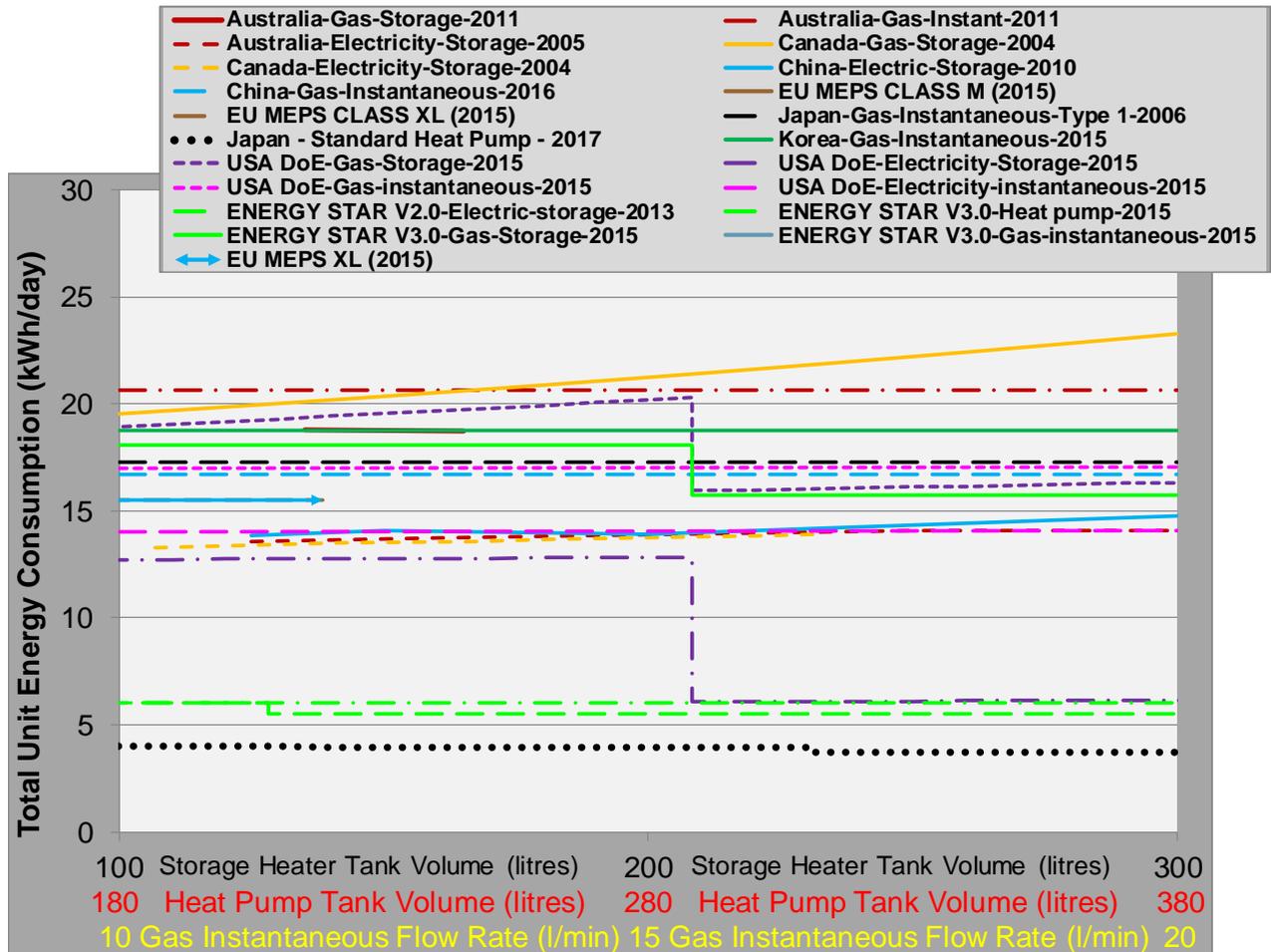
<sup>26</sup> Canadian ENERGY STAR requirements align with those in the USA.





normalising to the Benchmarking reference conditions (refer to section 2.2.2.3) and aligning similar service levels (refer to section 2.2.2.2), the performance requirements can be compared directly, albeit with a degree of caution. Figure 10 shows the most recent performance requirements under these normalised and aligned service conditions.

**Figure 10: Most recent product performance requirements for all countries under Benchmarked reference conditions and aligned to similar service levels (EU electric storage water heater only<sup>2527</sup>)**

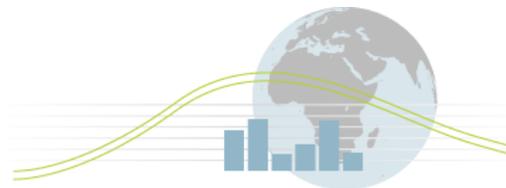


It is not a surprise to see, in general, the performance requirements fall into a series of bands:

- **Total Unit Energy Consumption of 4-6 kWh/day:** Air sourced electric heat pumps (and the de facto heat pump requirement for USA units above 208 litres).
- **Total Unit Energy Consumption of 13-15 kWh/day:** Most electric storage products.

<sup>27</sup> Normalisation of EU regulations requires information on typical product performance (refer to Annex 2). Unfortunately sufficient product performance information is available for the normalisation of only the small number of draw profiles shown, and for electrical storage water heaters only.





- **Total Unit Energy Consumption of 17-19 kWh/day:** Most gas instantaneous products. Australia is a clear outlier at approximately 21 kWh/day.
- **Total Unit Energy Consumption of 16-23 kWh/day:** Most gas storage products.

What is more surprising is the relatively large spread of these bands. The variations are 12% to 50% when looking at total daily energy consumption. Further, these ranges increase significantly to 30-100% when only examining the manageable elements of energy consumption related to the water heating and storage losses (i.e., when the embodied energy in the heated water is discounted). While undoubtedly some of the spread is the result of shortcomings in the normalisation process, it is highly unlikely to account for such a large variation. Thus, there appears significant potential scope for tightening performance requirements across a range of product types in countries where current performance requirements are more than a few years old.

It is also interesting to note, as far as it is possible to establish from the data available, no country has yet established a technology neutral set of performance requirements that results in the delivery of the lowest energy consumption for a given draw profile, irrespective of water heater type.<sup>28</sup> The closest example appears to be the USA, and even here it is limited to products that use a particular energy source (e.g. gas or electricity).<sup>29</sup> In the USA, the voluntary ENERGY STAR version 3.0 requirements for electric storage water heaters (and for larger electric storage water heaters under the imminent mandatory DoE federal regulation), may only be achieved through use of heat pump water heaters and *effectively* remove direct electrical resistance heated storage tanks from the market. Similarly, for gas storage water heaters above 55 gallons (approximately 210 litres), both the Federal regulation and ENERGY STAR require condensing technology performance levels (the potential market impact of these new USA requirements is investigated further in Section 4.6). Given the large disparities in energy consumption between the water heater types in many countries (at least on delivered energy basis), there seems to be an opportunity to significantly strengthen requirements to drive out the least efficient technologies where energy and building infrastructures allow.

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<sup>28</sup> The mandatory EU energy label is fully technology neutral for all water heaters across a number of draw profiles. However, the associated minimum performance requirements do not necessarily result in the most efficient technology solution being the only one available.

<sup>29</sup> Note the market change resulting from the ENERGY STAR revisions will also apply to Canada which helps develop and also applies the ENERGY STAR performance requirements.





## 4 Comparisons of water heater product performance

### 4.1 Introduction

This chapter provides direct comparisons of the energy performance of water heaters recently available in the various international markets. This performance data is presented based on technology (conventional storage, heat pump storage and instantaneous), the various energy consumption/energy losses associated with each technology type and, where applicable, further subdivided to differentiate between energy source (electric and gas). Subsequently, the various product performance data is brought together for direct comparison of overall energy performance across technology types.

As noted in Section 2.2, insufficient data was available for the accurate analysis of electric instantaneous water heaters, and no data was available for analysis of gas heat pumps. Therefore comparisons are limited to electric storage and electrical heat pumps, and gas storage and gas instantaneous water heaters. Comparisons of product performance are made on a 'delivered energy' basis due to the significantly different energy supply mixes in individual countries.

### 4.2 Storage water heaters (electric and gas)

#### 4.2.1 Heat loss during water storage

##### 4.2.1.1 Electric storage water heaters

Electric storage units are the simplest type of water heater. As the water is heated directly by a submerged electrical resistance heater, losses in the actually water heating process are limited. Therefore, the primary manageable loss occurs from heat energy in the stored hot water being lost to the ambient environment through the tank wall and insulation.

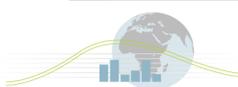
Consequently, a number of countries (Australia, China<sup>30</sup> and Canada) only regulate this aspect of electrical storage water heater consumption, thus making these losses transparent in the data sets provided.<sup>31</sup> Combined with limited product test data from Sweden,<sup>32</sup> direct comparisons of normalised heat loss rates are possible (Figure 11).

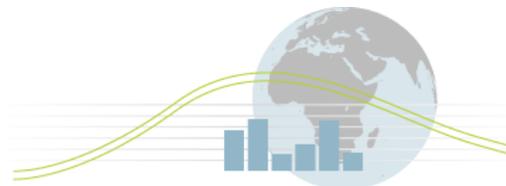
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<sup>30</sup> Technically China does not report heat loss rate. However, indirect derivation of values is possible to a relatively high degree of certainty. For more details refer to the China Mapping document at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>

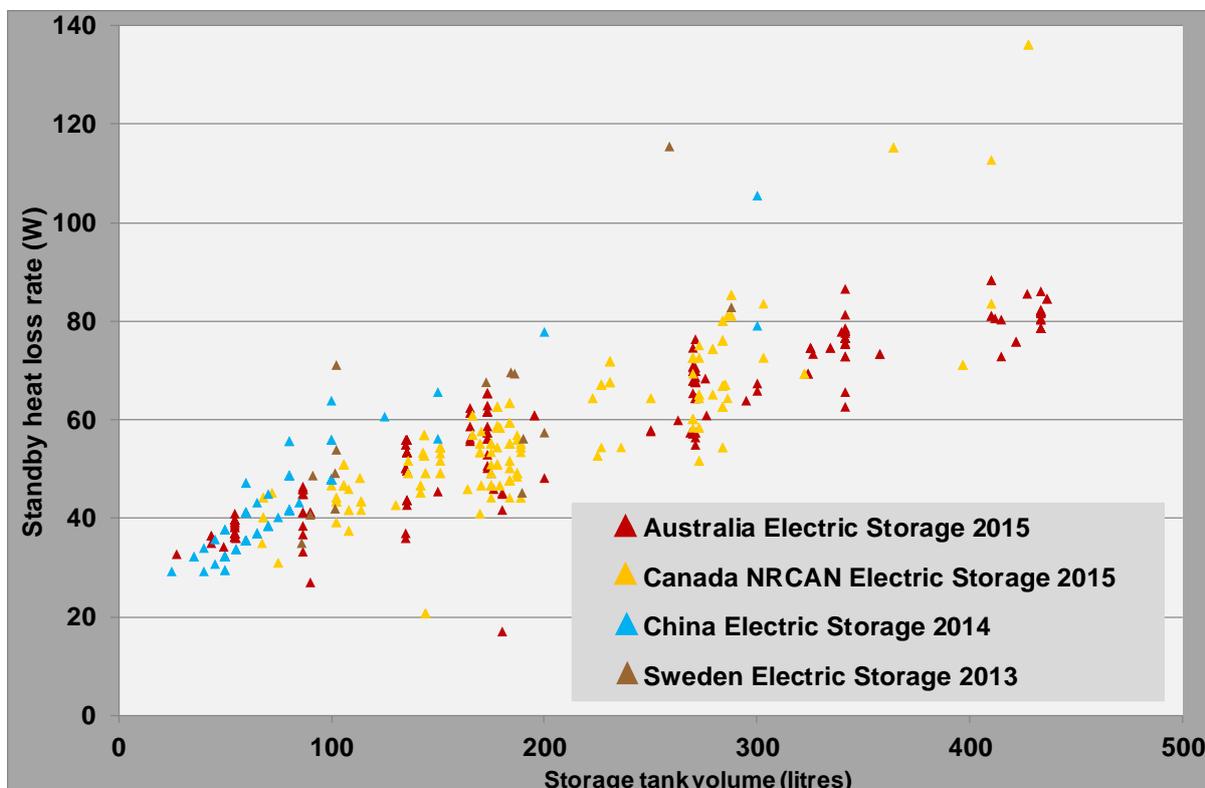
<sup>31</sup> A heat loss test for storage water heaters is also conducted in most other jurisdictions and in many cases regulated individually (e.g. in Canada.) or as part of daily energy consumption values (e.g. in the USA), but the resulting values are not always reported separately.

<sup>32</sup> Data from Sweden is based on tests conducted in 2013 which pre-date the current regulations. Hence, the products tested were not required to comply with any specific product performance requirements. However, tests were conducted in line with the current regulatory requirements.





**Figure 11: Normalised heat loss rate for electric storage water heaters in countries where values are directly reported (for most recent year data is available)**



For most volumes, the spread of heat loss rates from electric storage water heater models from Australia and Canada are broadly similar, and slightly lower than those in China. Overall, this results in a spread of over 50 W between the best and worst performing products available across international markets, or more than twice the heat loss rate of the best performing Australian and Canadian models at the internationally typical 200 litre tank size. Looking only within individual country data sets (which negates the uncertainties with normalisation), spreads of over 30 W are shown between the best and worst performing products around this typical 200 litre volume. Further, this differential between best and worst product will be larger in countries where water storage temperatures are higher than the reference delivery temperature (57.2°C)<sup>33</sup>, and/or average ambient conditions cooler than the reference (19.7°C).

While not directly reporting the heat loss rate, it is possible to add the USA’s CEC and DoE models to the heat loss graphics by adopting the typically assumed direct electrical heating efficiency of 98%.<sup>34</sup> This addition is made in Figure 12 and appears to suggest storage water heaters in the USA have significantly lower heat loss rates than elsewhere. However, in this

<sup>33</sup> In many countries hot water storage is 60°C or above. This is partly responding to the desire to maximise heat density in any particular tank size, but also as a response to perceived risk of the salmonella bacteria developing in the stored water.

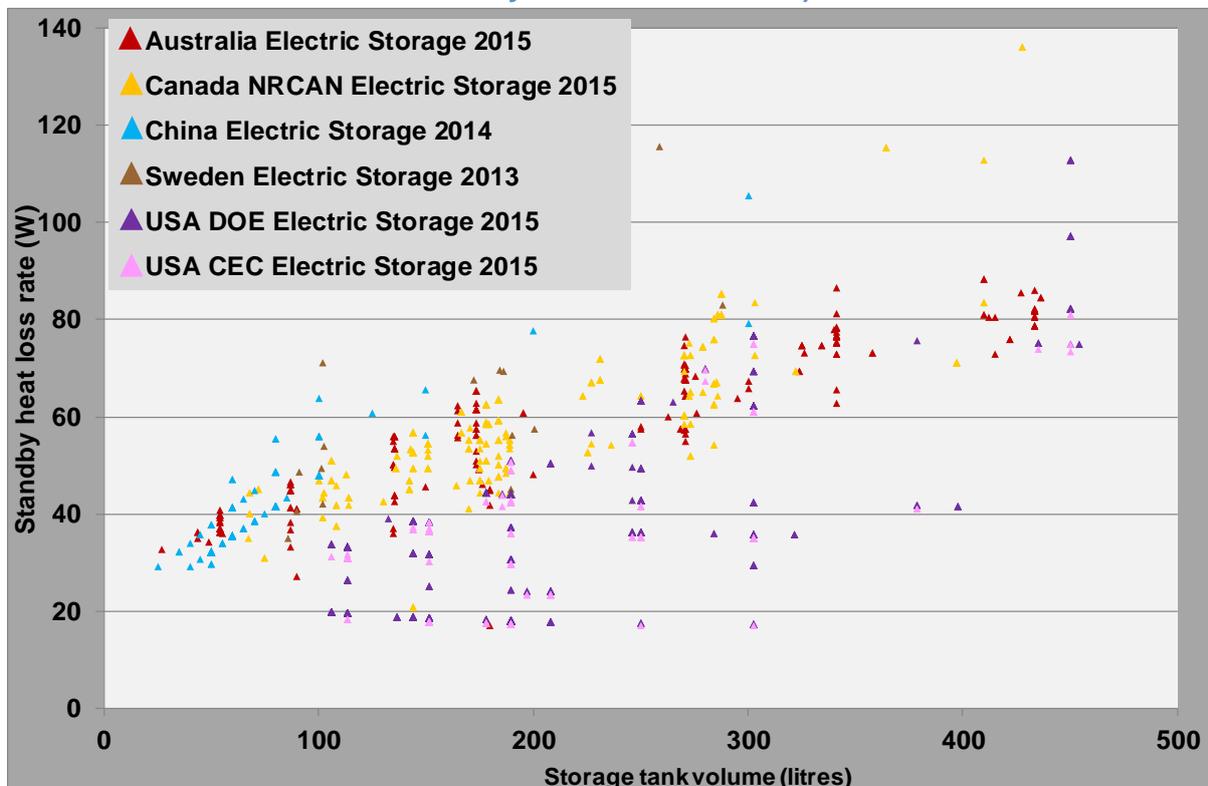
<sup>34</sup> While the energy is applied directly to heat water via a submerged element, radiant losses occur from the flange supporting the element at the point it penetrates the tank. Typically policy makers assume this value to be 2% when undertaking technical and cost benefit analysis.





