

Water Heating

HIGHLIGHTS

■ **PROCESS AND TECHNOLOGY STATUS** – In developed countries, modest efficiency improvements in water heating have occurred in recent years. Water heating is typically the third largest domestic energy end-use after space heating/cooling and lighting. For example, in 2010 water heating accounted for 13.2% of energy consumption in US buildings. Demand for domestic hot water averages at 24 litres per person per day across the EU, although substantial national variations are observed. This demand can be serviced by dedicated water heating systems or by combination systems that also perform a primary space heating role; such devices are considered in the ETSAP Technology Brief R02 (Space Heating and Cooling). Dedicated systems can be broadly characterised as **storage** systems, **instantaneous** devices or alternative systems, including **heat pumps** and **solar** systems. Fuel splits vary substantially; most countries rely chiefly on **gas** and **electricity**, although oil and biomass use can be significant. Sales and stock shares by device differ significantly between countries: in the EU, electric storage systems dominate the market with approximately 55% of dedicated water heater sales, whilst renewables contribute a small portion. Solar devices are popular in China and heat pumps are widespread in Japan. In the commercial sector, water heating consumption contributes a smaller proportion of total consumption and is concentrated in limited building types. In the US, 4.3% of total energy consumption in the commercial sector is attributed to water heating functions, with hotels, hospitals and food service buildings accounting for over 75% of this. Commercial water heating equipment is typically scaled up compared to domestic equipment, in terms of power and storage capacity or flow rate, with significant overlap between smaller commercial units and the upper end of the domestic market. **Booster** heaters are also utilised to deliver higher temperature flows, although the market for such devices is small.

■ **PERFORMANCE AND COSTS** – A variety of metrics can be used to characterise and compare the performance of water heating systems. The key determinant of price and efficiency is size, in terms of storage capacity or power/flow, with a wide range of systems servicing the market. Domestic storage devices in the EU can provide capacities of over 250L but suffer significant standby losses, with overall efficiencies in the range of 27-41% for gas systems and 27-30% for electric devices. Large commercial devices are increasingly subject to more stringent efficiency limits in the US. Typical gas systems provide thermal efficiencies in the range of 76-79% while average electrical devices offer thermal efficiencies of 97-99%. Alternative systems are better characterised by the energy factor (the ratio of useful energy output to the input energy, which can be greater than one), with commercial heat pumps offering values of 2.3-2.4, while solar systems can attain a wide range from 0.8-4.8, depending on size, technology and irradiation levels. Prices vary significantly with size, system type and technology level: average domestic prices fall within the range €80-450 for conventional EU devices and \$4,000-8,000 for US solar thermal systems. Commercial device costs range more broadly from €150-5,800, with gas systems being most expensive. In both sectors user behaviour is important; values are quoted for typical tapping patterns, which encompass the frequency and duration of cycles as well as flow and temperature demands.

■ **POTENTIAL AND BARRIERS** – There is potential for significant energy savings in the domestic water heating sector, with EU reports suggesting a potential for 60% per unit energy savings with the adoption of best available technology. The Energy Star scheme in the US is designed to promote the uptake of more efficient devices, including a focus on instantaneous systems, gas devices, and in particular heat pumps and solar systems. The US market for heat pumps is growing rapidly, having risen from 0.4% to 1.6% of total sales over 2009-10, but overall the stock share of the most efficient systems remains very small in both the domestic and commercial markets. Focus by nation varies: in the US, instantaneous gas systems are strongly promoted; solar systems are heavily endorsed in China and the EU; Japan leads the way with heat pump technology, and their gas utilities are strongly promoting high efficiency condensing units. Reports also identify opportunities for the development of new systems with higher efficiencies, which may be necessary to bring about full market transformation. In the commercial sector, US studies identify unit energy savings of up to 50% with switches to solar systems or heat pumps, relative to the currently prevalent gas storage systems. However, a number of barriers exist to slow the spread of more efficient water heating systems across domestic and commercial markets: high capital costs, market acceptance issues, constraints associated with emergency replacement, split incentives, and fuel availability are all significant factors.

PROCESS AND TECHNOLOGY STATUS

A water heater is a device or set of devices which is equipped with a heat generator and connected to an external supply of sanitary water, and can deliver

desired water temperatures at desired rates. It may or may not be equipped with a storage tank.

