

Dishwashers

HIGHLIGHTS

■ **PROCESS AND TECHNOLOGY STATUS** – Automatic household dishwashers are more energy and water efficient than manually washing dishes. However, they are still perceived as a luxury appliance by many consumers, and their market penetration is relatively low when compared to other white goods. Roughly two-thirds of US households own a dishwasher, and the figure falls to 48% as an average across the EU. There is low market penetration of domestic dishwashers in markets outside the US and EU. Professional dishwashers are used in the catering and hospitality sectors. These appliances run very short wash cycles, and range from small under-counter models to large multi-tank models. The professional dishwasher market has nearly 100% market penetration in developed countries, as it is seen as an essential kitchen item in restaurants, hotels and catering facilities.

■ **PERFORMANCE AND COSTS** – Most domestic dishwashers currently available on the market perform well on energy and water efficiency. In the EU, 90% of domestic models sold over the last five years have an A class energy label. Domestic dishwashers have an approximate service life of nine years. Domestic dishwashers have a typical price of around €300 excluding taxes. Over the ten years leading to 2007, energy consumption of professional dishwashers has reduced by 20% to 30%. The most widespread model of professional dishwasher, the under-counter one tank water system, can process 200 dishes per hour, and costs approximately €3,200. Large models with multiple tanks can process up to 4,000 dishes an hour and can cost up to €45,000.

■ **POTENTIAL AND BARRIERS** – Some commentators suggest that dishwashers have reached a floor in their ability to lower energy consumption. The perception of domestic dishwashers as a luxury item, compounded by their upfront cost may prevent further market penetration in many countries, including Western Europe. In emerging markets, the prevalence of hired help undermines the demand for dishwashers. In particular, the world's largest emerging markets Brazil, Mexico, China, India and Russia collectively accounted for 2% of dishwasher sales in 2010. The potential gains in water and energy efficiency can be hampered by a lack of consumer awareness to fully load the appliance for optimum performance. Around 50% of households pre-rinse dishes before loading, which lowers water efficiency. 90% of energy losses by professional dishwashers are due to heat loss. They can improve their energy efficiency by using an exhaust heat exchanger or heat pump to re-use heat. This is especially relevant for one-tank models that recycle much of their water for multiple loads.

PROCESS AND TECHNOLOGY STATUS

Domestic and professional dishwashers use electricity, detergents and hot and/or cold water to clean dishware, glassware, cutlery and utensils through a range of chemical, thermal and mechanical processes [2]. Numerous studies have come to conclude that it is more efficient to run a fully loaded modern dishwasher than wash by hand [12].

■ **Domestic models** – Two-thirds of US households own a dishwasher according to 2008 data [14]. In 2007, averaged across all European countries, 48% of households owned dishwashers [11]. Comparably, the emerging markets of Brazil, Mexico, China, India and Russia collectively accounted for only 2% of domestic dishwashers in 2010 [23].

Sales can differ by dishwasher type. For example, in 2006, 77% of domestic dishwashers sold in the UK were full size models with approximate dimensions of 80x60x60cm. These have a capacity from 8 to 12 place settings. The other 23% of the domestic market was taken up by slim line and compact (table top) models [16]. These models have a range of capacities, but are less than 8 to 12 place settings. The rise in single occupant properties could increase the market share of compact models. Most domestic dishwashers use a

spray technology to direct jets of water at soiled dishes from rotating spray arms at the top, middle and/or bottom of the tub. It is noteworthy that European dishwasher models are designed to heat water internally, whilst US models take in hot water heated externally [21]. Market research has shown that the programme length is not a major concern for users [18] because the appliances usually run overnight or between meals; however some users may select a shorter programme believing it to be less energy consuming, whereas it is often longer programmes which use less energy.

■ **Professional models** – In Europe, there is nearly 100% market penetration¹ of professional dishwashers as these are essential items in restaurants, hotels and catering facilities [17]. In the US, major end users are similar to European end users and there are similarities between the US and European marketplace [17]. Thus it could be assumed that US market penetration is also nearly 100%.

Professional dishwashers need to process large volumes of dishware in a short amount of time, usually running many cycles every day. The difference in their

¹ Based on dishwasher stock exceeding number of catering and hospitality businesses. This is not to say that all of these businesses have dishwashers, some other sectors may represent the stock figure.

functional requirement leads to very different technological solutions compared to domestic models. Professional dishwashers can broadly be divided into two categories; program automats and conveyor-type. Program automats apply different stages of the wash cycle consecutively to the same load, similar to domestic models. Conveyor-type appliances pass the load through a row of continuously operating jets and streams, similar to an automated carwash [17].