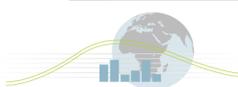
form, the USA data implies some models are available with remarkably low heat loss rates (below 20 W). Further, there is very limited overlap in the heat losses for the models available in Canada and models from the USA, which seems unlikely given the significant trade between the two countries. Finally, the overall *spread* of heat loss values of models in the USA mirrors the spread of models in countries where heat loss values are directly reported. Together this seems to suggest that heat loss rates from models in the USA should broadly align with those from elsewhere. Consequently, the 98% heating efficiency typically assumed by regulators is likely to be too low (the accuracy of this value is further discussed in section 4.2.2.1). Thus, the values for heat loss rates from USA models displayed in Figure 12 should be treated as illustrative only, although the relative distribution within the data set is broadly accurate.

**Figure 12: Normalised heat loss rates for all electric storage water heaters (for most recent year data is available)**



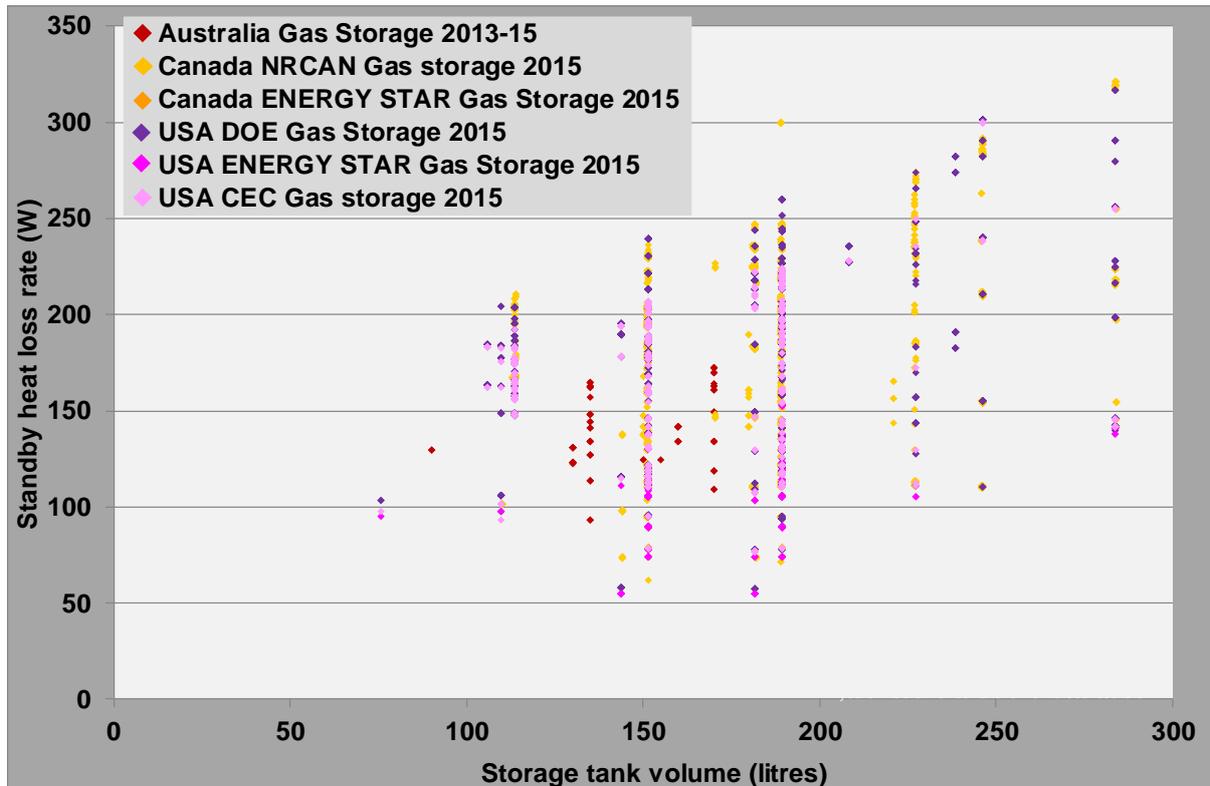
#### 4.2.1.2 Gas storage water heaters

Figure 13 shows the heat loss rates for individual gas storage models from all available data sets, with Figure 14 presenting a number of these data sets separately due to the large number of overlaid products at some volumes/energy consumptions. These heat loss rates should be treated as indicative as there is uncertainty in the derivation for gas storage units (particularly with the Australian models which have also gone through a normalisation process to align temperatures). However, this uncertainty is small compared with the large spreads of heat loss in North American gas storage water heaters.





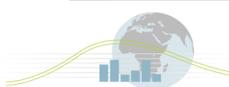
**Figure 13: Normalised heat loss rate for gas storage water heater  
(for most recent year data is available)**



Again, focusing on a typical storage tank of around 200 litres, the spread of heat loss rates in North America is from a low of approximately 60 W, to a high of 260 W, i.e. over 400% (Canadian models have slightly higher heat loss values on average, particularly at volumes above the USA's 55 gallon/208 litre regulatory threshold). A 260 W heat loss rate equates to an energy consumption of approximately 2,270 kWh per year under steady state conditions,<sup>35</sup> or over 50% of the embodied energy of the annual 4,420 kWh of delivered hot water at reference conditions. However in Australia, although based on a much smaller number of models, the spread is much tighter, approximately 100-170W, broadly mirroring the spread in the Canadian (not shown separately) and the USA ENERGY STAR models.

These varying spreads in heat loss are not entirely surprising. As described in Section 3, Australia, Canada and the USA (including ENERGY STAR) all set performance requirements for gas storage water heaters via maximum energy consumption for a fixed daily draw profile. Consequently, suppliers are free to design their products balancing management of heat loss, efficiency of the water heating process and price/aesthetic issues. Hence, a broad spread of heat loss rates may be expected as manufacturers balance these criteria to create the optimum product for their market niche.

<sup>35</sup> In practice the actual losses would be lower as heat loss reduces following a draw due to the average stored water temperature being reduced for the period while reheat/recovery is occurring. This is particularly so if typical draws are large. However, the reduced heat loss is normally more than offset by the inefficiency in the gas water heating process (refer to Section 4.2.2.2) required to restore the water to the target storage temperature.



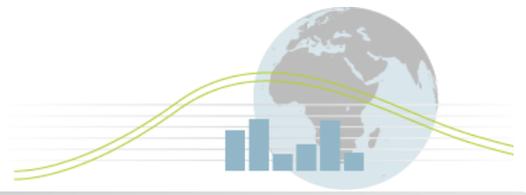
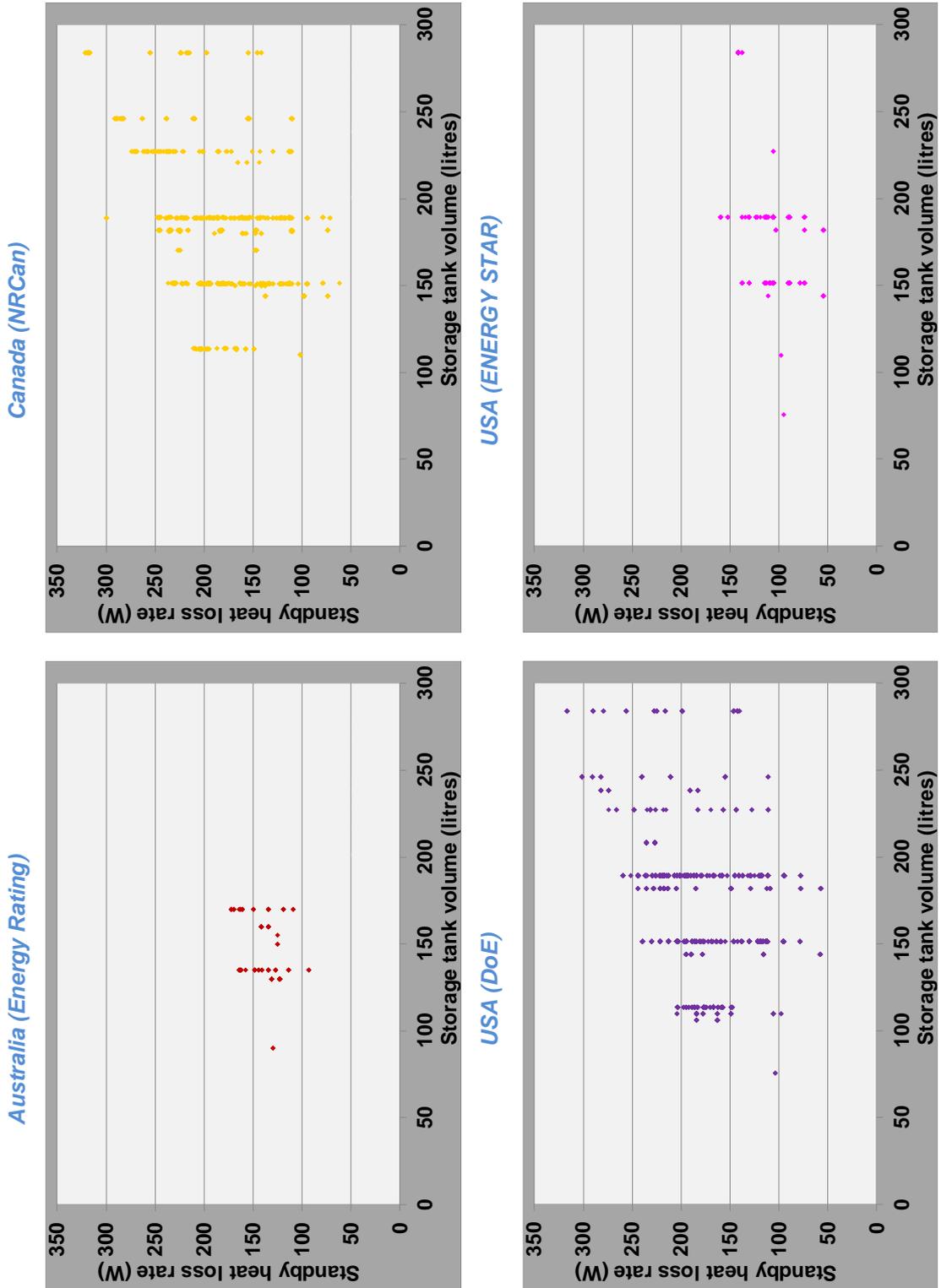


Figure 14: Normalised heat loss rate for gas storage water heaters available in selected markets (for most recent year data is available)



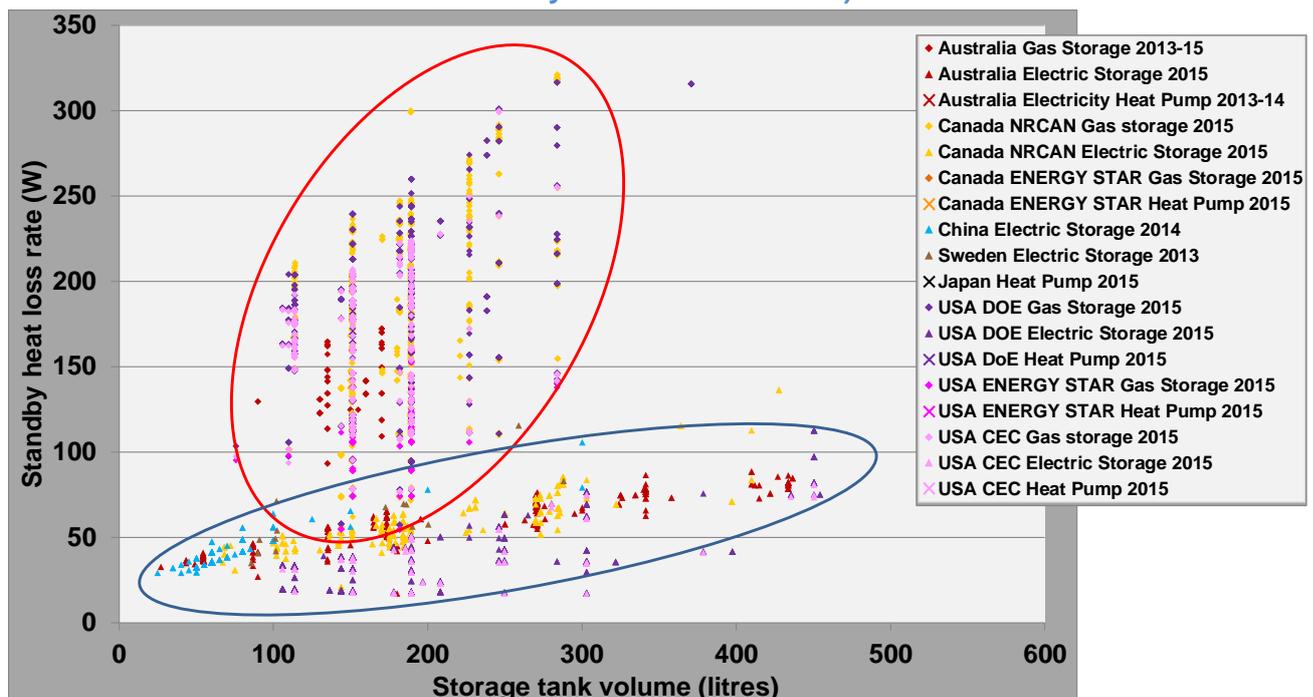


However, policy intervention is still directly impacting heat loss rates. As Figure 9 illustrated, for products below the USA's 55 gallon (208 litre) threshold, Australia has the most stringent daily energy performance requirement (set in 2011), followed relatively closely by the 2015 ENERGY STAR thresholds, with the (imminent) 2015 US DoE regulations noticeably more relaxed, and the Canadian 2004 regulations the least stringent. This order of stringency is clearly reflected in the heat loss rates of models available in each country/programme and demonstrates there are significant opportunities for reduction in heat loss rates in the USA and Canada (and potentially elsewhere) without jeopardising product availability. From the available data, and at the Benchmarking reference conditions, a heat loss rate of 150 W for a 200-litre tanks appears achievable without adversely affecting market competition. Compared with the worst performing products currently on the market, this would represent an annual reduction in energy consumption (at steady state conditions) of approximately 900 kWh (or greater reductions where hot water is stored at higher temperatures or ambient conditions are colder than the reference conditions used).

### 4.2.1.3 Comparative heat loss in electric and gas storage water heaters

Figure 15 brings together the heat loss rates for electric water heaters, highlighted by the blue oval, and the heat loss rate for gas storage water heaters, highlighted by the red oval. Directly heated gas storage water heaters are significantly more complex than electrically heated units, with more penetrations to the insulation to facilitate the water heating process. So it is unsurprising to see gas storage units displaying higher heat loss rates than experienced by electrically heated products. However, the graphic does serve to re-emphasise the very large spreads of heat loss in gas storage water heaters relative to their electric equivalents and the potential for policy makers to address this heat loss, particularly in the North American markets.

Figure 15: Normalised heat loss rate all electric and gas storage water heaters (for most recent year data is available)





## 4.2.2 Water heating efficiency

### 4.2.2.1 Electric storage water heaters

Electrical storage water heaters apply the energy to heat the water directly via a submerged resistive heating element. Simplistically, this process is 100% efficient as the element is fully submerged and consequently the supplied energy can only dissipate into the water. However, in practice, radiant losses occur from the flange supporting the element at the point it penetrates the tank. Typically policy makers this loss to be 2% when undertaking technical and cost benefit analysis. However, as discussed in section 4.2.1.1, using a 98% heating efficiency value for the USA's CEC and DoE data sets results in models displaying significantly lower heat loss rates than elsewhere when, in all likelihood, these heat loss values should broadly align. By manipulating the heating efficiency value it is possible to align the CEC and DoE heat loss values with those of other North American data sets, but at a heating efficiency value 99.1%. Consequently, the 98% heating efficiency typically assumed by regulators is likely to be too low and a value of 99% or higher might be more appropriate when developing future regulation.

### 4.2.2.2 Gas storage water heaters

The efficiency of the water heating process in gas storage water heaters is typically measured based on the amount of energy required to heat a full tank of water from cold to the target storage temperature. The efficiency being defined by the total heating energy input divided by the resulting embodied energy in the water.

Again, as Figure 16 illustrates, there is a very wide spread of efficiencies from 70% to 90%. Once more breaking these down by data set (Figure 17), the same broad hierarchy in the performance between markets is seen reflecting the local regulatory performance requirements, i.e. Australia demonstrating the best efficiencies overall clustered in the 80-90% range, followed by the USA's DoE mainly in the broader 75-90% range, and Canada with the biggest spread in the broader (and lower) 70-85% range. To give these ranges some perspective, under the Benchmarking reference conditions with daily hot water demand of 12.11 kWh (annually 4420 kWh), the difference in energy required to heat the water at the upper 90% efficiency and the lower 70% is 1400 kWh/year.<sup>36</sup> Again this value will be larger where local conditions have cooler water inlet temperatures or higher tank storage temperatures.

However, as noted in the previous section, suppliers are free to achieve maximum daily energy performance requirements through optimising heat loss vs water efficiency.

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<sup>36</sup> Using the simplistic assumption that recovery efficiency of draw equals that of a full tank reheat., to deliver the Benchmarking daily hot water demand of 12.11 kWh at reference conditions, 90% water heating efficiency requires 4,912 kWh to heat the water, and 70% requiring 6,316 kWh.