This brief deals with dedicated water heaters which provide hot water directly. Combination boilers (which provide both hot water and space heating) are

discussed in ETSAP Technology Brief R02 (Space Heating and Cooling). Also excluded are district water heating, systems using solid fuels (such as biomass) and co-generation systems (for example, combined heat and power systems). Heat pumps and solar systems are considered due to their growing importance as supplementary water heaters, although they may also have a space heating function.

This Technology Brief focuses on domestic and commercial water heating systems (in a broad tertiary sense). Domestic devices are commonly referred to as “domestic hot water” systems, while commercial systems are often termed “sanitary hot water” devices. Industrial water heating accounts for 1% of the 6% of 2005 energy-related GHG emissions in the EU-15 attributed to water heating (including combination systems) [1]. This brief does not cover industrial systems as these are often system-specific and difficult to characterise.

Heat can be generated by burning combustion fuels such as **oil and gas**, or by the Joule effect in **electric** resistance elements. Water heaters can be broadly split between **storage heaters** (with a storage tank) and **instantaneous** (tankless) **heaters**. Storage heaters are typically multi-point appliances and have an internal store of at least 15L, allowing on-demand delivery. Gas systems use a gas burner to heat air, which rises through the flue inside a tank, transferring heat to the flue walls and surrounding water. Electric devices operate on the same principle using electrical heating elements.

For gas systems a further breakdown occurs between **standard and condensing systems** for both storage and instantaneous devices. Condensing systems have greater efficiencies as they capture the latent heat of flue gases. Standard gas and electric models also have high-efficiency variants with superior insulation and thermal improvements. **Instantaneous** devices run a water supply pipe through a heat exchanger and are typically used as single point appliances, in the kitchen or bathroom, with either no or a small internal water store (<15L). These systems heat water through a continuous flow process, thus eliminating standby losses. Hybrid systems do exist; these utilize small storages tanks in an attempt to gain the advantages of both systems.

For electric instantaneous water heaters, a division occurs between **hydraulic and electronic systems**; systems with hydraulic flow rate are controlled by a simple on/off switch dependent on water pressure. This category comprises mainly electric showers, which are almost entirely restricted to the UK and Irish markets – they are found only in small quantities in some other European or Asian nations [2]. Electronic instantaneous devices using electronic flow-rate control can maintain a set temperature through a range of flow rates, and may allow user control. This category also encompasses devices designed to deliver water up to boiling point.

Alternative systems include solar devices and heat pumps. These are often incorporated as auxiliary

systems alongside conventional water heaters which offer a backup.

Solar thermal systems use solar energy to heat mains water (direct) or a working fluid (indirect). Heated water flows via a heat exchanger to transfer energy to a hot water cylinder. The conventional collector type is a flat plate which is popular globally, although more efficient evacuated tube models are predominant in China and are becoming increasingly popular elsewhere. Systems, cost and performance differ substantially depending on climate. In the US, solar thermal systems typically reduce domestic hot water needs by 40-85% [3]. In warmer countries, solar irradiation levels are consistently high throughout the year, so solar devices can often be sized to service the full hot water demand. Pumped (active) systems are far more common in Europe, the US, Australia and New Zealand. Thermosiphon, or natural circulation (passive) systems utilise convection to operate without pumps, offering a cheaper but less efficient option in warmer regions. These are popular in Asian markets, especially China. Globally, solar devices are used chiefly to provide domestic hot water for a single house. However, in some European markets and India, a substantial number are used for large domestic hot water applications, or in combination systems to provide an additional space heating function [4].

Heat pumps are commonly used for space heating or cooling, but can also be used to provide sanitary hot water. They capture ambient heat, using refrigeration cycles to bring the heat to a higher energy level. They can be characterized by the principle process: Carnot cycle, adsorption or absorption, or by the heat source, which can be ground source, ground water, air or solar. In the EU, it is extremely rare for heat pumps to provide only hot water. However, the technology is advancing rapidly and this may develop to be a significant area in the future¹.

Some studies further distinguish between primary and secondary systems. Standard definitions state that primary systems service full domestic water heating demand while secondary devices fulfil a limited purpose.