Professional dishwashers can be further classified into two sub-categories, water change systems and tank systems. Dishwashers with **water change systems** heat and dispose water after each cycle. Dishwashers with **tank systems** re-use the wash water over several cycles, maintained at a high temperature to save time and energy for heating the water. Fresh rinse water is used. One-tank dishwashers include front loader program automats, pass through program automats, ware washing/ utensil/ pot dishwashers, and transport dishwashers. There are also multi-tank transport dishwashers, also known as conveyor or basket dishwashers.

■ **Components** - Dishwashers function at temperatures between 55°C and 70°C [20]. Heating water is the main source of energy consumption in dishwashers that take in cold water [6]. Dishwashers that heat water internally are common in Europe. They use a water heater inside the dishwasher to bring cold water to the optimal 60°C [14] or 50°C with a hotter rinse cycle. Most US models bring in hot water heated externally and rely on an internal or external booster heater to bring water temperature to 49°C.

Other less energy intensive components are pumps, control solenoids and machine drying equipment. It is estimated that energy and water consumption of commercial dishwashers has decreased by 20 to 30% over 10 years up to 2007 [2]. This has been achieved through the introduction of heat recovery technologies, and the enhancement of rinsing systems and water pumps. Energy consumption and life-cycle costs play a role in the purchase decisions of domestic and commercial consumers.

Modern dishwashers are equipped with a range of programs and sensor combinations that determine the length and type of cycle. In high end domestic models, programmes are computer controlled dishwashing processes that adjust the length of the cycle to the size of the load. Simpler models vary only the temperature of the water and the length of the cycle, irrespective of the load. Chemical and/or optical sensors are used to determine the number of dishes or the level of soiling in the rinse water, which in turn determines the length of the cycle [14]. Most modern dishwashers also feature a drying sensor which determines the end of the wash/dry cycle [20].

PERFORMANCE AND COSTS

The performance of domestic and professional dishwashers is assessed on the basis of a number of parameters. The functional unit for dishwashers is defined as the machine's capacity and is measured in a

variety of ways including plates per hour, racks per hour, cycles per hour, place settings per hour or meals per hour [17, 29, 30]. The functional performance of a unit is measured by its cleaning and drying performance [19]. Domestic dishwashers have been reported to operate an average of 280 cycles per year [17] in Europe. The US ENERGY STAR uses an average of 215 cycles per year for its standards [24]. Cycle lengths vary depending on the programme and the degree of soiling. Cycles range from under one hour to three hours.

There are no estimates available for the average cycles of professional dishwashers as this will depend on the type of business which operates them. Also, some models, like the conveyor-type run continuously for multiple loads and cannot be measured in terms of cycles. European estimates of the number of dishes cleaned annually by each model are [17]:

- Under-counter water-change models 24,000
- Under-counter one-tank models 237,600
- Hood-type models 518,400
- Utensil/pot models 9,000
- One-tank conveyor-type models 2,165,600
- Multi-tank conveyor-type 4,455,000.

The lifetime for a domestic dishwasher has been quoted as nine years in US sources [15] and 15 years in EU sources [26].

In the US, professional dishwashers can process from 100 to more than 2,000 meals per hour [29]. In Europe, professional dishwashers can process between 18 to more than 3,000 plates per hour [30].

The lifetime for professional dishwashers ranges from 8 to 17 years, depending on the type of dishwasher [17].

■ **Domestic Dishwasher Energy Efficiency** – Since January 2012 the US ENERGY STAR rated domestic dishwashers of standard size must consume no more than 295 kWh per year (1.37 kWh per cycle²). The US Federal minimum standard (2010) is no more than 355 kWh per year [24]. Since 1993 the US Federal maximum energy consumption has been set at 2.17 kWh per cycle [14], or approximately 568 kWh per year³. With an average dishwasher life of 9 to 15 years, it is unlikely that there are any worse performing models currently in use in the US [15].

By 2005, it is estimated that 90% of EU domestic models were performing at the A class energy label efficiency limit of 1.05 kWh per cycle [11]. This appears to be slightly more stringent than the ENERGY STAR requirement of approximately 1.37 kWh per cycle⁴. Some commentators argue that the energy efficiency of dishwashers is approaching the technological limit [13].