**Figure 16: Normalised water heating efficiency of gas storage water heaters (for most recent year data is available)**

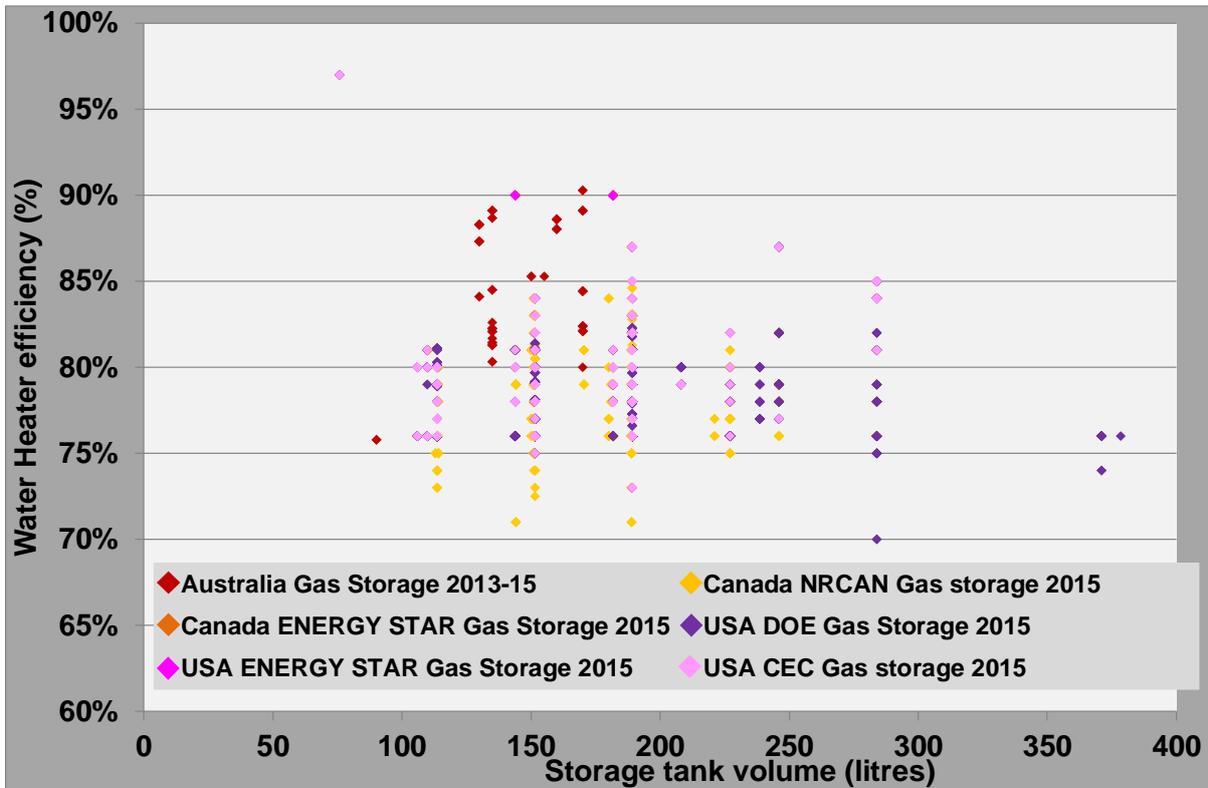
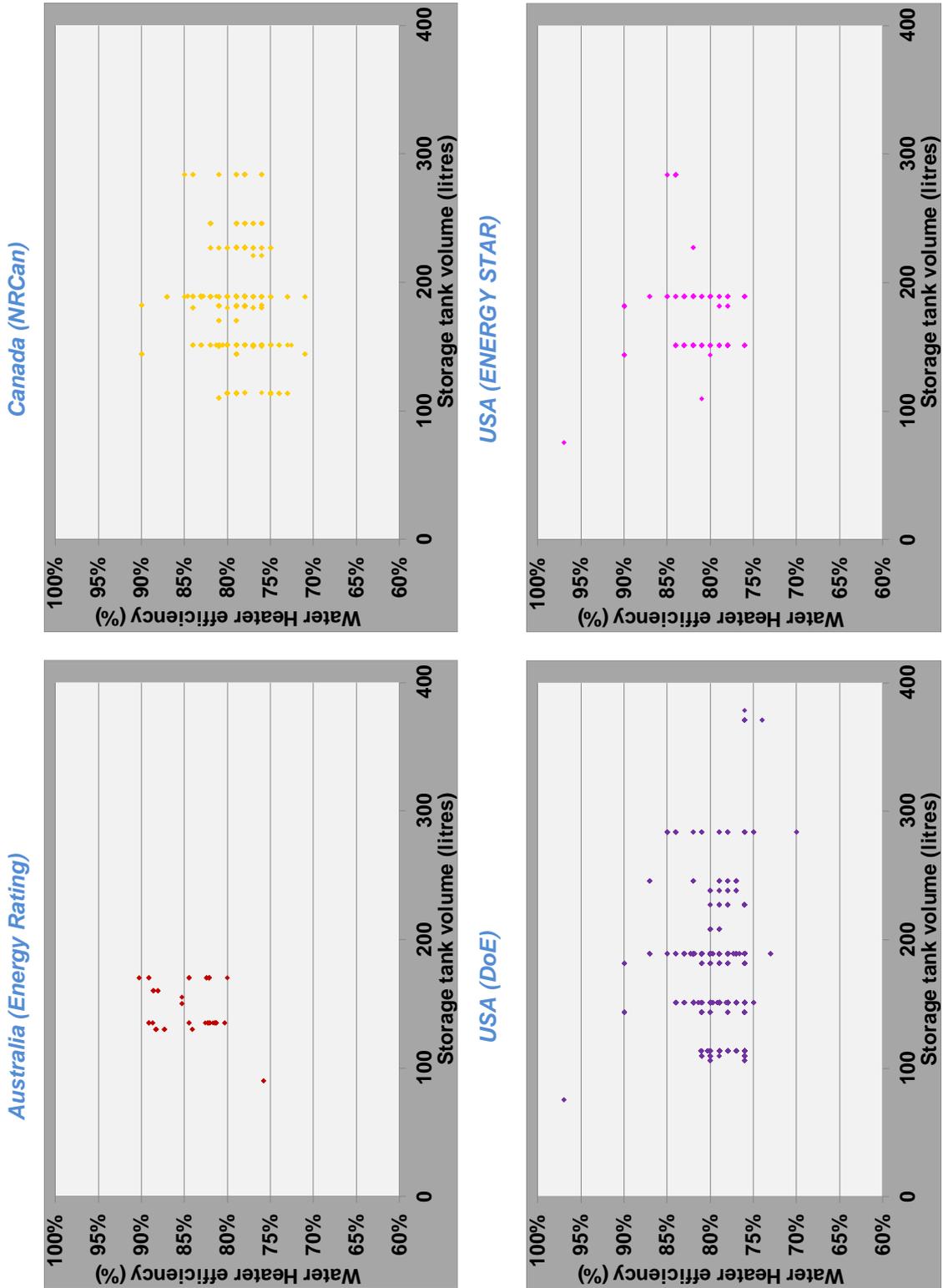


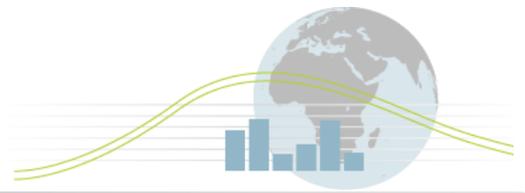


Figure 17: Normalised water heating efficiency of gas storage water heaters available in selected markets<sup>37</sup> (for most recent year data is available)



<sup>37</sup> USA ENERGY STAR is chosen over the equivalent for Canada as it contains more models and all Canadian are a subset of the USA listing.





### 4.2.3 Total daily energy consumption

#### 4.2.3.1 Electric storage water heaters

Given the generally assumed water heating efficiency of 98%, for a specific hot water demand the variation in total daily energy consumption of electrical storage water heaters is entirely dependent on heat loss presented in Section 4.2.1.1. As illustrated, spreads of over 30 W are shown between the best and worst performing products around the typical 200-litre volume units, with this differential being larger in countries where water storage temperatures are higher than the reference delivery temperature (57.2°C)<sup>38</sup>, and/or average ambient conditions cooler than the reference (19.7°C).

In some respects such differences are marginal given that a steady state 30 W heat loss rate equates to total annual energy loss of just 6% of the embodied energy delivered in the hot water at reference conditions (Figure 18 shows graphically the total daily energy consumption of individual electric storage water heater models, including heat loss, compared with the red highlighted area defining the embodied energy in the daily hot water demand under the Benchmarking reference conditions). Further, the cost benefit of improved insulation and the physical size of resulting tanks relative to potential installation positions limit how much this heat loss value can be reduced. Nevertheless, the annual loss of 262 kWh/year<sup>39</sup> is significant relative to many other products and so policy makers may wish to consider at least some action to close the gap between best and worst performing products.

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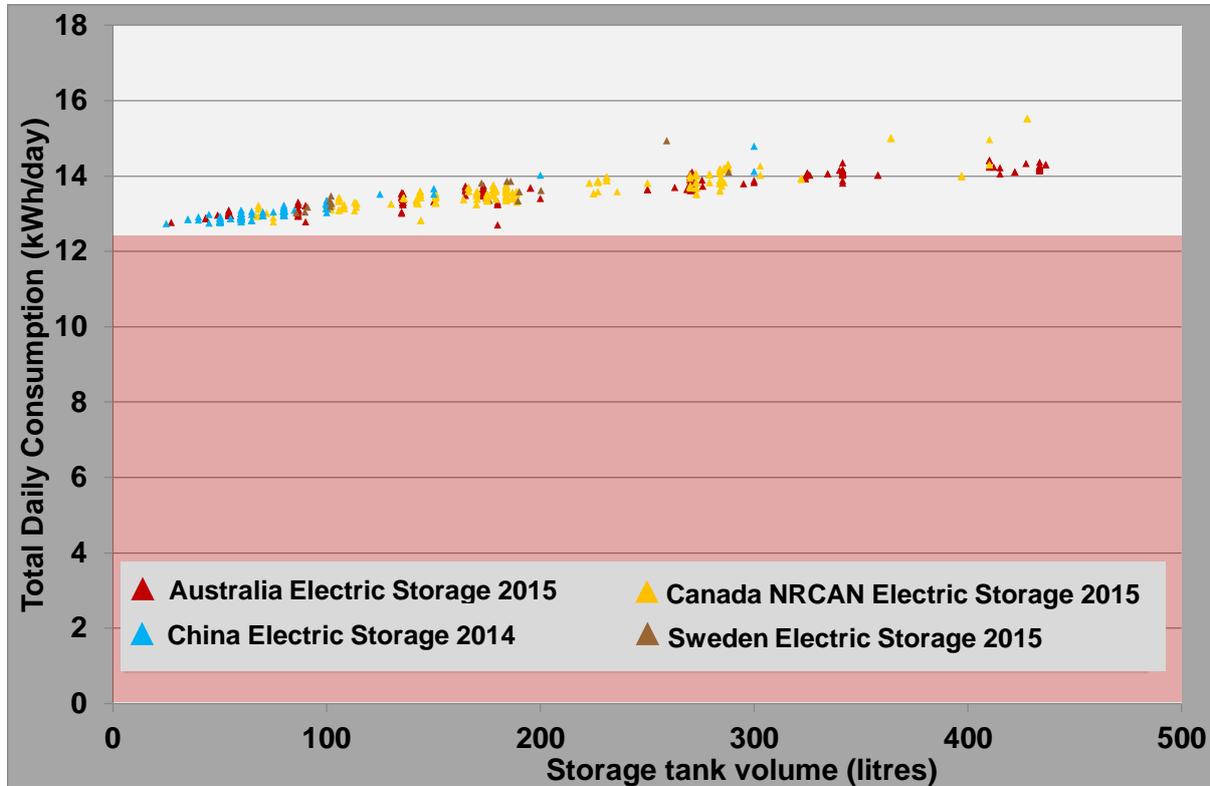
<sup>38</sup> In many countries hot water storage is 60°C or above. This is partly responding to the desire to maximise heat density in any particular tank size, but also as a response to the perceived risk of salmonella bacteria developing in the stored water.

<sup>39</sup> In practice the actual losses would be lower as heat loss reduces following a draw as the average stored water temperature is reduced for the period while reheat/recovery is occurring. This is particularly so if typical draws are large.





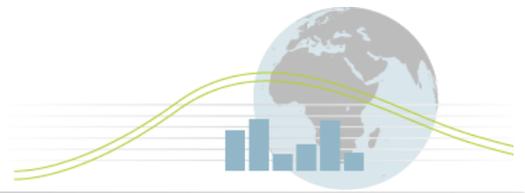
**Figure 18: Comparison of the normalised total daily energy consumption of electric storage water heaters relative to embodied energy in daily delivered water demand (for most recent year data is available)**



### 4.2.3.2 Gas storage water heaters

Figure 19 brings together the individual energy losses during the water heating and storage phases to present the total daily energy consumption of gas storage water heaters in comparison with the embodied energy in the daily hot water demand (again highlighted by the red area). As illustrated, the best models available are losing less than 50% of the energy required to deliver the hot water demand, while the worst are consuming twice as much.





**Figure 19: Comparison of the normalised total daily energy consumption of gas storage water heaters relative to embodied energy in daily delivered water demand (for most recent year data is available)**

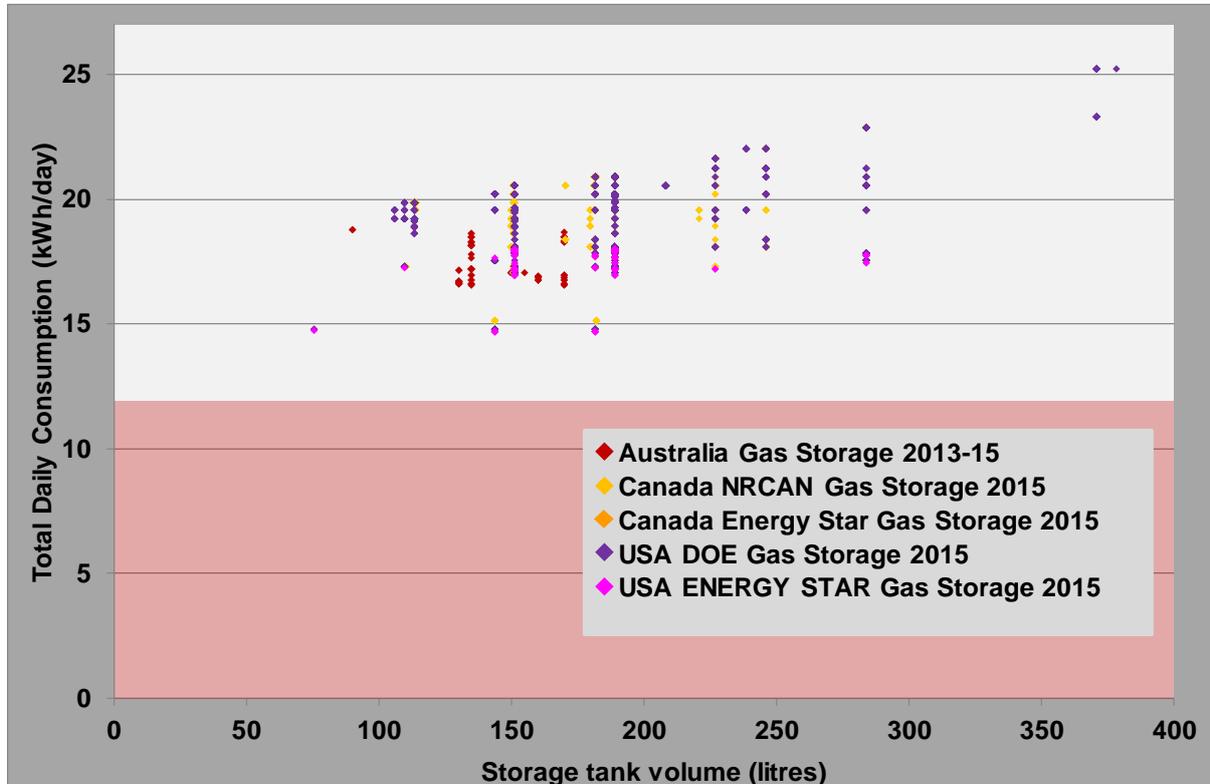
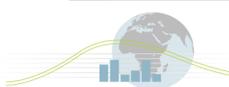


Figure 20 expands this view to show the spreads of total daily energy consumption more clearly. The two ovals highlight Australian models (red) and the USA and Canadian models registered under ENERGY STAR (purple). It is interesting to note that despite Australia having a number of models with the lowest heat loss rates, and models with some of the best water heating efficiencies, overall there are a significant number of ENERGY STAR models that outperform Australian models when total daily energy consumption is considered. This suggests suppliers of these models have identified a more optimal heat loss/water heating efficiency balance.<sup>40</sup> In particular, there are a small number of Canadian and USA ENERGY STAR qualified models with total energy daily energy consumption under 15 kWh per day which indicates they are condensing units.

However, around the typical 200 litre storage volume, overall Australian and ENERGY STAR qualified products are broadly aligned with an annual total energy consumption of 16.5 - 18.5 kWh/day (equivalent to approximately 6,000-6,750 kWh/year). This compares with the broader full North American markets with ranges from 16.5 - 21 kWh/day (6,000-7,650 kWh/year). Again this demonstrates the significant potential for market improvement in North

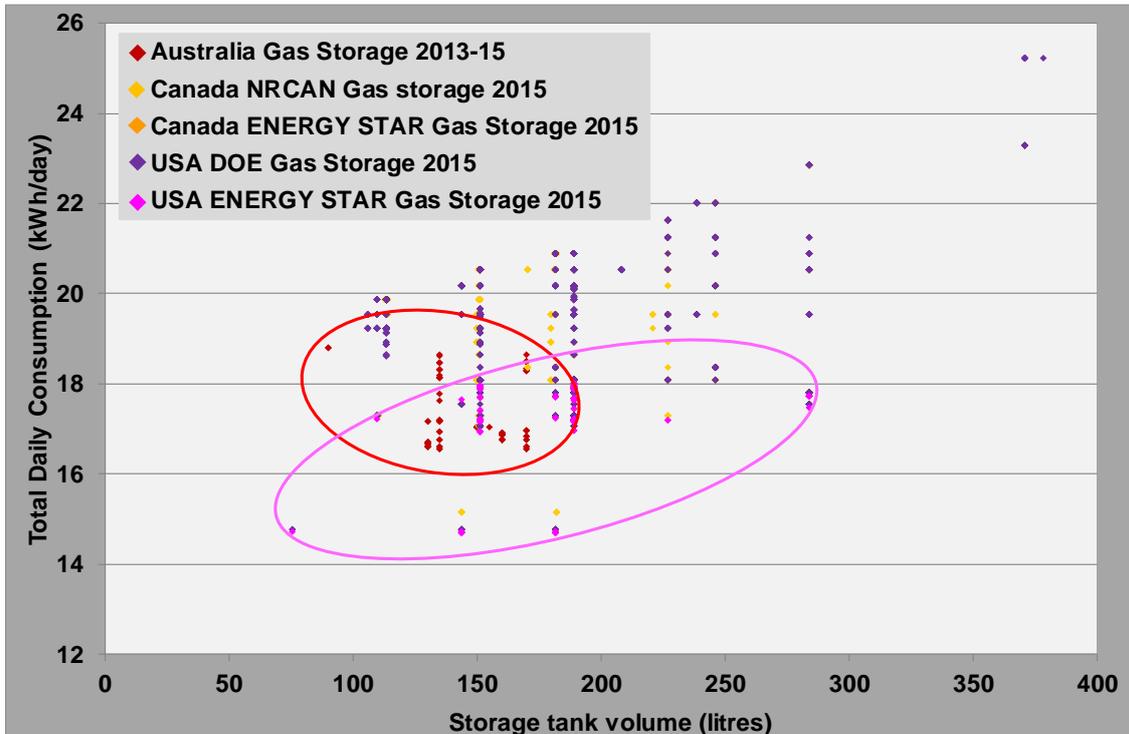
<sup>40</sup> It should be noted the North American test method and ENERGY STAR specification do allow a number of allowances in energy declarations depending on product functionality. These variations in functionality are not accounted for in the comparisons and may be partially responsible for the apparent model differences.