EU-wide statistics suggest that domestic and commercial water heating consumed a total of 3,790 PJ of primary energy and was responsible for 6% of all fuel-related CO₂ emissions in 2005 (~2% residential, 1% industrial, 1% tertiary and 3% electricity generation) [1]. These figures do attempt to account for the overlap with space heating systems through the inclusion of combination central heating boilers. Estimates give a total internal EU market of 17.2 million units, with 6.8 million of these units being linked to boilers. This equates to a market of €4-5 billion at 2005 prices, including ~15% of combination boiler prices [1].

The installed stock of dedicated water heaters in the EU in 2004/05 was estimated at 146 million, accounting for

¹ At the present time limited information exists to accurately report cost and performance information, so stated figures apply to devices which also serve a space heating function.

49.6% of primary heaters (50.4% were central heating systems) and 100% of secondary water heaters [1]. Results suggest that 32.4% of EU households have a secondary water heater with the following breakdown: small electric storage device for the kitchen (18.5%), second electric instantaneous unit (7.9%) and small gas system (5.9%) [1]. About 10.4 million dedicated water heaters were sold in 2004/05, of which 8.3 million were electric and 2.1 million used gas [1]. Estimates give a long-term average growth rate of 1.5%, with around 70% replacements sales and 30% new sales [1].

The split between domestic and commercial devices is not clear, as there is much overlap between the two markets (see Table 5). The EU Eco-Design study classifies systems by size, using volume ranges (L) for storage systems and maximum power bands (kW) for instantaneous devices. Size classifications run from 3XS to 4XL, with no clear distinction between the domestic and commercial sectors. Within the EU, 52% of units were medium, with all other size categories contributing less than 15% of market share [1].

■ **Domestic Water Heating** - In the US, water heating accounts for around 14-25% of individual domestic energy consumption [5]. It is the third largest energy end-use after space heating/cooling and lighting, accounting for 13.2% of total energy consumption in 2010 [6]. Most US households use natural gas systems, with around 40% using electric devices [7]. Pool heaters are excluded from these figures.

An IEA report shows single-family dwellings have typical water heating capacity of 2.1-4.2kW, while multi-family dwellings average 35kW across the OECD in 2007 [8]. In multi-family dwellings, the growing use of individual water metering and billing has accompanied a move towards decentralized systems. Virtually all new units use separate systems and many centralized systems are being replaced [9].

Examination of average building requirements in five EU member states suggests a standard of 22-33 litres per person per day of hot water at 60°C [10]. Other evidence suggests a real-life range of 10-50 litres per day, due to difference in habits amongst different regions, with an EU average of 24 litres per person per day [10]. This equates to 59 litres or 1,246 kWh heating energy per household per year [10].

Domestic markets differ substantially between countries. In the US, 2010 domestic water heating shipments totalled 8.1 million, with an installed base of around 100 million units [11]. The majority of sales are gas and electric storage devices, which represent 95% of the market in 2010. The remainder of the market is dominated by instantaneous systems (~5%) with Energy Star gas devices accounting for the vast majority of these sales. Alternative systems capture a very small proportion of the US market, although this is predicted to grow. In particular, heat pump sales grew from 0.4% to 1.6% of the US market from 2009 to 2010 [12].

In the EU, there is a push towards the use of alternative water heaters, with solar and heat pumps becoming increasingly significant. The EU-27 is the second

largest market for solar systems, with the majority of devices situated in the south. The UK and Ireland represent unusual markets given the use of electric showers, accounting for around 60% of EU electronic instantaneous hydraulic systems. Advancing technology means solar energy is becoming more versatile; over the course of a year, solar arrays can be used to generate 30-60% of hot water demand for a typical household in Scotland [13].

The picture is very different elsewhere. Different customs and practices can strongly influence consumption rates. High solar irradiation levels per capita mean that solar systems are already cost-competitive in sunny regions like the Middle East, North Africa and southern Europe. Globally, China leads the way with 39% more installed capacity of solar thermal systems than rest of world combined [8]. The market for Thermosiphon systems are most developed in the Asian countries, especially China. These systems account for 70-80% of installed global stock, and more than 85% of the new systems installed in 2009 [4].

Heat pumps are especially popular in Japan, where CO₂ systems sold under the brand name "Eco Cute" have grown rapidly in popularity; estimates for 2010 indicate that 5.2 million units were in use in Japan [14].