Note that energy used in heating of water outside of the dishwasher in some US models is not always included

² Based on 215 cycles per year [24]

³ Based on pre-2004 US average annual cycles value at 264/year [24]

⁴ Figure based on annual threshold/215 cycles [24]. Actual per cycle consumption is not specified by ENERGY STAR.

in the assessment of overall appliance efficiency [14], although this is required for ENERGY STAR.

■ **Domestic Dishwasher Water Efficiency** – Water consumption in domestic dishwashers has reduced over the past two decades. In 1990, levels of 25 to 30 litres per cycle were typical. This was reduced to 13 litres per cycle by 2006 and to less than 10 litres per cycle for the latest models [11]. US ENERGY STAR limit standard sized domestic models to 16 litres per cycle, and the Federal Standard is 24.6 litres per cycle [24]. Best in class models in the EU must use no more than 10 litres per cycle [26].

Although there are no direct comparisons available, it is generally assumed that the US domestic models are less energy and water efficient than EU models [25], although the top of the range models are converging in their overall efficiencies, as can be seen by the standards' requirements above.

■ **Professional Dishwasher Energy Efficiency** – EU data suggests the following energy consumption per 100 plates for typical professional dishwashers [17]:

- Under-counter water-change models 4.3 kWh
- Under-counter one-tank models 1.6 kWh
- Hood-type models 1.7 kWh
- Utensil/pot models 0.5 kWh
- One-tank conveyor-type models 2 kWh
- Multi-tank conveyor-type models 2kWh

The US ENERGY STAR program established voluntary requirements for professional dishwashers. Efficiency requirements have been established for four machine types [30]:

- Under counter with a high temperature idle energy rate less than or equal to 0.90kW
- Single tank door type with a high temperature idle energy rate less than or equal to 1.0kW
- Single tank conveyor with a high temperature idle energy rate less than or equal to 2.0kW
- Multiple tank conveyor with a high temperature idle energy rate less than or equal to 2.6kW.

■ **Professional Dishwasher Water Efficiency** - EU data suggests the following water consumption per 100 plates for typical professional dishwashers [17]:

- Under-counter water-change models 80 litres
- Under-counter one-tank models 16 litres
- Hood-type models 16 litres
- Utensil/pot models 5.2 litres
- One-tank conveyor-type models 13 litres
- Multi-tank conveyor-type 12 litres.

The US ENERGY STAR program established voluntary requirements for professional dishwashers. Water efficiency requirements have been established for four machine types [30]:

- Under counter with a high temperature water consumption of less than or equal to 1 gallon per rack of dishes.
- Single tank door type with a high temperature water consumption of less than or equal to 0.95 gallons per rack of dishes.

- Single tank conveyor with a high temperature water consumption of less than or equal to 0.70 gallons per rack of dishes.
- Multiple tank conveyor with a high temperature water consumption of less than or equal to 0.54 gallons per rack of dishes.

■ **Amount of detergent and chemicals** - For more complex professional models, these parameters are influenced by the types of dishes loaded, the degree of soiling, the quality and ambient temperature of the water [3]. Simple domestic models will use standard doses of detergents and release them completely during the cycle. Professional dishwashers mostly use liquid detergent, whilst domestic models mostly use tablets, although liquid and powder detergents are still available to consumers [17].

Most manufacturers and industry specialists conclude that the most advanced and efficient professional dishwashers are produced in the EU [17]. US professional dishwashers use more energy and water than European models. The US ENERGY STAR thresholds are not very ambitious when compared to European products [17].

■ **Prices of Dishwashers** - Domestic dishwashers have a typical price of around €300⁵ [22]. The full range of prices spans from €190 to €1530 [28]⁶ depending on the manufacturer and on additional features such as automated programs, outward appearance (stainless steel models are expensive), design and colour. Energy efficiency has a significant effect on the starting price of full-size domestic models. A price survey [28] has found that A++ rated appliances cost between €470 and €995, A+ rated appliances between €285 and €530, and A rated appliances between €190 and €1480. The non-linear relationship of the top price can be attributed to other additional features. There are more A rated models on the market with a wider range of features, therefore a greater price range.