America (particularly Canada). Here, removal of the worst products from the market could yield annual energy savings of 1-2 MWh per year per model.

**Figure 20: Potential reductions in normalised total daily energy consumption of gas storage water heaters (for most recent year data is available)**



#### 4.2.4 Heat loss rate and water heating efficiency

##### 4.2.4.1 Trade off in heat loss rate and water heating efficiency

Because performance requirements for gas water heaters are all based on maximum daily energy consumption for a given demand profile, it is possible that performance requirements are approaching the point where design constraints lead to a trade-off between reducing the heat loss rate and improving the water heating efficiency. For example, extra penetrations may be required in the insulation (thus increasing heat loss) to enable the installation of optimum condensing water heating units. Hence, the marked difference in model heat loss rates and water heating efficiencies demonstrated in the previous two subsections could simply be demonstrating this trade-off, i.e. those models with high heat loss are actually those that heat the water most efficiently.

However, as illustrated by Figure 21, based on the data for models currently available in the various markets, there appears to be almost no correlation between high levels of heat loss and high levels in the efficiency of water heating, or vice versa (with the exception of the Canada ENERGY STAR dataset which is somewhat skewed by a number of identical models,  $R^2$  values are below 20% in all cases).<sup>41,42</sup> This seems to suggest that the point has

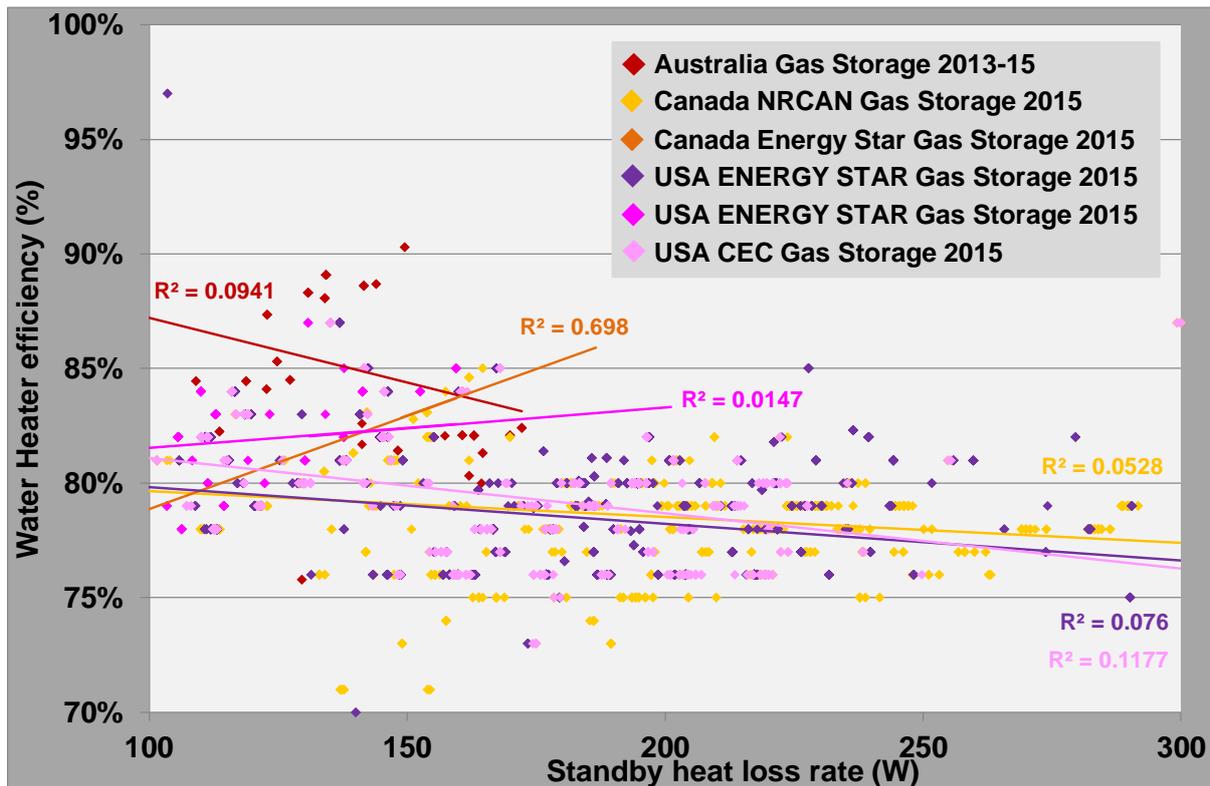
<sup>41</sup>  $R^2$  is a statistical measure of how close the data points are to the fitted regression line (also known as the coefficient of determination). An  $R^2$  of 0 indicates the regression explains none of the variability of the data,





not been reached where there is a serious trade-off between heat loss and water heating efficiency. This suggestion is supported by the observation made in the previous subsection that only a small number of suppliers have identified something approaching an optimal heat loss/water heating efficiency balance.<sup>43</sup> Consequently, significant potential exists for regulators to relatively aggressively increase performance requirements to move towards the optimal heat loss/water heating efficiency balance.

**Figure 21: Normalised water heating efficiency and heat loss rates of gas storage water heaters available in selected markets (for most recent year data is available)**



#### 4.2.4.2 Water heating efficiency and heat loss in relation to model input power

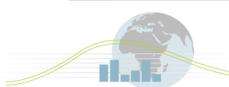
For completeness, Figure 22 and Figure 23 compare the rated input power to the water heating efficiency and heat loss rates of the gas water heaters at reference Benchmark conditions<sup>44</sup>. From these figures it is interesting to observe:

while a value of 1 indicates all data values sit on the (linear) regression line. However, the measure is somewhat simplistic and should be interpreted with caution, particularly in skewed datasets as is the case with Canada in this instance.

<sup>42</sup>Variations in draw cycles appear to have little effect on this relationship except under extreme circumstances, particularly frequent large draws.

<sup>43</sup> It should be noted the North American test method and ENERGY STAR specification do allow a number of allowances in energy declarations depending on product functionality. These variations in functionality are not accounted for in the comparisons and may be partially responsible for the apparent model differences.

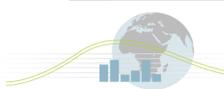
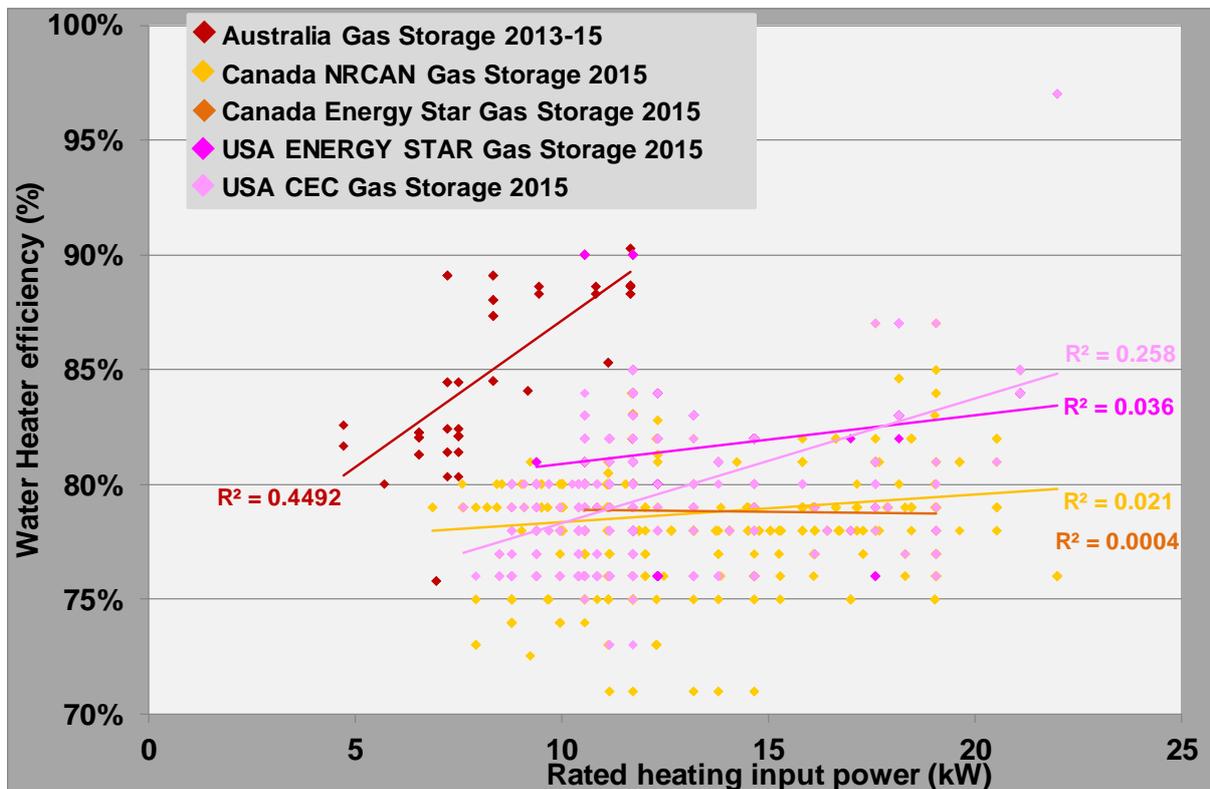
<sup>44</sup> Note both graphics exclude USA DoE data as rated power is not disclosed in the public DoE data set and, where necessary for the analysis, rated powers were added to DoE data based on a regression of tank volume to rated power of models within the CEC data set.





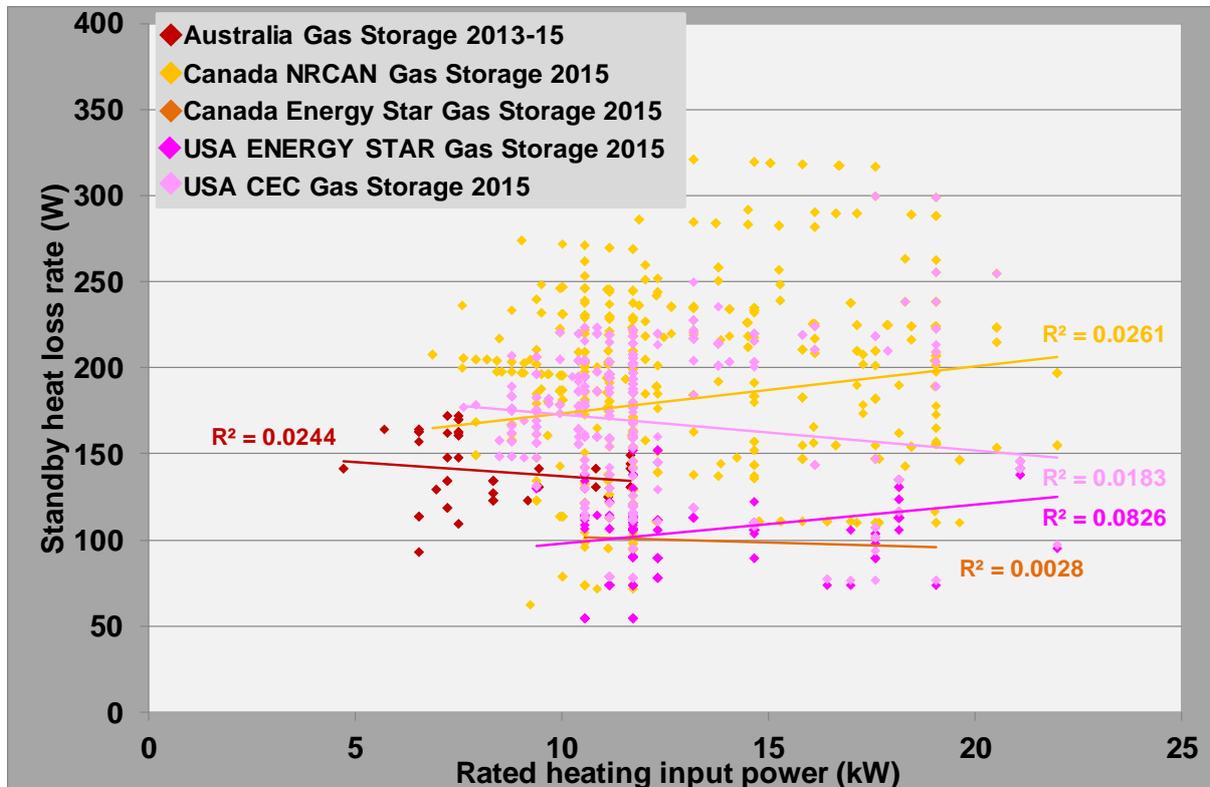
- Australian water heaters tend to have smaller rated input power than those used in North America. While this is partly related to the volume of Australian gas water heater tanks being smaller than many North American models (refer to Annex 2), it is more likely to reflect the 'First Hour Draw' capability defined as part of the US regulatory system. Effectively this is the total quantity of hot water that can be delivered within a one hour period. This encourages the deployment of higher power systems to speed tank reheat times.
- In Australian models there is a degree of correlation between increased input power and increased water heating efficiency ( $R^2$  value of 0.45), but this is not reflected elsewhere (no  $R^2$  value above 0.26).
- There is little correlation between input power and heat loss in any data set (no  $R^2$  value above 0.08).

**Figure 22: Normalised water heating efficiency and rated input power of gas storage water heaters available in selected markets (for most recent year data is available)**





**Figure 23: Normalised heat loss rate and rated input power of gas storage water heaters available in selected markets (for most recent year data is available)**



### 4.3 Storage water heaters (air source heat pumps)

Rather than the traditional direct application of energy to heat the water, air source heat pumps take the low grade heat energy from the ambient environment and, via the vapour compression cycle, impart this energy to the water to raise the water temperature.<sup>45</sup> In appropriate conditions this is a highly efficient method of heating water. However, the quantity, frequency and temperature of water demanded, and particularly the variation in environmental conditions, all have a significant impact on the performance of individual air source heat pumps. Consequently, to ensure measurable, comparative performance at representative local conditions, test methods and associated regulatory frameworks tend to be more complex than for most other products<sup>46</sup>, and product designs are optimised accordingly. When the complexity of the test method and prescribed conditions are combined with the limited individual model performance information in the available data sets, normalisation of heat pump performance has been challenging. **Hence, in all cases the performance of individual heat pump water heater models at Benchmarked reference conditions should be treated as illustrative only.** Further, a detailed

<sup>45</sup> Conceptually air source heat pumps can be thought of as air conditioners working in reverse. Instead of the evaporator removing heat energy from the enclosed space and dispersing it to the external ambient environment via the condenser, the heat pump evaporator is capturing energy from the external environment and imparting it to warm the water via the condenser.

<sup>46</sup> These specifications often define different requirements for individual climate zones with some specifying upwards of 30 different daily air and incoming cold water temperatures over the course of a 12 month period.