■ **Commercial Water Heating** - Commercial water heaters can be characterized in the same way as domestic heaters, but are generally larger and more powerful devices. Splits vary per country; in Italy, heaters become classed as commercial at over 35kW but 70kW in France [1]. In the US, the classification scheme used by the Air-Conditioning, Heating and Refrigeration Institute (AHRI) uses power and capacity ratings, specific by device-type [15].

In the EU, data is limited for commercial and institutional users. Projected baselines provided by the European Climate Change Programme for 2010 indicate that hot water emissions for the EU tertiary sector (defined as non-domestic and non-industrial, with cooking included) contribute around 7% of total CO₂ emissions, with electric systems contributing 9 MtCO₂ and fossil fuel systems contributing 30 MtCO₂ [1].

Models suggest that there are around 70 million tapping points in the EU non-residential sector (including industrial), with 25% in sports facilities, 16% in hotels and 12% in hospitals and clinics. In total, this is equivalent to around 33% of the estimated number of domestic tapping points [1].

In the US, water heating in commercial buildings accounted for 4.3% of total energy use in the commercial sector in 2010. Estimates suggest that overall commercial water heating consumption equates to around 30% of the energy used for water heating in residential buildings. Commercial water heating tends to be focused in limited building types with hotels, hospitals and food service buildings accounting for over 75% of 2010 US commercial water heating consumption [6]. An average of 9% of the energy delivered to commercial buildings is used for water heating. In the wider tertiary sector it is a more

significant end use, accounting for 20-30% of consumption in hotels, hospitals and restaurants [16].

US studies report a roughly even fuel split between electricity and gas devices, with approximately 75% of commercial buildings relying on a centralized heating system with storage tank and boiler. Unlike typical domestic systems, these use a re-circulation loop which continually distributes hot water to each end-use, leading to significant heat losses. In 2003, 22% of commercial buildings used a distributed point-of-use system with dedicated heating devices [17].

Estimates suggest that, of the 3.5 million commercial buildings with water heaters, around 50% have commercial storage heaters (mainly gas systems) and approximately 17% have commercial instantaneous devices [17]. It is suggested that others have high-efficiency technology, and that smaller buildings with lower demands use residential heaters [11].

Some commercial buildings also use **booster** heaters: these accept pre-heated water and raise temperatures to 80°C or more. They are typically small units used in commercial dishwashing, laundry buildings, hospitals and car washes. Gas and electric devices exist with capacities of up to around 100L. The market share for such devices is small [11].

PERFORMANCE AND COSTS

The performance of a water heater can be measured with a range of metrics.

- **Efficiency:** Figures can refer to thermal, specific or gross calorific value (GCV, common outside the EU). All provide a measure of the ratio of useful output to input energy, expressed as a percentage, but the metrics use different definitions and consider various conditions².
- **Nominal capacity:** This metric refers to the measured power output of system under standard conditions.
- **Flow rate:** Provides a measure of the maximum delivery rate of a system for a specific temperature rise, typically 45°C. This metric is often used to characterise instantaneous systems.
- **Energy factor:** This is a measure of overall efficiency, and is the ratio of useful energy output to the input energy. This can exceed a value of 1 with the use of renewables and heat pumps.
- **Consumption rate:** This can be expressed as energy per unit time, typically kWh/year to factor in seasonal variations.
- **Effective useful lifetime:** This measure expresses the average lifetime of a product under typical operating conditions.

Storage systems maintain a constant stock of hot water and are thus subject to substantial standby-by losses. The performance of instantaneous devices may be constrained by the ability to deliver large flows to multiple fixtures.

² Note that the efficiency of combination systems is typically indicated by the combined appliance efficiency metric (CAE) which can vary from 0.59 to 0.90 [7].

Other measures better capture the relative efficiencies of alternative systems, with the energy factor being a common metric in the US. The solar fraction is an important metric for solar systems: this is the portion of total conventional hot water heating load provided by solar energy. The coefficient of performance (COP) is common for heat pumps with values in the range of 2.0-6.0, to be compared to a COP of 1.0 for traditional electric heaters [18].

Figures vary with device type, technology type and fuel. Moreover, efficiency varies significantly with loading so typical device figures are generally quoted for different sizes.