For professional dishwashers, costs can vary dramatically depending on the size and technology. The most widespread professional dishwashers are suitable for smaller restaurants and cafes. They are small under-counter models with a water change system and can be purchased for €3,200 [17]. Large conveyor-type models are suitable for large catering operations. They have multiple water tanks and can process up to 4,000 dishes an hour. They can cost up to €45,000 per unit [17]. In between these price extremes, the following costs for European models are reported [17]:

- Under-counter one-tank models €3,500
- Hood-type models €4,700
- Utensil/pot models €10,500
- One-tank conveyor-type models €15,000.

⁵ Originally a UK estimate. Average 2011 exchange rate to convert GBP to Euro obtained from http://www.ecb.int/stats/exchange/eurofxref/html/eurofxref-graph-gbp_en.html

⁶ Ibid. GBP to Euro to the nearest €

Data from the United States uses four professional dishwasher categories. Under counter dishwasher prices range from \$4,800 to \$5,000 per unit. Door type dishwasher price ranges from \$6,500 to \$6,900 per unit. Conveyor dishwasher prices range from \$11,000 to \$20,000 per unit and flight type dishwashers cost up to \$100,000 per unit [30].

POTENTIAL AND BARRIERS

Innovations that can be applied to both domestic and professional models include the use of ultrasound and ozone cleansing technologies [5]. This will improve the hygienic cleansing of dishware compared to hygiene levels achieved by hot water, and improves the potential to operate at lower temperatures.

Although some commentators feel that dishwashers are close to achieving optimal energy consumption [13], further reductions in energy consumption can be achieved by optimizing the hydraulics [8]. Optimising the drying system can achieve up to 20% energy saving, for example by sorption using compounds such as zeolite rather than heat drying systems [10].

Further improved performance can be achieved through use of an exhaust air heat exchanger, an exhaust air heat pump, a waste water heat exchanger, high efficiency pumps and motors, insulation, and auxiliary rinsing [4]. These improvements can be particularly applicable to professional dishwashers with multiple continuous loads.

Although largely proven to be more efficient than manual washing, domestic dishwashers are still seen as an unnecessary luxury item compared to other household appliances [16]. This may prevent further penetration of new and efficient models into the market.

The up-front cost of domestic dishwasher appliances is an added barrier to market penetration [6].

In emerging markets, the prevalence of domestic service undermines the demand for dishwashers [23]. In particular, the world's largest emerging markets Brazil, Mexico, China, India and Russia collectively account for 2% of dishwashers sales in 2010 [23].

The efficiency gains in use can only be achieved through optimally filling a dishwasher because not filling to capacity leads to poor efficiency performance. Consumer awareness should be raised.

Whilst most modern dishwashers can cope with all types of soiling, previous experience or cultural habits lead an estimated 50% of users to pre-rinse dishes before loading [13]. The need or wish by the consumer to pre-rinse or soak the dishes before dishwashing significantly increases water consumption [11] and energy use, if pre-rinsing involves hot water.

A consumer survey in 2007 [19] revealed that the most important dishwasher features for consumers were lower energy and water consumption and better cleaning performance. The two priorities may be opposed because lower energy and water consumption relates directly to shorter cycles and cooler wash temperatures, which are likely to inhibit cleaning performance.

Another survey finding revealed that manufacturers felt shorter wash cycles were important to consumers in 2007. The survey also found that connectivity with other household appliances would be important to consumers in five years.

The surveys demonstrate the challenge that manufacturers face to deliver energy and water efficient products while improving cleaning levels of dishwashers.