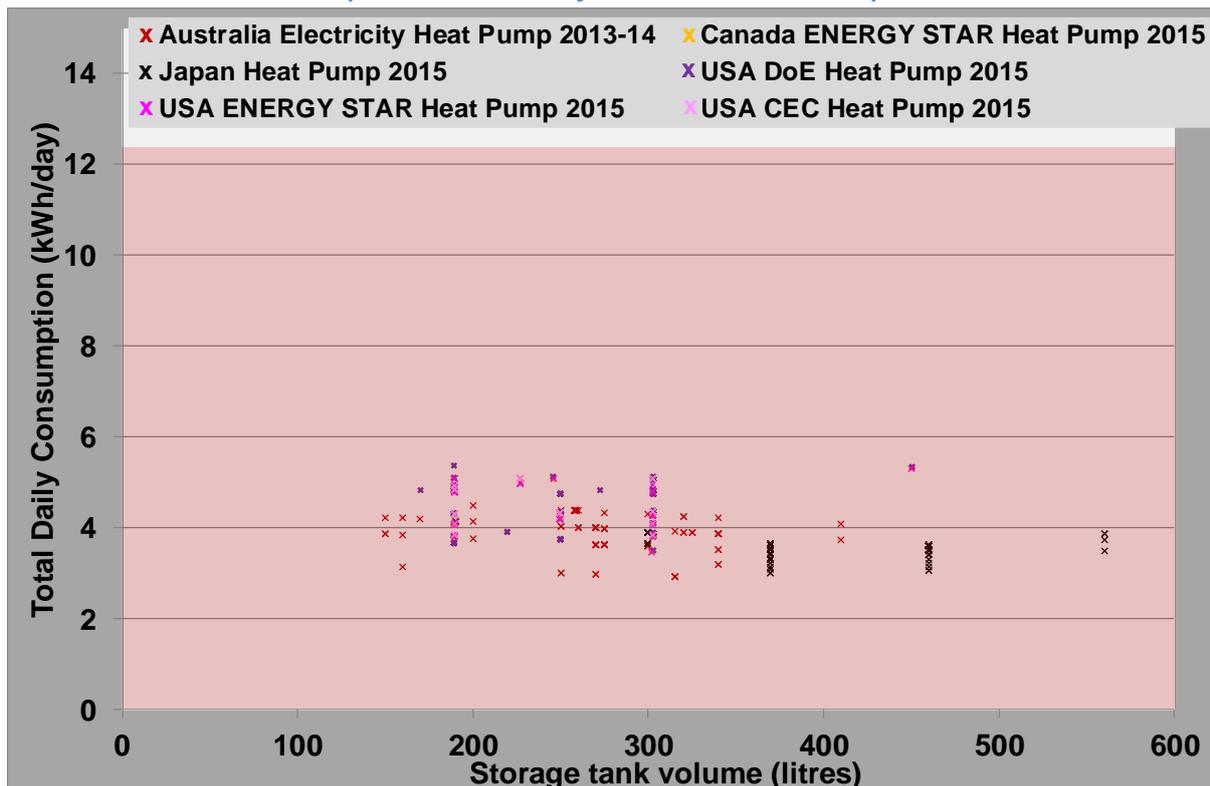




breakdown of individual energy flows, e.g. heat loss rates from the stored water, is not possible.

However, even accepting these limitations, there are still valuable insights to be gained from the examining the available data. Firstly, and most importantly, unlike other water heaters, the actual delivered energy to drive the system is appreciably lower than the heat energy imparted to the water. Using the same representation as for the preceding products analysed, Figure 24 shows the required normalised energy consumption of individual heat pump models to deliver the reference water delivery profile. Clearly heat pump water heaters maximise the benefit of drawing the heat energy from the prevailing environment, with total electrical energy input broadly in the 3-5 kWh range to deliver the reference 12.1 kWh daily water heating requirement. This is approximately 30-40% of the electrical energy required by directly heated electric storage water heaters.

**Figure 24: Comparison of the normalised total daily energy consumption of electric heat pump water heaters relative to embodied energy in daily delivered water demand – all individual model values to be treated as indicative only (for most recent year data is available)**



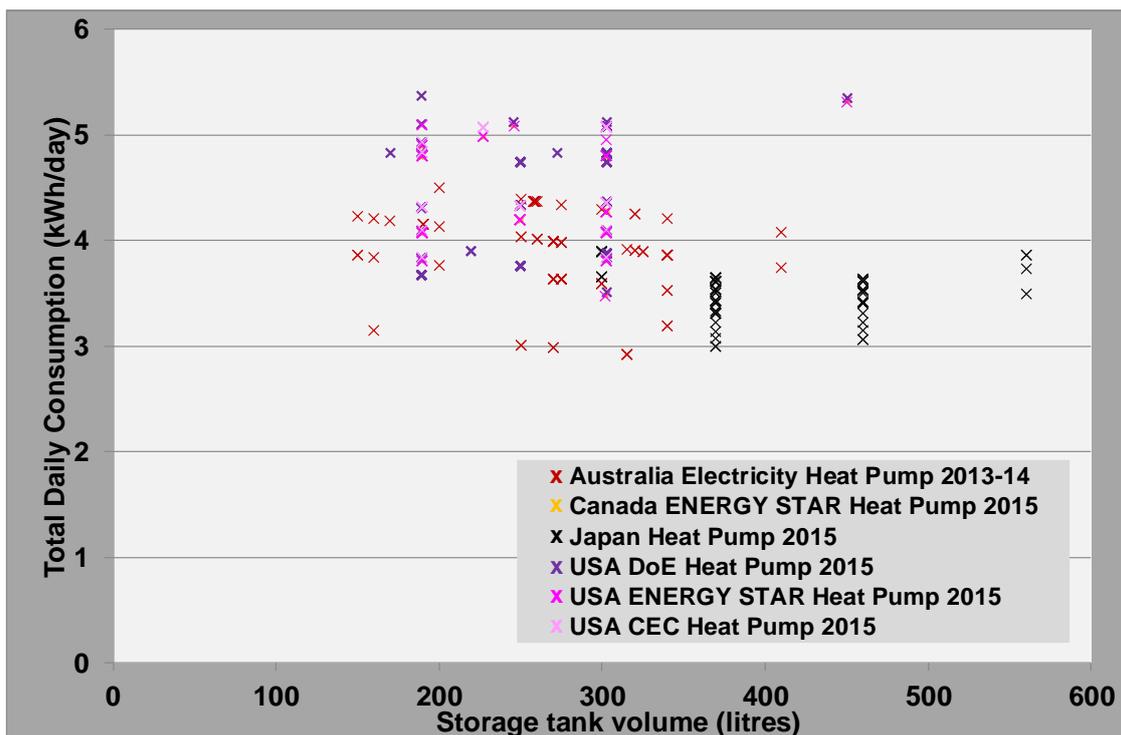
Looking in more detail via Figure 25, the first and most obvious observations relate to Japanese heat pump units. Overall, Japanese products have the lowest energy consumptions, and the range of consumptions between models is limited relative to other countries. The Japanese products broadly fall into a range of 3-4 kWh for total daily energy consumption, and more limited still for the two groups of products at 370 litres and 460





litres<sup>47</sup> where products have total daily energy consumptions of 3-3.7 kWh. The profile of model distribution is not surprising given the primary Japanese policy intervention in water heating is through the Top Runner programme. This programme sets future product performance targets based on the weighted average value of the shipment volume by manufacturer and by category on an application-specific basis, i.e. there is an incentive for manufacturers to improve efficiency of product groupings with the highest sales, in this case the 370 and 460-litre models. This has resulted in particularly high COPs<sup>48</sup> in the range 3.3-4.0. While there is uncertainty in the normalisation process, these COP levels appear realistic given that, under the relatively challenging Top Runner programme testing regime, models have reported COPs of 3.9. It is also of value to note that 98% of Japanese heat pumps (and all products included under Top Runner programme and included in this analysis) use CO<sub>2</sub> as a refrigerant. While having a broadly similar COP response to temperature change as the synthetic refrigerants used elsewhere, CO<sub>2</sub> based products tend to perform better at the sub-zero temperatures which are often experienced in Japan.

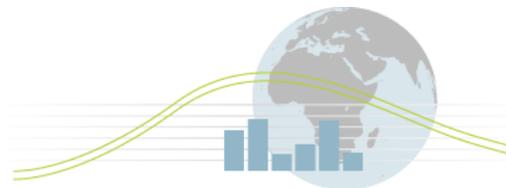
**Figure 25: Comparison of the normalised total daily energy consumption of electric heat pump water heaters – all individual model values to be treated as indicative only (for most recent year data is available)**



<sup>47</sup> Note in Japan there are limitations on volume declarations accounting for the tightly defined volume ranges of Japanese products shown on Figure 24. Further, the two groups of Japanese products are displayed, those providing water heating-only functionality, and those capable of also providing bath reheat. However, as both cases involve heating of water under set conditions have very similar COPs, input data can be adjusted accordingly. Therefore both product groups are included.

<sup>48</sup> Coefficient of Performance is the typical measure of efficiency of products using the vapour compression cycle (refrigerators, air conditioners and heat pumps), and is simply the ratio of heating or cooling provided relative to the work required. In this case this is the ratio of heating energy delivered in the hot water to the electrical energy input into the system.





Looking more broadly:

- Both Canada and the USA exhibit a much wider spread of product performance with daily energy consumptions of 3.5 – 5.4 kWh per day with the upper values aligning with ENERGY STAR thresholds, although the majority of models fall into the 3.5 – 4.4 kWh range (COP 3.5 – 2.8).
- Australia also has a broad spread of model performance. The best models available have similar performance levels to those in Japan, with the worst consuming 4.4 kWh per day. In this case, the relatively broad spread may be expected as there is no regulatory requirement for performance in Australia. Here, the penetration of heat pumps is primarily driven by a White Certificate (emissions based) scheme which leaves suppliers free to balance the incentive they receive with the cost of supplying products of varying efficiency.

Accepting the limitations of the normalisation process, there are substantial differences in the performance of heat pumps across national boundaries. The best Japanese and Australian products consuming around 3 kWh per day of energy to deliver the daily hot water demand (with an associated COP of around 4.0), contrasted with the worse performing North American models which consume over 5.4 kWh per day (COP 2.2). Hence, there is a significant potential for improvement by removal of the worse performing products from the market, although such a statement should be considered within the context that even the worse performing products use well under half the energy of the equivalent direct electrically heated storage tank.

#### 4.4 Instantaneous [tankless] water heaters

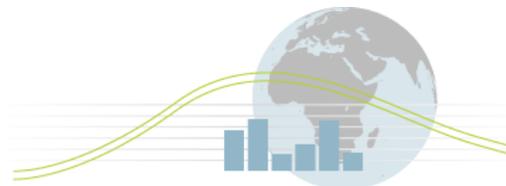
Rather than heating water for storage to supply future demand, instantaneous water heaters heat the water at the time of the demand. Because of the need to rapidly heat the inflowing cold supply water to the required delivery temperature as the water passes through the heat exchanger, the gas combustion unit or electrical heating elements must be significantly larger than their hot water storage counterparts.<sup>49</sup> Further, unlike storage systems, the water flow rate becomes more significant as the higher the flow rate required at the point of delivery, the larger the heat capacity required to heat the water heater as it passes through the heat exchanger.

In operation, when a draw is made, the instantaneous water heater senses the flow of water and ignites the burner or switches on the electrical element. If it has been some time since the last draw, the heat exchanger will be close to the ambient air temperature and so some energy is required to heat the components of the water heater to the steady state hot water temperature. Depending on the design of the unit, this warming process typically takes 5-15 seconds. During this period, cold water will be flowing through the heat exchanger and

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<sup>49</sup> For example, a shower flow rate of 7 litres per minute and requiring a temperature rise of 32 K (from 10°C to 42°C) requires an input power of 15.2 kW before any conversion losses are considered, i.e. approximately 20 kW input power for a burner with an efficiency of 75%, and it is not unusual for larger instantaneous gas systems have a rated input of twice this size.





hence, the initial flow (typically 1.5-4 litres<sup>50</sup>) of delivered water will not be heated to the desired delivery temperature and may be viewed as wasted energy.<sup>51</sup> The initial heating of the water heater components and the 'wasted' water flow can be considered together as the start-up energy of the instantaneous water heater. Once this 'start-up' phase is complete and the water heater is at operational temperature, the water flowing through the heater will be fully heated to the desired temperature. Hence, when considering the energy consumed by instantaneous water heaters it is sensible to consider the start-up energy use and water heating efficiency separately.

#### 4.4.1 Start-up energy consumption (gas)

As noted above, the start-up energy in gas instantaneous water heaters consists of the energy required to heat the water heater components (discounting any residual heat from the previous draw), plus the wastage of water that hasn't reached the required delivery temperature. The normalisation process that converts locally declared values to the reference Benchmarking conditions<sup>52</sup> takes account of these variables. However, with the exception of Australia, none of the available data sets contained any information on model start-up energy, most only reporting the water heating efficiency of units. Therefore, no inter-country comparisons of start-up energy can be presented. In itself this does not negate the overall comparisons of gas instantaneous water heaters with other products as an assumption of average start-up energy has been made based on a small data set made available by Australia.

This data from Australia is presented in Figure 26<sup>53</sup> and illustrates that start-up energy consumptions vary from a low of around 0.05 kWh/start to a high of around 0.15 kWh/start, with little correlation between the flow rate and required start-up energy. However, as noted above, the heat exchangers and peripheral equipment for higher flow rate products are necessarily larger and should require higher amounts of energy during the start-up phase. This implies there is sub-optimal design in a number of smaller flow rate products.<sup>54</sup> This should be of concern to policy makers in countries where start-up energy is not apparently regulated, i.e. Japan, Canada, China and Korea<sup>55</sup> as, although the difference between the start-up energy of the best and worst model is just 0.1 kWh, this may result in several kilowatt hours of wasted energy consumption in a day depending on how many draws are

<sup>50</sup> Some electronic systems can restrict the initial water flow rate during start-up to minimise the volume of water delivered below the required hot water temperature. This type of flow restriction also reduces the 'waste energy'. However, from the data available it has not been possible to identify these units and the reference 'start-up' energy is applied to all models.

<sup>51</sup> For an application such as a shower, the hot water that is below the required temperature will mostly likely be wasted. However, for a bath or a washing machine, where hot water is accumulated for the end use, it can be argued that the initial hot water that is below temperature is not actually wasted.

<sup>52</sup> Refer to Section 2.2.2.

<sup>53</sup> Values shown are for a start from ambient conditions with a water temperature rise of 40°C with energy consumption measured to the point where water temperature achieved 80% of target delivery temperature.

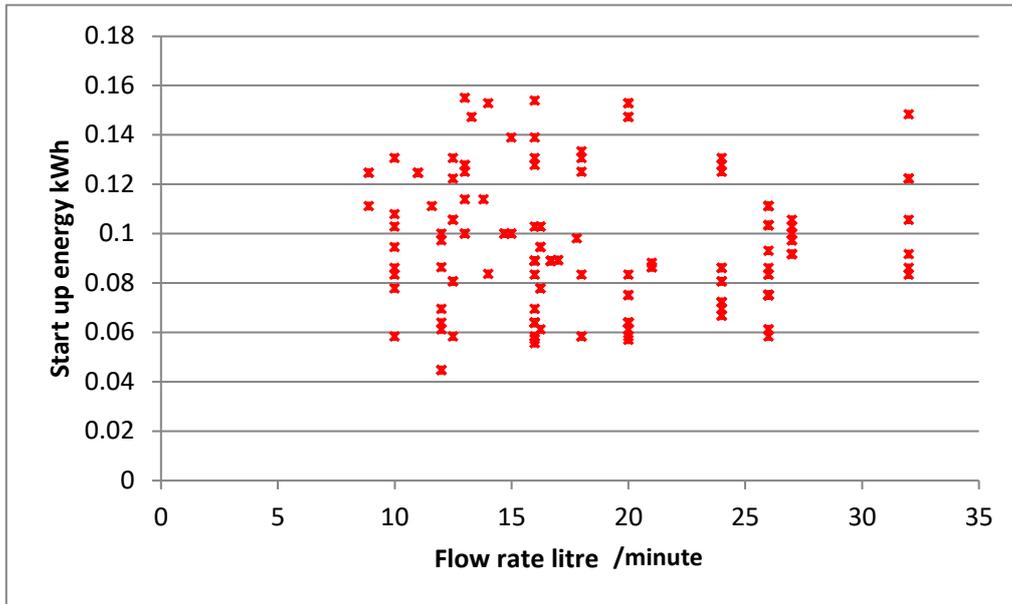
<sup>54</sup> There is some anecdotal evidence to suggest that, rather than suboptimal design, suppliers are actually producing a small number of 'base' models that are then derated to supply across a variety of flow rates. Hence the majority of the start-up heat loss will apply irrespective of the ultimate flow rating of the product.

<sup>55</sup> Australia, the EU and the USA capture start-up energy as part of the total energy consumptions for delivered hot water profiles.



made (or potentially around 1 MWh of annual consumption if typical usage patterns result in 30-40 draws over 24 hours).

**Figure 26: Start-up energy of a selection of gas instantaneous water heaters in Australia**



This last point is particularly pertinent to the Benchmarking product comparisons as the normalised total daily energy requirement for instantaneous water heaters is much more sensitive than other water heater types<sup>56</sup> to the number of draws assumed in the reference conditions (and where no start-up energy is included in data sets, the assumed start-up energy value). Therefore a degree of caution must be exercised when comparing total daily energy consumption of gas instantaneous products from countries where start-up energy is captured in their daily energy consumption declarations and those where start-up energy is assumed. Equally caution must be exercised when comparing total daily energy consumption of gas instantaneous models for all countries with storage and heat pump water heaters.

#### 4.4.2 Water heating efficiency

The water heating efficiency (normally referred to as the thermal efficiency) of gas instantaneous water heaters is measured at a steady state flow rate, with the efficiency being defined as the energy input relative to the increased embodied energy in the water.

<sup>56</sup> For countries where start-up energy has to be estimated, start-up energy is assumed to be 0.083 kWh. Therefore, for the 39 draws under the reference conditions, daily start-up energy is approximately 2.6 kWh per day after accounting for residual heat energy and useful hot water delivered. However, if an alternate number of draws was used, for example the 6 draws specified in the USA prior to the introduction of the new performance requirements, this start-up energy would be less than 0.5 kWh per day. Similarly, if the assumed start-up energy of 0.083 kWh is varied, this can have a significant impact on the resulting total daily energy consumption of the products.