Real-life efficiencies differ from nominal values, partly due to standby losses (relating to storage insulation) and piping layouts. Consumer tapping behaviour is a key determinant: the number and duration of tapping cycles, temperature and flow rate all control practical efficiencies. Key factors include user number, frequency, duration and timing of usage, and kitchen and bathroom use [1].

The EU Eco-design project reports that a spread of product lifetimes exist for different dedicated devices, with an EU-average of 15 years across both sectors [1].

■ **Domestic Water Heating** - In the US, the domestic market for energy efficient heaters has grown rapidly in recent times, fuelled partly by the Energy Star water program launched in January 2009. Under US Department of Energy (DOE) and US Environmental Protection Agency (EPA) standards, this voluntary scheme offers independent validation of efficiency claims and, in September 2010, covered 1,155 models of gas storage and instantaneous, heat pump and solar devices [19].

The US Government is promoting efficient instantaneous devices, and as a result the vast majority of systems now sold in the US are Energy Star qualified equipment. Shipments of high efficiency equipment rose from 0.6 million units to 1 million units between 2006 and 2009, reaching a 13% market share, despite a shrinking market overall [12].

However, most of the existing US stock of ~37 million domestic water heaters just meets original 1990 federal regulations, with the vast majority being storage systems. Electric systems typically have energy factors of around 0.9 while gas systems are generally rated around 0.6 [7]³. Energy Star qualified equipment consumes 14-55% less energy than standard low-efficiency models [19].

Prices vary significantly with size. Studies indicate EU average prices for a range of smaller system sizes as follows [1]:

- €400 for medium gas storage devices
- €250-350 for gas instantaneous devices
- €99-295 for electric storage heaters

³ Note that gas and electric consumption and efficiency rates should not be directly compared, without consideration of electricity production and transmission. In terms of primary energy efficiency, gas systems are generally superior [7].

- €81-252 for electric hydraulic instantaneous devices
- €245-448 for electronic instantaneous systems.

Larger systems can be significantly more expensive but relative price relationships are roughly maintained. Alternative systems require large initial investments, which rise with size and technology level. Typical US prices for solar thermal devices are in the range of \$4,000 to \$8,000 [3].

■ **Commercial Water Heating** - EU reports suggest that commercial users with low demand may utilise larger devices also used in the domestic market (see Table 2), as well as larger specifically commercial systems (Tables 3) [1].

In large buildings, distributed systems utilising instantaneous or small storage devices to provide hot water on demand can offer efficiency advantages over central heating systems, which utilise re-circulation loops so are subject to substantial heat loss.

The US Federal water heating standards (planned to take effect in 2016) use minimum energy factor limits; these are significantly more strict on devices over 55 gallons (~210L). Large commercial-scale gas storage systems will be required to attain energy factors of around 0.75-0.80, electric systems must satisfy limits of nearly 2.0 while instantaneous systems will need to reach values of 0.82 [19].

Typical current US commercial gas systems have measured thermal efficiencies of 76-79% and electrical devices attain figures of 97-99% [11].

Prices vary substantially with system type, technology level and size, with gas instantaneous and booster devices being more expensive than their electric equivalents. Indicative US price ranges are as follows [11]:

- \$2,500-4,500 for gas storage devices
- \$950-1,250 for instantaneous gas devices
- \$4,100-5,800 for gas booster devices
- \$3,000-3,500 for electric storage devices
- \$150-250 for electric instantaneous systems
- \$1,350-1,750 for electric boosters
- \$1,400-4,000 for heat pumps
- \$6,000-12,000 for solar thermal devices

POTENTIAL AND BARRIERS

Government initiatives and regulatory measures covering water heaters differ substantially across the world. Overall, a focus on primary consumption means that limits tend to be stricter on electric devices. The US leads with the most stringent Minimum Energy performance standards (MEPS), certainly for storage systems. Their example is followed by Canada, Australia and New Zealand. For gas-fired instantaneous devices, Japan lead the way with minimum gross calorific values of 83%, probably followed by China. Limits on NOx and CO emissions remain rare [1].