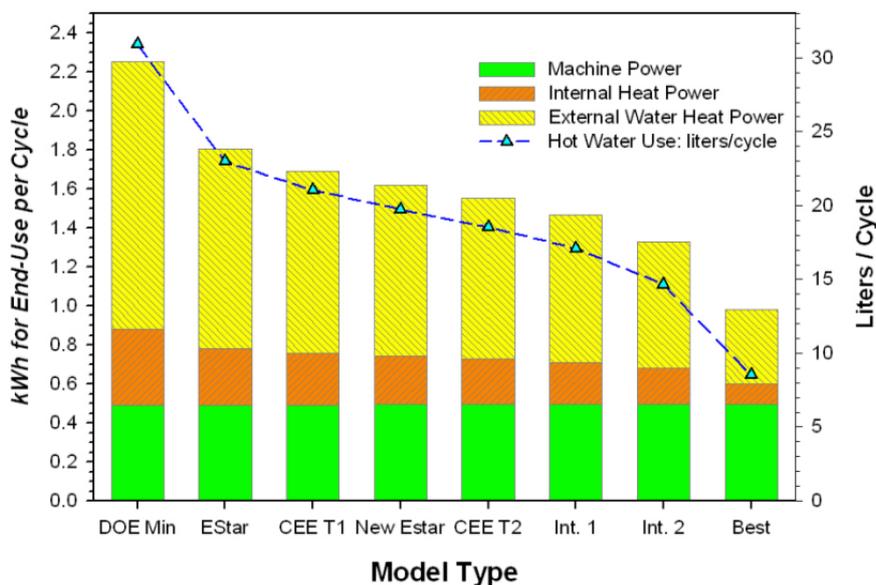


Figure 1- Energy End-Use of Generic Types of Standard Size Dishwashers (US-DOE, NIA for dishwashers, 2007 and [14])

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Table 1 – Summary Table – Typical Key Data and Figures for Dishwashers Technologies

Domestic Dishwashers (Typical current international values and ranges)						
Technical Performance	EU Average	By label class				
		EEl 55 (1 class above A)	A	B		
Energy Input (2010 projected at 65°C) kWh/cycle, [1]		1.18	1.39	1.66		
Typical size [1]	80cm x 60cm					
Energy efficiency (kWh/year) [estimate]	250	245	289	345		
US ENERGY STAR compliant [24]	295kWh/year or 1.37kWh per cycle					
US Federal Standard compliant [14]	568kWh/year or 2.17 per cycle					
Technical lifetime [15, 26]	9 to 15 years					
Use (cycles per year) [9] [17] [24]	215 to 280					
Product cost, euro/unit (2009) [22] [28]	c.€300	€285 - €300	€190-€285	€256		
Market size – UK (2007) [16] ⁷	€319,000,000					
EU market share (2010 projected) [1]		3%	95%	2%		
Market saturation	Germany	Sweden	Italy	UK	EU av.	US
Household ownership in 2007 [11]	64%	60%	37%	33%	48%	60-65% [14]
Data Projections for the UK market ⁸	EEl 55 (1 class above A)	A		B		
% sales in 2009 [1]	1	96		3		
% sales in 2010 [1]	3	95		2		
% sales in 2015 [1]	21	79		-		
% sales in 2020 [1]	30	70		-		
% sales in 2025 [1]	40	60		-		
% sales in 2050 [1]	50	50		-		
Projected prices 2015 [1]	€277	€275		€246		
Projected prices 2020 [1]	€263	€261		€234		
Projected prices 2030 [1]	€239	€236		€211		

Non-domestic dishwashers (Typical current international values and ranges)						
Technical Performance	Under-counter water change	Under-counter one tank	Hood type	Utensil/ pot	One tank transport	Multi-tank transport
Typical capacity (dishes/hr) [17]	200	550	860	0.42m ² x 20 cycles	1,750	3,600
Energy consumption (kWh/unit/year) [3]	1,150	4,540	10,020	7,070	48,300	103,870
Water consumption, average performing, new (l/100 dishes) [17]	58	17	16	5.2	13	12
Technical lifetime, years [17]	12	8	8	8	12	17
Product cost, Euro/unit excl. VAT (2009-10) [17]	€3,200	€3,500	€4,700	€10,500	€15,000	€45,000
Product cost, USD/unit (2009) [30]	\$4,800 - \$5,000		\$6,500-6,900	No data available	\$11,000 – 20,000	
Additional product cost to be ENERGY STAR compliant, USD/unit (2009) [30]	\$1,000		\$2,000		\$3,000 - 4,000	
EU Market share (2005), % [2]	68%		28%	1.1%	2.8	0.6%
EU sales volume (2009 annual units est.) [17]	20,000	138,000	65,900	2,600	6,600	1,300
US sales volume (2008 annual units est.) ⁹ [29]	40,000 [US data only uses four sub-categories]					

⁷ Market size originally in GBP. Average 2011 exchange rate to convert Euro to GBP obtained from <http://www.ecb.int/stats/exchange/eurofxref/html/eurofxref-graph-gbp.en.html> and rounded to the nearest million.

⁸ Ibid.

⁹ Note that figures taken from 2009 report referencing 2006 figures that were projected to 2008.