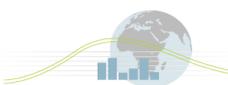


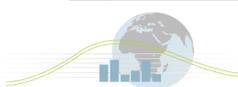


Figure 27 illustrates the comparative water heating efficiency of instantaneous water heater models available where thermal efficiency is directly recorded in the data sets, i.e. Australia, Japan, Korea and the USA.<sup>57</sup> What is most striking about Figure 27 is the two distinct groupings of products irrespective of origin; those enclosed by the blue oval being models with traditional combustion efficiencies; and those enclosed by the red oval that are condensing models. In this latter group, some models are achieving water heating efficiencies of 98%. This is a stark contrast with the gas storage water heating efficiencies where only a very few models currently have condensing efficiencies. However, looking beyond this big picture:

- Overall, Korea has the highest average model efficiency. This is particularly interesting as the water heating [thermal] efficiency is the regulated metric in Korea, but the minimum performance standard is not particularly challenging at 73% in the 2011 regulations (rising to 75% in October 2015). Further, despite instantaneous units dominating the water heater *only* market in Korea, the major source of water heating is from combination boiler systems which heat water and supply underfloor heating. Hence, it appears the prevalence of high efficiency instantaneous products may be a spin-off from the aggressive advertising promoting condensing boiler systems spilling over into a consumer demand for condensing instantaneous products which are easily identifiable as Category 1 products on the Korean energy label<sup>58</sup>. The labelling may also account for the relatively high proportion of models just below condensing efficiencies with label Category 2 set at 88% thermal efficiency, and Category 3 set at 83%
- The USA (CEC and ENERGY STAR) closely follows Korea in overall average model water efficiency, again with a high proportion of products in the condensing range. This may be a function of the market responding to the relatively challenging (imminent) 2015 performance requirements, although it may also be the result of predominately premium products in these data sets.
- The majority of Japanese models fall in the 80-85% efficiency range, with only a small proportion of models at flows rates of 15 litres and above falling in the 90-95% efficiency range. This *relatively* poor performance is perhaps a function of the most recent policy intervention being the target standard value set in 2003 and achieved in 2006. Hence the current model distribution in Japan does not reflect the more ambitious levels now possible across international markets which might usually be associated with Top Runner programme.
- Overall, Australia is the worst performer with the majority of models with efficiencies in the range 77-84%, with only a small number of larger flow rate models reaching condensing efficiencies. While regulation was introduced relatively recently (2011), these regulations set the same performance requirements for both gas storage and gas instantaneous products resulting in performance requirements that are not particularly challenging for instantaneous products.

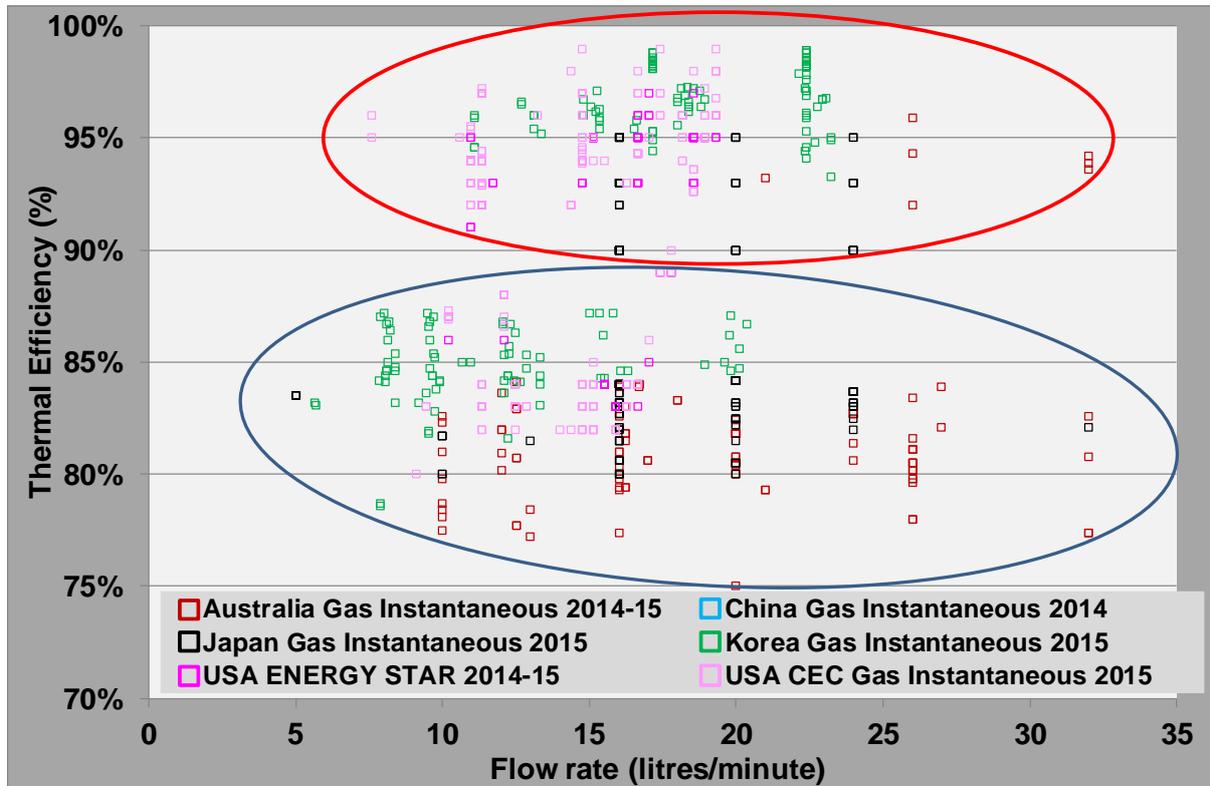
<sup>57</sup> Note the USA CEC data is presented as no flow rates were available for the USA DoE data set. This may present a skewed picture of the USA market as, typically, products listed in the CEC registration system have a higher average efficiency than the market as a whole.

<sup>58</sup> Refer to the Korean mapping document available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>





**Figure 27: Comparison of the thermal efficiency of gas instantaneous water heaters (most recent year data is available)**



#### 4.4.3 Water heating efficiency and flow rate in relation to model rated input power

For completeness, Figure 28 and Figure 29 compare the rated input power and respectively flow rates and water heating efficiency of the gas instantaneous water heaters at reference Benchmark conditions.<sup>59</sup>

Not surprisingly there is a very strong linear relationship between flow rate and input power in all regions. However, while the relationship is still linear, it is interesting to note that in the USA rated input powers are significantly higher for any given flow rate (as indicated in Figure 28 by the displacement of US models to right of models from other regions). The specific reason for this is unknown as, unlike storage water heaters, the ‘First Hour Draw’ capability should be unaffected by rated input power for a given flow rate.

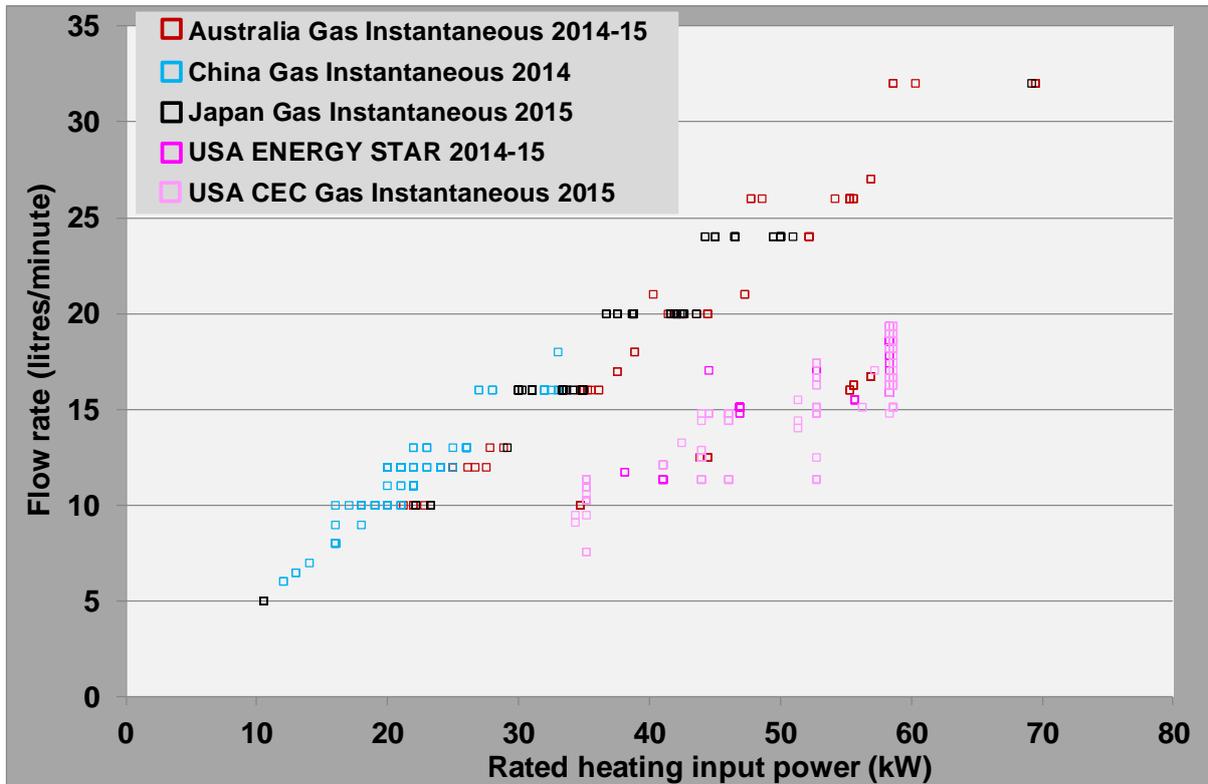
Given the very strong relationship between flow and input power, the water heating efficiency as a function of input power very closely matches the distribution of efficiency as a function of flow, albeit with the USA models being displaced to higher input power ranges.

<sup>59</sup> Note both graphics exclude USA DoE data as rated power is not disclosed in the public DoE data set.

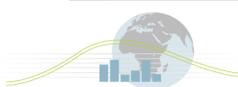
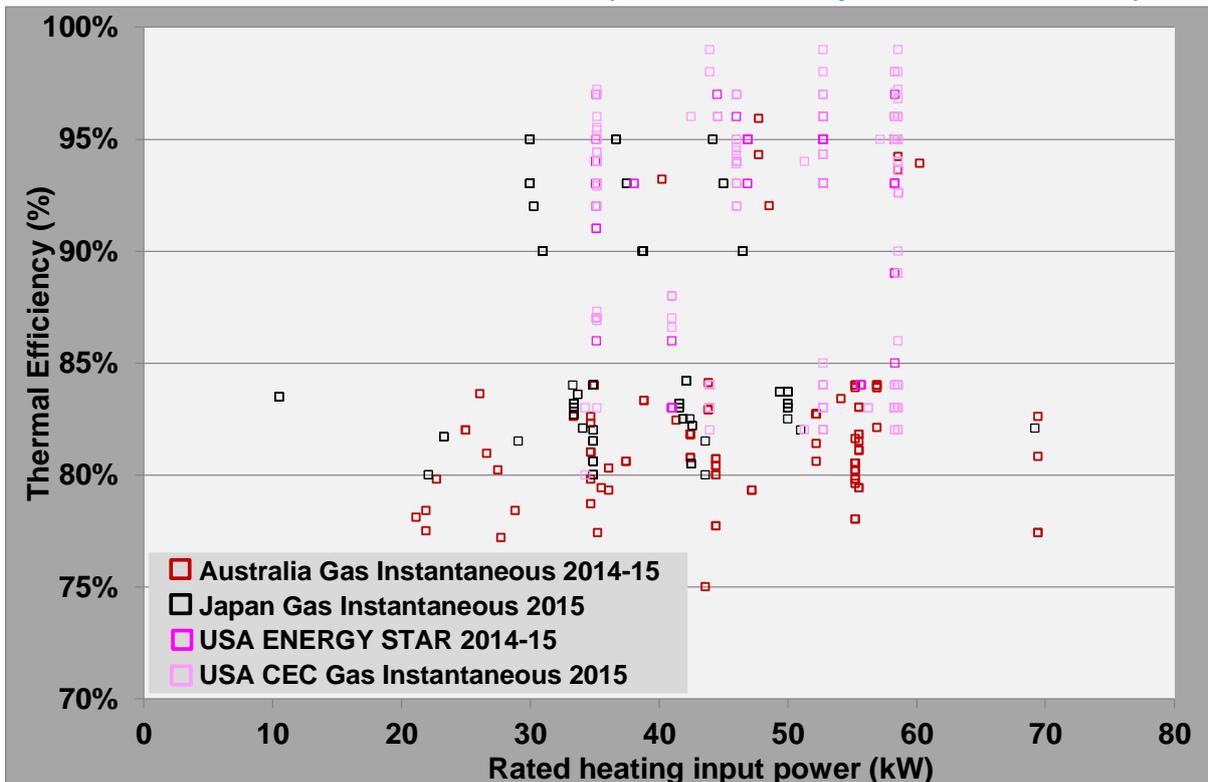




**Figure 28: Flow rate and rated input power of gas instantaneous water heaters available in selected markets (for most recent year data is available)**



**Figure 29: Water heating efficiency and rated input power of gas instantaneous water heaters available in selected markets (for most recent year data is available)**





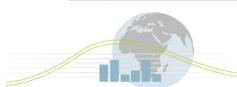
#### 4.4.4 Total daily energy consumption

Bringing together the start-up energy and water heating efficiency of instantaneous gas water heaters the range of normalised total daily energy consumptions across countries can be examined (Figure 30), as can the consumptions in comparison with the reference daily water heating demand (Figure 31).<sup>60</sup>

As the start-up energy for all models is an assumed value constant across all countries (with the exception of Australia where normalised declared values are used), the total daily energy consumption of models reflects the comparative range of water heating efficiencies. Therefore, the individual daily consumption values should be treated as illustrative only. However, they do serve to demonstrate the impact of the broad spread of water efficiencies on the overall energy consumption. Around the internationally typical 15 litres per minute flow rate, the range of energy consumptions from the worst Australian model to the best condensing Korean/ENERGY STAR model is over 4.5 kWh/day, or equivalent to approximately 1.5 MWh per year. Even allowing for existing infrastructure which limits the installation of condensing products in some locations, and excluding the outlying models, there is still broadly a 1-2 kWh/day spread in the energy consumption of the best and worst non-condensing systems in most countries, equivalent to approximately 350-700 kWh per year. Therefore, even where existing infrastructure limitations restrict policy makers from setting performance levels requiring condensing water heater efficiencies, there are still significant gains available to policy makers by tightening regulation addressing non-condensing instantaneous water heaters.

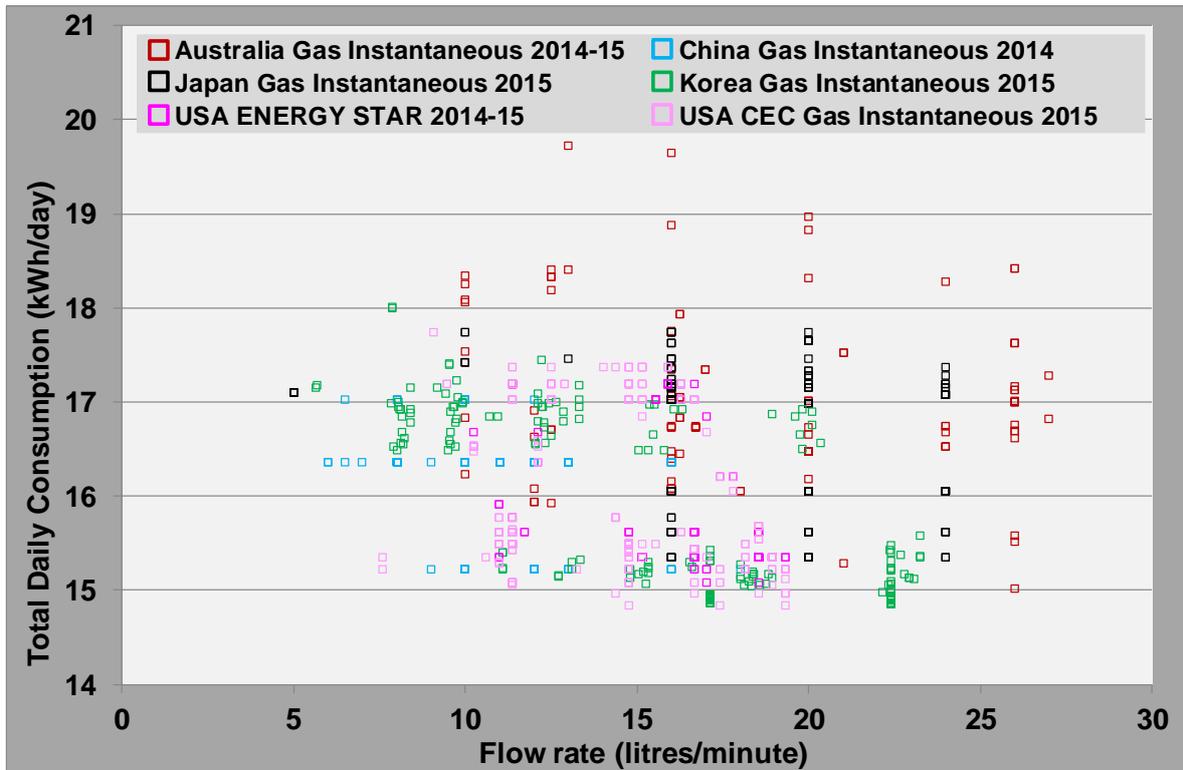
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<sup>60</sup> Chinese model data has been added to these figures. However, to do so, a further number of assumptions have been made and the individual model performance data should be treated as strictly illustrative. Actual model energy consumption will be slightly lower than the values shown. Details of model assumption made can be found in the Chinese Mapping document available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>