Reports identify a number of key barriers to more efficient water heating, which are common to both the domestic and commercial sectors [12], [1]:

- **High capital cost/affordability:** High-efficiency equipment can provide life cycle savings through lowered operating costs but many consumers are deterred by high initial expense. Associated with this are sales driver issues: up-selling is difficult since water heaters are often perceived as a commodity, as there are few premium features beyond improved efficiency.
- **Market acceptance:** High-efficiency devices must achieve sustained superior performance to gain consumer and installer acceptance. Additional space requirements may also deter consumers.
- **Replacement urgency:** Emergency replacements often necessitate immediate availability so high-efficiency alternatives are rarely considered. Plumber stock and training often constrains choice.
- **Split incentives:** Buyers are not always users, so may prioritise low initial cost over long-term energy savings. This is particularly important in new constructions where builders may opt for the cheapest allowed solution. Furthermore, choices are often prescribed by installers as consumers often perceive themselves to have insufficient knowledge, so motives and training level may be significant.
- **Lack of fuel choice:** Grid limitation mean gas options are often unavailable. House structure may also be significant with regards to the availability of chimneys. Solar systems may not be possible for all roofs and are not an appropriate option in all climates.

In the EU, there are no region-wide mandatory measures covering energy efficiency or emissions of water heaters in the domestic or commercial sectors, although initiatives are forthcoming via the Ecodesign Framework Directive. Business-as-usual (BaU) models suggest that EU energy consumption of water heating will rise by 12.5% from 2010 to 2020 as the influence of projected rises in demand, with 10-12% more households and more frequent and longer showers, outweighs efficiency gains through stock replacement [1].

The 2007 Eco-design study concluded that least life cycle cost targets would achieve an energy saving of around 35% per unit on the base case. Targets would be dependent on size, with point-of-use appliances being required to meet minimum primary efficiencies of 24% and large commercial systems achieving at least 90%. The introduction of stages targets generates a 'realistic' scenario in which minimum energy standards bring down net consumption in 2020 by 41.4% compared to the business-as-usual scenario [1].

Utilising best available technologies (BAT) could realise energy efficiency gains of over 60%. Alongside these targets, the study advocates the use of a comprehensive labelling scheme covering 10 efficiency classes over 9 size categories. The report suggests that such measures would boost EU competitiveness, benefit installers and reduce consumer expenditure, since volume production of BAT will lower prices [1].

Bloomberg reports suggest that solar systems will become more economically attractive for a broader range of climates and technology costs fall and efficiencies rise. Forecasts suggest that global capacity

will double to 975 GWh by 2030, with China accounting for 50% and India growing to 10% [20].

Another report highlights the importance of consideration of usage patterns. Importantly, it also draws attention to the under-analysed area of distribution system optimisation, in terms of design, operation and maintenance [12].

■ **Domestic Water Heating** - In the US, business-as-usual estimates suggest domestic consumption in 2030 will be approximately 149TWh for electrical water heating devices and 35TWh for gas systems [22]. The same report identifies a techno-economic potential saving of 27% and 29% for electric and gas systems respectively.

The US Energy Star programme is expected to combat the sales driver issue by boosting consumer awareness of the potential savings with efficient devices. However, despite the rise in Energy Star high-efficiency sales, the majority of water heaters still just meet minimum efficiency standards. The most efficient systems (heat pumps and solar devices) account for a very small portion of the current US market. However, the sales of heat pump devices appear to be growing rapidly [12].

Energy Star reports that the US could save 2% of the nation's total energy consumption by switching to efficient heat pumps and solar heaters. However, despite the range of high-efficiency technologies available, reports suggest that true market transformation is not possible without more advanced development at more marketable prices [12]. Attention is drawn to the potential for significantly higher efficiency electric heat pumps, as well as the feasibility of gas varieties.

The US Department of Energy has announced that it will raise minimum energy efficiency standards in 2015, following the most recent update in 2004. Standards will be based on minimum energy factor limits, dependant on fuel type and tank volume. For models under 250L, this will bring a 4-5% efficiency improvement over current minimum standards [11]. For larger storage models the requirements will represent efficiency improvements of 30% and 120% for gas and electric respectively [11]. Gas instantaneous heaters will be required to meet current Energy Star requirements, a 32% rise [12].

■ **Commercial Water Heating** - The lack of current global figures means commercial water heating projections are not readily available. In the US, business-as-usual estimates suggest commercial consumption in 2030 will be approximately 59TWh for

electrical water heating devices and 31TWh for gas systems [22]. The same report identifies a techno-economic potential saving of 11% and 15% for electric and gas systems respectively.