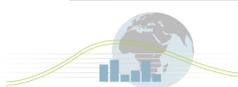
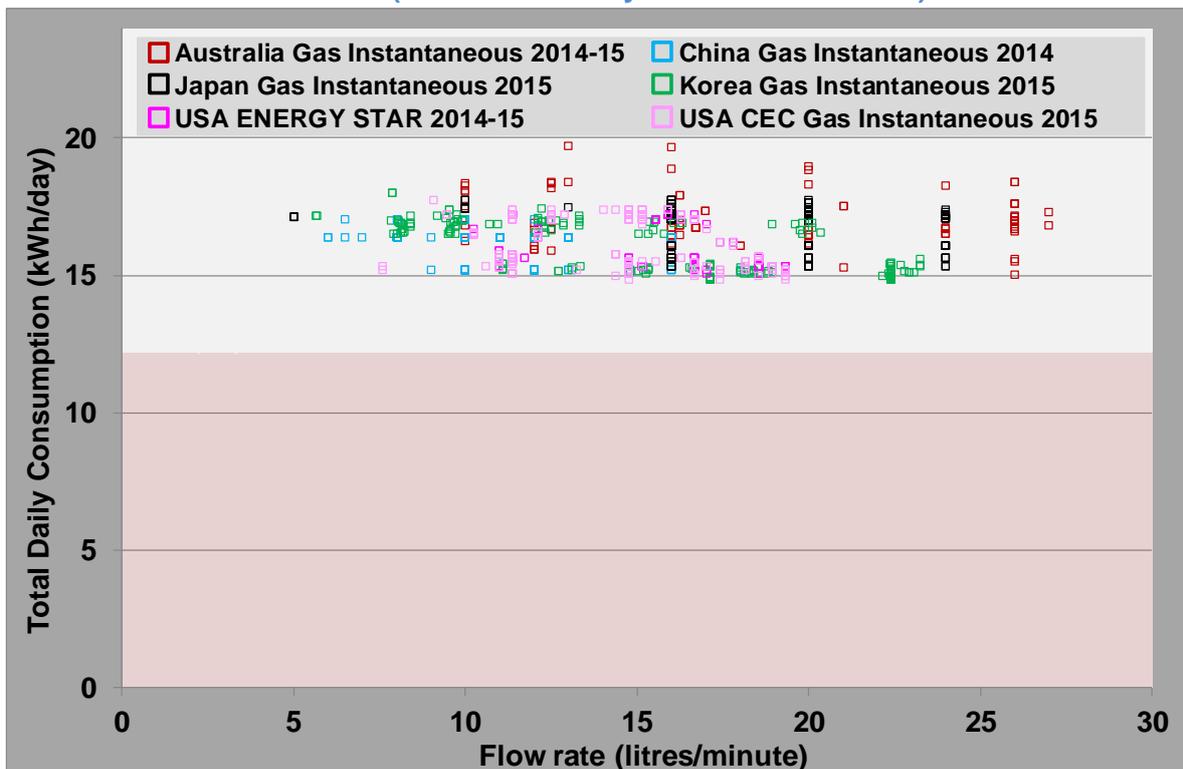


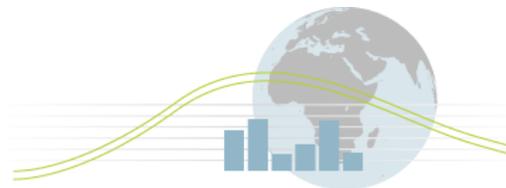


**Figure 30: Comparison of the normalised total daily energy consumption of gas instantaneous water heaters (for most recent year data is available)**



**Figure 31: Comparison of the normalised total daily energy consumption of gas instantaneous water heaters relative to embodied energy in daily delivered water demand (for most recent year data is available)**





## 4.5 Comparison of the normalised total daily energy consumption of all water heater types

Drawing together the performance of all water types, Figure 32 presents a comparison of the normalised total daily *delivered* energy consumption of electric and gas storage, air sourced electric heat pump, and gas instantaneous water heaters relative to embodied energy in the daily delivered water demand of 12.11 kWh *at reference Benchmarked conditions* and on the basis of *comparable service*.<sup>61</sup>

As would be expected from the preceding analysis, at the broadly internationally equivalent 200-litre gas and electric storage, 280-litre air source heat pump, and 15-litre/minute flow rate gas instantaneous models, three distinct bands of product daily 'delivered' energy consumption are evident, broadly:

- Air sourced heat pump water heaters benefiting from using the vapour compression cycle to capture heat energy from the environment consume 3.0 - 5.4 kWh per day to deliver the reference water heating requirements making them by far the most efficient water heating technology.
- Direct electrically heated storage water tanks are the next lowest energy consumer, benefiting from over 98% efficiency in converting the electrical energy to heat within the water consuming around 12.3 - 13.4 kWh per day.
- Gas storage and instantaneous water heaters have the highest daily energy consumptions. Gas storage models broadly fall into the range 16.5 - 21 kWh/day due to relatively inefficient water heating, and higher heat loss rates during storage. Instantaneous water heaters are mainly in the slightly tighter 15 - 17 kWh/day range because an appreciably higher number of condensing products improve water heating efficiencies. Further, due to the significant sensitivity of the energy consumption of instantaneous water heaters to the number of draws per day, if operating in a regime requiring significantly fewer daily draw-offs than the 39 used in the reference conditions, instantaneous water heaters would most likely create a separate performance band sitting above electric storage and below gas storage products.

In themselves the differences appear significant, but this becomes more obvious when converted to an annual energy consumption. To deliver the 12.11 kWh daily water heating requirement for a full year on a *delivered* energy basis, ranges of annual energy consumption are 1.1 - 2 MWh for heat pump units, 4.4 - 5 MWh for electrically heated storage systems, 6.5 - 6.2 MWh for gas instantaneous products and 6 - 7.7 MWh for gas storage water heaters. For each water heater type there are clear opportunities to further enhance efficiency in almost all countries. Based on the models currently available within the individual markets, these savings opportunities range from 200-400 kWh per year for heat pump and electric storage units, to around 2 MWh per year for some gas storage products. However, the scope for improvement varies significantly, with no one country having the best products across all types.

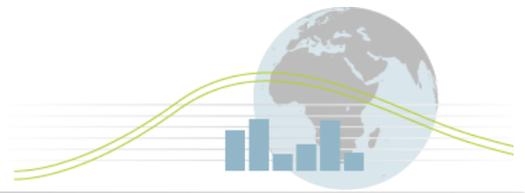
<sup>61</sup> Note the figure has been extended to include larger products beyond typical international equivalence range to ensure the high performance of larger Japanese heat pumps is captured.





Figure 32: Comparison of the normalised total daily 'delivered' energy consumption of electric and gas storage, gas instantaneous and electric heat pump water heaters on an equivalent service basis relative to embodied energy in daily delivered water demand (for most recent year data is available)





These savings assessments focus on the opportunities within individual water heater types. Nevertheless, on a delivered energy basis, it is clear there is potentially more benefit to policy makers encouraging switching of water heater type. To take the most extreme example, a switch from the worst performing gas storage water heater to the best heat pump model analysed (within the comparable service range) would reduce energy consumption by almost 7 MWh at Benchmarking reference conditions. Clearly the actual savings potential varies at the local level depending on a whole range of factors, and particularly when product comparisons are made on primary energy bases which differ considerably due to country specific energy mixes (for example, in the EU, the average conversion factor for delivered to primary energy is set at 2,5, thereby considerably reducing the savings potential). However, in the short term, the significant market changes currently under way in the USA may prompt switching of product type used, and hence yield step changes in overall product efficiency rather than improvements within a single product category?

## 4.6 Impact of 2015 performance requirement on the US market for water heaters

### 4.6.1 IMPORTANT CAUTION

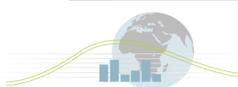
Major regulatory transitions are ongoing in the USA with respect to hot water heaters as follows:

***On 11 July 2014, the US DOE released a revised test procedure for residential and commercial water heaters.<sup>62</sup> The effective date of this rule is 13 July 2015. Compliance will be mandatory starting one year after the publication in the Federal Register of a mathematical conversion factor which converts the existing efficiency ratings to efficiency ratings under the test procedure adopted by this new rule. These mathematical conversion factors for translating efficiency ratings (Energy Factor - EF) using the original test method to the ratings under the amended test method (Uniform Energy Factor - UEF) were published on 14 April 2015 as a Notice of Proposed Rule. The proposal also includes revised efficiency standards (MEPS levels) for different products in terms of UEF.***

***The data used in the analysis was downloaded from DoE and ENERGY STAR online systems in September 2015. Hence, at this time all downloaded data is still reported based on Energy Factor declarations and, being less than 1 year after publishing of the conversion factors, products are NOT required to be compliant with the '2015' performance requirement and comparisons of registered models to performance requirements are presented only to indicate the likely impact on the market. However, the ENERGY STAR version 3.0 requirement became mandatory for products manufactured on or after 16 April 2015 and therefore products shown should be compliant with this requirement (more details are available in the USA Mapping Document<sup>63</sup>).***

<sup>62</sup> Document ID: EERE-2011-BT-TP-0042-0082 RIN: 1904-AC53. Federal Register Number: 2014-15656.

<sup>63</sup> All available at <http://mappingandbenchmarking.iea-4e.org/matrix?type=product&id=18>





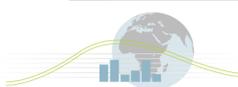
#### **4.6.2 A step change in for the storage water heater market the USA with potential impacts elsewhere**

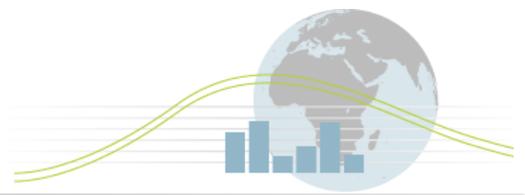
Figure 33 shows the distribution of USA registered electric storage, gas storage and heat pump water heaters in September 2015 relative to the 2004 and 2015 DoE mandatory performance requirements, and those of the voluntary ENERGY STAR version 3.0 specification of 2015 (noting once more that Canada also contributes to the development of ENERGY STAR specifications and promotes registered products in their local market).

As illustrated, a significant proportion of registered products available in September 2015 will cease to meet the new 2015 federal regulations when the regulations become mandatory. This is particularly true for electric and gas storage water heaters above the 55-gallon (208-litre) threshold where the new regulations effectively require the respective application of heat pump and condensing technologies. Hence, above this 55-gallon threshold, at the time of comparison only a small proportion of registered electrical products would comply with the new regulations (heat pump models), and no gas storage water heaters would be compliant. The apparent implication is the market has been slow to respond to these changes, or manufacturers expect that the likely change in price required for compliance of gas storage and electrical (heat pump) water heaters may drive the market to alternative technologies (e.g. instantaneous [tankless] products).

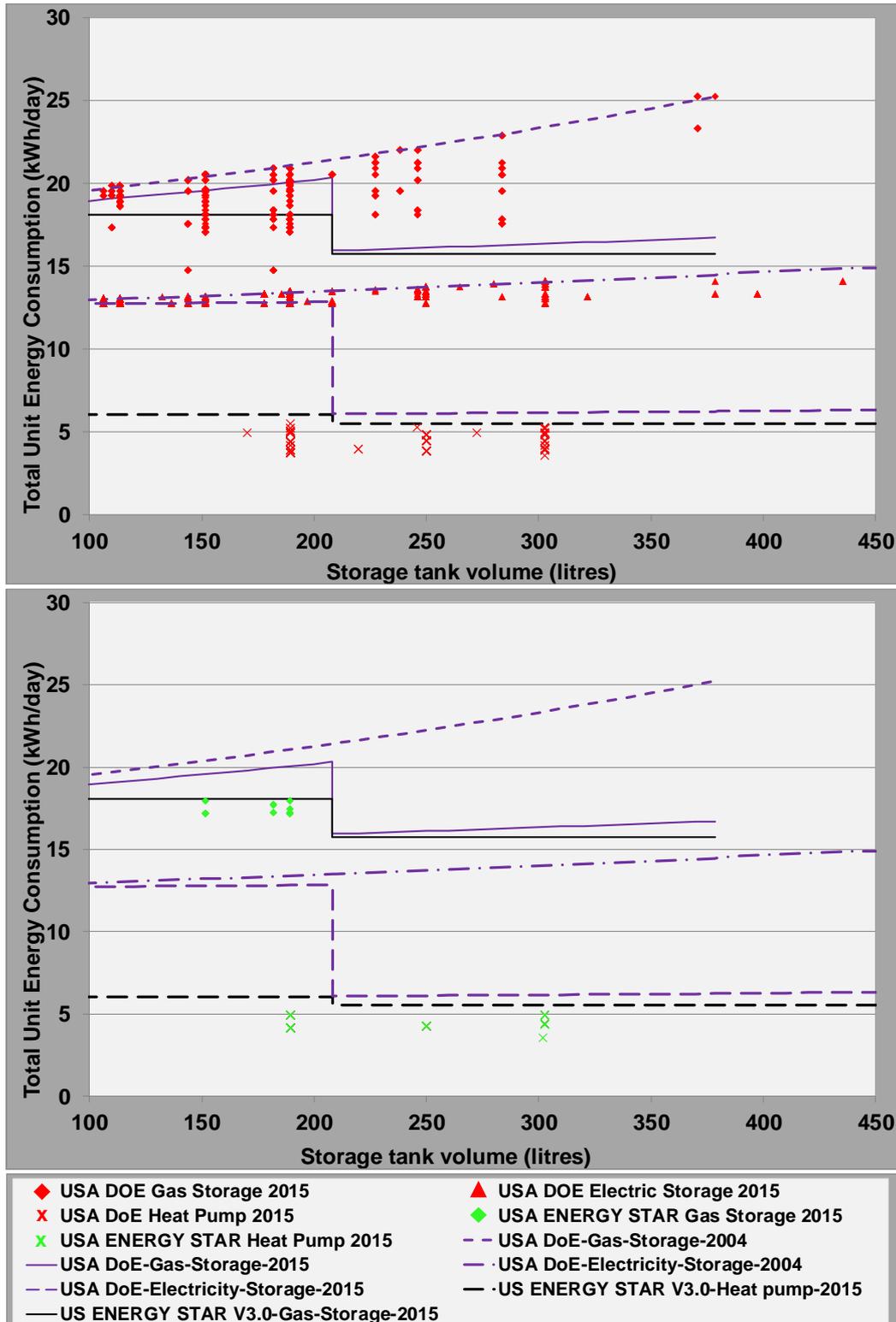
An *indication* of the significance of the likely market impact is shown by the relative paucity of products registered under ENERGY STAR version 3.0. It is recognised that ENERGY STAR only seeks to promote the best products on the market, and hence typically sets performance requirements that are challenging. However, the fact that 6 months after the new specification entered force no gas storage water heaters above 55 gallons had been registered to qualify for the number of market advantages offered to ENERGY STAR products indicates that manufacturers may be finding the new specifications particularly challenging to deliver at market acceptable prices.

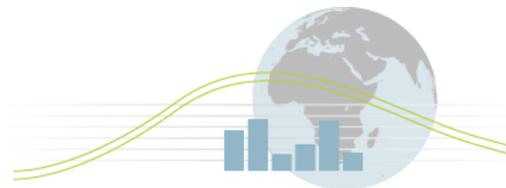
Whatever the eventual outcome, whether rapid introductions of new products take place; a migration to competing product types occurs; a move to smaller gas storage units below the 208-litre threshold; or most likely, a combination of all of the above, it will result in a paradigm shift in the market resulting in a significant fall in energy consumption for water heating in the USA.





**Figure 33: Distribution of electric storage, gas storage and heat pump water heaters relative to the 2015 performance requirements (DoE and ENERGY STAR data - September 2015)**





## 5 Conclusions

The specific mix of water heater types used and the actual energy consumptions of individual models vary considerably between countries. However, for all countries there is a potential to make savings across almost all water heater types. The magnitude of the savings potential varies but in some cases the potential is very large. For example, savings of over 1 MWh per year per product are available to policy makers in Canada if they are able to move the local market towards the more efficient gas storage water heaters already available in their market. Even for electric storage water heaters where manageable losses are limited, savings of 100 - 200 kWh/year per product are available to policy makers in most countries. Within the context of the total annual energy consumption of water heaters, such savings might appear insignificant. However, savings of this magnitude are often sought for other products (e.g. refrigerators) and could be achieved simply by eliminating the worst performing products from the market with no apparent loss of service to the consumer.

However, water heaters are a complex product for policy makers to address. Variations in existing infrastructure and energy source availability are obvious limiting factors. Also, potentially more than any other domestic appliance, consumer usage patterns and ambient environmental conditions have a major impact on water heater energy consumption. Further, these variations have differing impacts depending on the type of water heater in use. Thus, the specific strategies developed and deployed by policy makers vary significantly depending on local conditions. However, where mandatory or voluntary product performance standards have been deployed, they tend to fall into two broad categories:

- **Product specific:** Typically individual aspects of product energy consumption are limited. For example, in Australia and Canada heat loss for electric storage water heaters is directly regulated, whereas in Korea, it is the thermal efficiency of instantaneous water heaters to which limits are applied;
- **Technology neutral:** Specific levels of water heating service are defined, with an associated maximum energy consumption assigned to that level of service irrespective of technology deployed. Such an approach is used by Australia for gas water heaters, and is used in the EU across water heater types.

In practice, almost all regulatory regimes deploy a hybrid of the two approaches. For example, until the current transition, the USA specified a generic set of hot water service requirements for almost all water heater types, but applied differing minimum performance standards for each water heater type delivering that service. Even where 'pure' technology neutral standards are deployed, the specific service requirements selected may favour one particular product type.

However, it is interesting to note that some of the best performing products across international markets have resulted from alternate policy interventions. For example:

- In Japan, the Top Runner programme does set mandatory performance requirements but, rather than setting minimum requirements for individual products, future product performance targets are based on a category/application specific weighted average value of shipments from manufacturers. This has led the Japanese heat pump water





heater market to be dominated by some of the best performing products in the world.

Australia also has some very high performing heat pump models apparently drawn into the market by emissions based white certificate schemes in some States.

- Korea has a high proportion of the best performing instantaneous water heaters despite the Korean minimum performance standard not being particularly challenging. This may be a spin-off from the aggressive advertising promoting condensing boiler systems spilling over into a consumer demand for condensing instantaneous water heaters which are then easily identifiable via the Korean energy label.
- The North American ENERGY STAR programme is encouraging premium performance products across all water heater types.

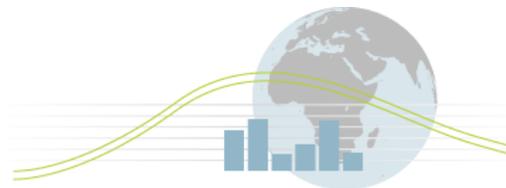
Hence the specific strategies currently being deployed by policy makers are tailored to local technical, environmental, cultural and political priorities. Consequently, it is not surprising that no one country has the best performing products across all water heater types. The only caveat that should be added is, from the data available, it appears that the more recent the policy intervention, the better the resulting product performance. This is evidenced by the relatively poor performance of a number of Canadian products where the most recent intervention (with the exception of ENERGY STAR) appears to have been in 2004. Similarly, the Japanese Top Runner programme for instantaneous water heaters may have been successful in the 2006 target year, but products elsewhere have now far exceeded the performance of products currently in the Japanese market.

The discussion so far has focused on the savings potential available from individual water heating technologies. However, there are much larger potential savings *between* types of water heater. On a delivered energy basis, and at the reference conditions used, water heater types providing similar levels of service have annual energy consumptions of:

- Air sourced heat pumps: 1.1 – 2.0 MWh;
- Direct electrically heated storage: 4.4 – 5.0 MWh;
- Gas instantaneous: 6.2 - 6.5 MWh;
- Gas storage: 6.0 - 7.7 MWh per year.

Hence, to take the most the most extreme example, a switch from the worst performing gas storage water heater to the best heat pump model would reduce annual energy consumption by almost 7 MWh. Given the product performance levels set to date, policy makers seem to have been reticent about pursuing policies that would drive switching of product type, even where technology neutral policy measures have been deployed. However, the technology neutral labelling of water heaters in the EU clearly has such technology switching as a long term goal. Further, the transition in regulatory requirements currently under way in the USA appears to be moving towards technology neutrality (with practical limitations), based on primary energy. For water heaters above 208 litres, it appears the likely impact will be to drive electrically heated water heaters to heat pump technology, and gas storage water heaters to condensing efficiencies. Not only is this likely to yield significant energy savings in the US market, it is likely to stimulate the introduction of a large number of higher efficiency gas storage and electric heat pump products into the market. If this is the case, such products (or similar derivatives) may become more widely available internationally and present policy makers elsewhere with more options for managing their own markets.





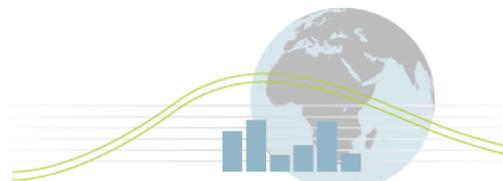
## Annex 1: Summary description of the normalisation process for minimum and premium performance requirements

In a number of cases the normalisation process for minimum and premium performance standards may follow the same methodology as used for products. For example, where national electric storage water heater minimum performance requirements are defined based on a maximum heat loss rate relative to tank volume, by making similar assumptions as that for individual products where only heat loss is known (i.e. a heating efficiency of 98%), the normalisation can follow the same process as that for products.

However, where national requirements are defined based on maximum energy consumption for a defined load profile, normalisation becomes more complex. For example, for a gas storage water heater, energy flows are split between the water heating process and replenishing energy lost during storage. The normalisation process has differing impacts on the energy used for water heating (normalised based on changes in the hot and cold water temperatures) and storage losses (normalised based on differences in hot water storage temperatures and ambient conditions). On the product level, this does not hamper the normalisation process as the heating efficiency and storage losses are fixed for the individual model. However, a supplier may choose to meet performance requirements by maximising the efficiency of the water heating process, minimising the losses during storage, or a combination of both, so attribution of energy flows to the water heating and storage elements is not fixed and the normalisation cannot take place.

In these circumstances, an analysis is conducted of all models of that water heater type available in the local market (at specific volume or flow rates) to establish the average breakdown of energy flows under the regulated conditions. Once this breakdown is known for each volume/flow range, nominal 'policy products' are created which mirror these average energy flows, but which align with the total allowable energy consumption under local performance requirements. These 'policy products' are then normalised and a linear regression undertaken to create a normalised performance requirement. However, it should be noted that this approach has significant uncertainties and normalised performance requirements derived in this way should be treated with caution. In particular, the normalisation for the EU is based on a **very** small number of electric storage models and no other product type, and Australian instantaneous models are limited in the volume range that can be reliably reported; therefore these performance requirements should be treated as illustrative only.





### Annex 2: Volume analysis to enable alignment of products capable of providing similar service

Comparisons of the performance of products of the same type can be undertaken directly on a like for like basis. However, such comparisons become more complicated for water heaters of different types where the typical characterisation of an ability to service a demand varies. To use a simplistic example, in many markets storage water heaters are typically marketed based on storage tank volume, while instantaneous water heaters are marketed on their ability to supply hot water at a specific flow rate. Therefore, an approach has been developed for comparison of water heaters of different types capable of delivering broadly equivalent service.

While recognising the demand for hot water is very climate and culturally dependent, and indeed varies depending on family size, age distribution, etc, a simplistic assumption has been made that the distribution of service demands for hot water will be *broadly* similar in all countries. Further, it is assumed that the distribution of products available in the market will mirror the distribution of service demands.<sup>64</sup>

Figure 34 and Figure 35 illustrate the proportion of products in each data set with flow and volume rates for individual product types segmented into the following ranges.<sup>65</sup>

- Electric and Gas Storage and Heat Pumps in ranges of <100 l, 100-150 l, 150-200 l, 200-250 l, 250-300 l, >300 l.
- Gas and Electric Instantaneous in ranges of <2 l/m, 2-4 l/m, 4-6 l/m, 6-13 l/m, 13-18 l/m, >18 l/m.

Based on these product distributions, average volumes were established with equal weighting given to each country. Points at approximately 50% on either side of the gross average volume/flow were then taken as minimum and maximum volumes/flows for equivalence values (rounded). Table 5 show the resulting estimates of equivalent service levels.

**Table 5: Estimated size/capacity of water heaters of different types delivering equivalent levels of service**

Product Type (comparative metric)	Estimated Product Equivalence		
<i>Electric and Gas Storage Water Heaters (volume in litres)</i>	100	200	300
<i>Air Sourced Heat Pumps (volume in litres)</i>	180	280	380
<i>Electric and Gas Instantaneous (flow rate in litres/minute)</i>	10	15	20

<sup>64</sup> This approach is simplistic as, beyond consumer preference and demographics, there are a wide range of other factors influencing products available in national (and local) markets ranging from physical limitations to the size or type of product that can be deployed (e.g. limited space for storage water heaters), to the availability of energy sources (e.g. no access to gas supplies). However, given the limited data available to the analysis, the simplistic approach described is the only apparent practical option to estimate equivalence of service between product types.

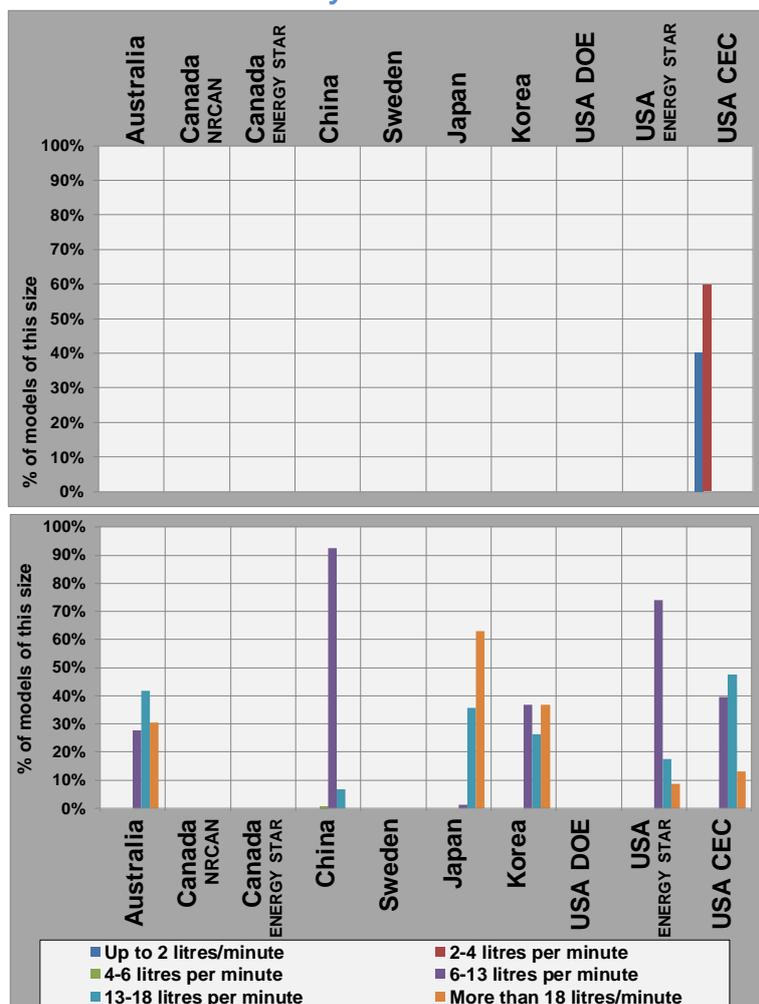
<sup>65</sup> Based on models available over the most recent 3 years, with at least 40 models available required for distribution analysis.

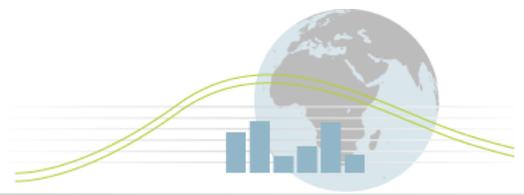


However, it should be noted:

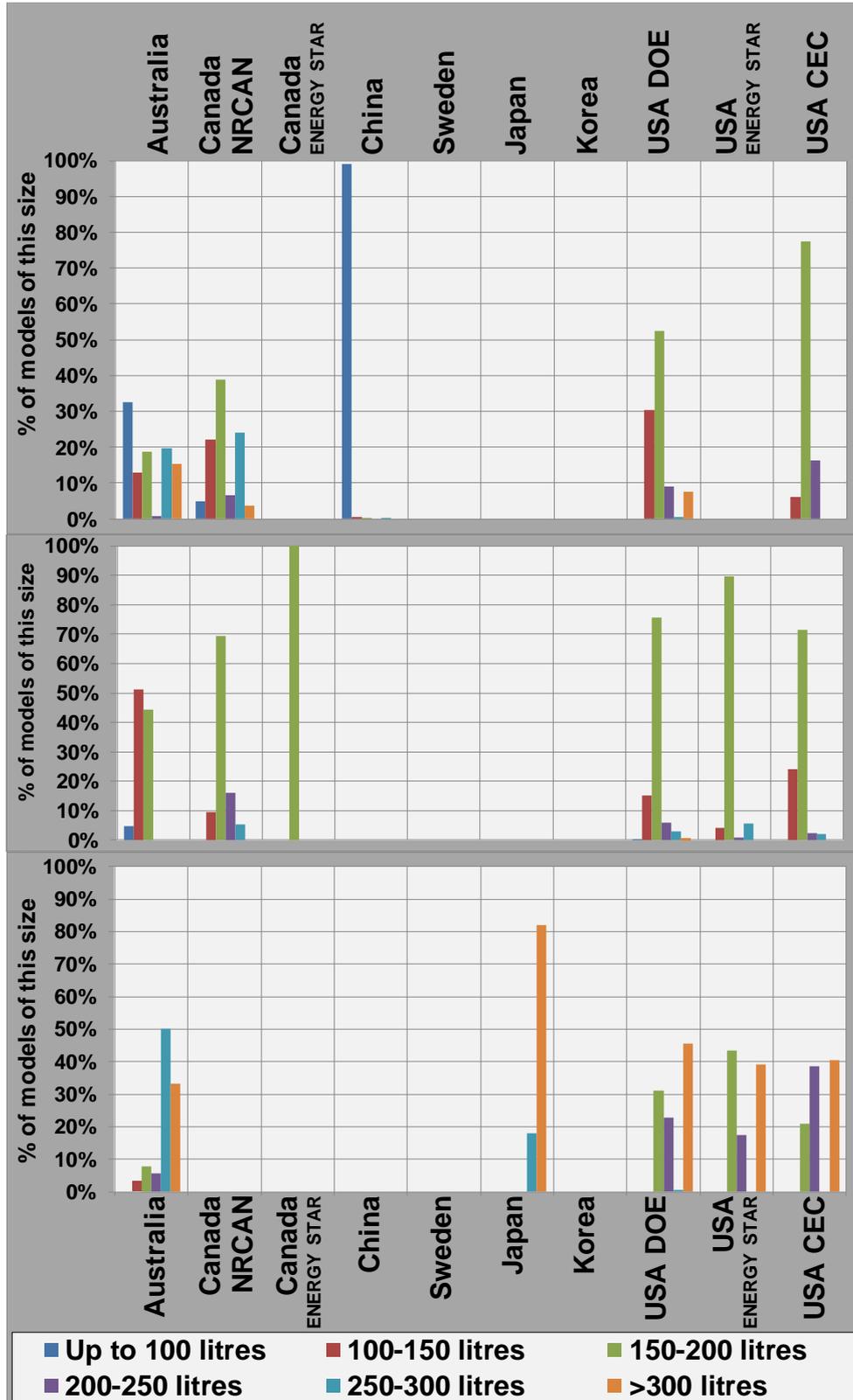
- Volumes for gas storage water heater tanks are typically smaller than electrical equivalents given the ability of gas systems to more quickly recover stored water temperature following hot water depletion. Further, where electrical water heaters are designed to operate primarily on off-peak electricity tariffs (as is the case with a number of Australian models), this difference in tank sizes is typically larger still. However, in the data sets available, this difference is offset by notably smaller units in the Chinese market (all under 100 litres). As a result, the gas storage tank volumes are only approximately 10% smaller than the electrical units and so have been aligned to assist in presentation.
- Heat pump systems typically have larger storage volumes than both electric and gas water heaters due to their extended reheat times. However, the extent of this difference is skewed in the available data sets by a cultural preference for large seasonal hot water demands in Japan (average Japanese heat pump tank volume is over 350 litres compared with approximately 250 litres elsewhere). Hence equivalence volumes for heat pump water heaters may be somewhat larger than should be the case.

**Figure 34: Characterisation of national electric and gas instantaneous water heater markets by flow rate**





**Figure 35: Characterisation of national electric, gas and heat pump storage water heater markets by volume**





## Annex 3: Framework for grading mapping and benchmarking outputs

The grading system developed by the Annex to provide a measure of the 'reliability' of analysis and outputs enables the allocation of a 'robust', 'indicative' or 'illustrative' grading to each output. The grading system is based on an appraisal of the type and quality of the initial data input, and the degree to which any consequential manipulations are *likely* to have degraded the reliability of the original data and/or the comparability of outputs with those of other countries. While expert opinion is used to formulate the specific grading allocated to individual data sets or outputs, this expert opinion is formed based on a consistent framework detailed below.

### Grading of data/mapping outputs

**Robust** – where typically:

- The data is largely representative of the full market and
- The data includes at least a significant element of individual product data and
- The data is from known and reliable sources and
- Test methodologies are known and reliable and
- Any data manipulations are based on solid evidence and should not unduly distort results.

Conclusions from such data sets are as reliable as reasonably possible within boundaries of the Annex operation.

**Indicative** - where typically:

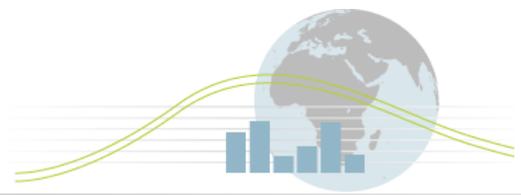
- Data sets may not be fully representative of the markets (but do account for a majority, ideally a known and understood majority) and/or
- Any data manipulation used includes some assumptions or unavoidable approximations that could unintentionally reduce accuracy.

However, accuracy is such that meaningful but qualified conclusions could be drawn.

**Illustrative** – where typically:

- One or more significant parts of a data set is known to represent less than a majority of the full market or
- Test methodologies used to derive data are not known or
- Test methodologies used to derive data are known but could lead to significant differences in outcome or
- Data manipulations for the analysis contain an element of speculation or significant assumption or
- Conflicting and equally valid evidence is available.

Rather than being rejected completely, perhaps because the flaws in the data are at least consistent, such data could provide some insight into the market situation and so is worth reporting, but results must be treated with caution.



## Grading of comparison between country outputs (benchmarking)

**Robust** – where typically:

- The data sources being compared are each largely ‘robust’ and
- No data manipulations for benchmarking were necessary; or if manipulations were used they were based upon solid evidence and should not distort results.

Conclusions from comparisons within and between such data sets are as reliable as reasonably possible within the boundaries outlined above.

**Indicative** - where typically:

- Data sets being compared are themselves only ‘indicative’ and/or
- Any data manipulation used for benchmarking includes some assumptions or unavoidable approximations that could unintentionally reduce accuracy and/or
- For any other reason(s) subsets of the data may not be strictly comparable which leads to some distortion.

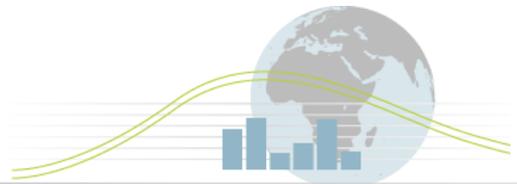
However, accuracy is such that meaningful but qualified conclusions could be drawn.

**Illustrative** – where typically:

- One or more significant parts of the data sets are themselves ‘illustrative’ and/or
- Data manipulations for the benchmarking process contain an element of speculation or significant assumption.

Rather than being rejected completely, perhaps because the flaws in the data are at least consistent, such data could provide insight into the market situation and so is worth reporting, but results must be treated with caution.





## Annex 4: History of Document Revisions

Revision Date	Version	Summary of Revision
September 2016	1.0	First draft of full Benchmarking issued for review
February 2017	2.0	Final Benchmarking issued