In the US, reports suggest that the commercial water heater market has not changed significantly in recent years, despite federal regulations and promotions. Several states use policies to encourage the purchase of high-efficiency and solar devices, but advanced commercial units make up less than 3,000 units of the 0.6-0.9 million units sold to US businesses [9].

In the US, minimum standards (set in 2004) are more stringent for commercial devices: electric systems must satisfy minimum standby losses, which vary with size, while gas systems must achieve thermal efficiencies of 80%. The Energy Star scheme does not classify specifically commercial devices, so standards and registered devices cover both markets [21].

There is potential for primary energy savings in the US commercial water heating market, relative to traditional gas storage systems, which remain most prevalent [11]. Estimated unit energy savings are as follows:

- 50% for solar thermal systems
- 40% for absorption heat pumps
- 50% for heat pumps
- 18% for condensing devices
- 15% for instantaneous systems.

Commercial heat pumps do appear to be particularly promising devices to deliver large energy savings. Studies find that these are at least twice as efficient as electric resistance water heaters [22].

Modifications to existing systems can also bring significant savings: models suggest storage tank jackets, heat traps and piping insulation bring standby savings of 40%, 25% and 3% respectively. Cost-effective savings may also be realized through reduced usage with water-saving fixtures and devices; the potential for such savings is most significant in water-intensive buildings like restaurants [9]. Improvements in the design of distribution systems may also bring especially significant gains in the commercial sector.

Solar thermal systems are forecasted to develop in a similar manner in the commercial market, with China expected to receive around 50% of the investment in commercial scale solar water heating systems, followed by India and other smaller markets like Australia, Brazil, Japan [20].

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Table 1 – Water Heating Technologies -Small Systems [1], [2]

XXS - M Water Heaters (domestic and small commercial, see table 5)						
Technical Performance		Gas/oil		Electricity		
		Storage	Instantaneous	Storage	Instantaneous	
					Hydraulic	Electronic
Storage size (L)		<100	N/A	<100	N/A	N/A
	XXS	5-10		5-10		
	XS	10-15		10-15		
	S	15-30		15-30		
	M	30-100		30-100		
Flow rate (L/min at 45°C)		-	5-10 (S) 10-13(M)	-	<12-27	2-9 4-9 [2]
Power (kW)	XXS	-	-	2	8	6.3 [2]
	XS	-	9.4	2	8	12.5 [2]
	S	-	17.5	2.5	18	
	M	5	21-27	2.5	23	
Base Energy Consumption (kWh/yr) [2]				1780-4670	1350-3400	1350-1510 (XXS-XS)
System Efficiency (%) ^a	XXS	-	25%	30%	34%	34%
	XS	-	23%	30%	34%	34%
	S	-	21%	30%	34%	34%
	M	27%	27%	34%	38%	38%
Costs						
Capital Cost (euro/unit)		€400(M)	€250-350	€99-295	€81-252	€245-448
Market data						
EU sales share ^b		1.0%	15.8%	34.8%	19.0%	3.8%

a) System efficiency values are the output of the Ecohotwater model: this uses a heat load defined by the applicable base-case tapping pattern, and calculates at the system level to include unavoidable losses relating to distribution.

b) EU sales shares derived from BRGC 2005 data, grouped by size as proportion of relevant market (such that shares total 100%).

Table 2 – Water Heating Technologies - Large Systems [1], [2],

Large – 4XL Water Heaters (large domestic, multi-family households and commercial, see also table 5)						
Technical Performance		Gas/oil		Electricity	Alternative	
		Storage	Instantaneous	Storage	Heat pump	Solar ^a
Volume (L)		120-250+		-	-	-
Flow rate (L/min at 45°C)		-		>13 (L)	-	-
Power (kW)	L	7.5	40 (L)	2.5	10 -500 (electric) 15 -150(gas)	35-130 [9]
	XL	9.3		3		
	XXL	15.6		3		
Annual Consumption (kWh) (230L device)		6,600-7,600	5,400	4,600-4,900 94,800-14,300 [2]	2,200	2,400 (Electric) 3,800 (Gas)
System Efficiency (%) ^b	L	29%	44% (L)	27%	-	-
	XL	37%		29%		
	XXL	41%		30%		
Energy Factor, 230L device [19], [7] ^c		0.55 (oil) 0.6 (gas) 0.65 (HE gas) 0.67 (E* gas) 0.86 (condensing)	0.82 (E*)	0.904 (FS) 0.95 (HE)	2.0 (E*)	1.8 (electric backup) 1.2 (gas backup)
Technical Lifetime, yrs [19]		13		20	13	15-20 20
Costs						
Capital Cost (euro/unit) ^d		€600-1250	€312-508 €600 (L)	€394-973	-	€2940-5880 [3]
Energy Star installation costs [19] ^{d, e}		€661 €955 (E*)	€1470	-	€1323	€2350-3530
Markets data						
EU sales share		1.1%	1.5%	20.6%	-	2.3%

a) Quoted values apply to solar thermal systems in the US. Higher efficiencies and lower unit prices apply in warmer regions. b) System efficiency values are the output of the Ecohotwater-model: this uses a heat load defined by the applicable base-case tapping pattern, and calculates at the system level to include unavoidable distribution losses. c) Energy factor is the ratio of useful output energy to input energy. FS refers to devices just meeting minimum Federal Standards, HE indicates typical high efficiency values and E* refers to devices just meeting Energy Star standards. Energy factors for solar devices are expressed for systems incorporating typical US electric and gas backups. d) Prices converted using average last year exchange rate of 0.7349 \$/€ e) Installation costs capture capital cost and cost of installation, for typical Energy Star equipment.

Table 3 – Commercial Water Heating Technologies [11]

Large US Commercial Water Heaters								
Technical Performance	Natural gas			Electricity			Alternative	
	Storage	Instantaneous	Booster	Storage	Instantaneous	Booster	Heat pump	Solar
Volume (L)	1,000-2,200	N/A	1-110	150-9,500	N/A	20-80	>190	-
Flow rate/recovery rate (L/min at 45°C)	-	<53	-	-	<45	-	-	-
Power (kW)	150-8,500	50-1,300	190-680	5-3,000	2-100	6-58	-	-
Thermal Efficiency (%)	77	76	79	97	99	98	-	50% of load
Energy Factor, 230L device (E*)	-	-	-	-	-	-	2.3-2.4	0.8-4.8
Technical Lifetime, yrs	12	20	3-8	14	20	3-8	14	-
Costs								
Capital Cost – total installed cost (\$/unit)	\$2,500-4,500	\$950-1,250	\$4,100-5,800	\$3,000-3,500	\$150-250	\$1,350-1,750	\$1,400-4,000 >\$10,000 (absorption)	\$6,000-12,000
Market data								
US sales, 2010 [12]	78,600	-	-	58,400	-	-	-	-

Table 4 – Summary of US Energy Star Requirements and Savings [19]

Metrics	Energy Star water heaters (domestics and commercial)				
	Gas			Electric	
	High Efficiency gas storage	Whole-home gas instantaneous	Solar with gas backup	Heat pump	Solar with electric backup
Energy factor	0.67	0.82	1.2	2.0	1.8
Annual consumption, kWh	6,563	5,362	3,838	2,195	2,429
Life expectancy (years)	13	20	20	10	20
Approximate cost of unit and installation	\$1,265	\$1,470-2,500	\$3,200 ^a	\$1,500	\$3,200 ^a
Approximate simple payback period ^b	10	7-19	16	3	9.5
Approximate US units sold, 2009 (000s)	650	330	7	15	7

a) Based on price premium on standard model and expected saving in consumption.

b) This is an average figure; costs vary widely since installations are often custom.

Table 5 – Summary of typical domestic and commercial water heating demands [1]

Size	Maximum flow rate required, T=45°C L/min	24hr net demand (kWh/day)	Typical residential demand	Typical commercial
XXS	2	2.1	Sink, no dishwashing	Office toilets
XS	4	2.1	Average sink	Office kitchen
X	5	2.1	Large sink/small shower	Professional practice, shop, bar, small restaurant
M	6	5.85	Average shower	
L	10	11.7	Bath	
XL	10	19.1	Large bath	Medium restaurant, barber shop
XXL	16	24.5	Simultaneous bath and shower	Large restaurant, barber, collective sauna
3XL	48	46.8	Collective heating	Small hotels & camping, small collective
4XL	96	93.6	Collective heating, large	Hospitals, sports facilities, prisons, car wash, military, large collective