Preparatory Studies for Eco-design Requirements of Energy-using Products

Lot 24: Professional Washing Machines, Dryers and Dishwashers

Tender No. TREN/D3/91-2007

February 2011

Final Report, Part: Dishwashers

Task 6: Technical Analysis Best Available Technologies (BAT)

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For reasons of better readability, two Task 6 reports were prepared.

The report at hand covers ***professional dishwashers***.

The Task 6 report on *professional washing machines and dryers*
is published separately.

Part: Professional Dishwashers

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1 Introduction

1.1 Objective of Task 6

Task 6 entails a technical analysis not of current products on the market but on currently available technology, expected to be introduced at product level within 2–3 years. It provides part of the input for the identification of part of the improvement potential (Task 7), i.e. the part that relates especially to the best available technology. Therefore, objective of Task 6 is to describe the principal design options for improving the efficiency and environmental performance of professional dishwashers.

1.2 Methodology and assessment of data quality

In Section 2, we start the technical analysis of best available technologies with a short repetition of the general energy flows and losses of professional dishwashers using examples of different dishwasher types (for details, cf. Task 4). This analysis provides an initial insight into the environmentally most important areas and improvement potentials.

In Section 3, several design options at component or product level leading to a reduction in water and energy demand during the use phase are described. In order to assess possible trade-offs through additional environmental impacts in the production, distribution or end-of-life phase, for each design option the differences in material composition between a standard product and a product with integrated design option(s) were analysed. Further, we provide a rough estimation of the proportion of the respective BAT options already being implemented. These best available technologies in the areas identified for improvement as well as indicative quantitative data were derived from manufacturers' brochures supplemented by personal communication with and input from manufacturers based on a working paper.

Further, we describe which combinations of different best available technologies are possible and which design options are actually applicable to the different dishwasher types (as many, but not all of the listed improvement options can be used within every dishwasher category). After these more general analyses of several possible design options, we asked manufacturers to describe the components of currently best available products on the market for each dishwasher category.

Finally, in Section 4 state-of-the-art of best existing product technology outside the EU are presented.

Important note: Assessment of data quality throughout Task 6 report

It is important to note that all information with regard to the saving potential of improvement options should be seen in the following context:

- There are currently no European applicable standard measurement methods for quantifying the energy and water consumption of professional dishwashers, and there are likewise no standards requiring manufacturers to define the measurement procedure for potential savings (see Task 1).
- Energy and water savings depend on many different factors such as: ambient air temperature, inlet water temperature, temperature and humidity of exhaust air, temperature of waste water, type of machine and, last but not least, the reference case to which savings are compared.
- Quantification based on information from independent side is not possible as there is no scientific literature about the results of BAT and the potential saving impacts of improvement options in the professional dishwashing sector published.
- Within the study we also tried to collect usage data from different categories of end-users (e.g. large canteens). But it was not possible to get data which enable us to quantify the impact of BAT on water- and energy-savings.
- Manufacturers assess their innovative systems in different ways to their competitors.
- The figures in sales brochures are usually used for marketing purposes and therefore might over-estimate the actual savings.
- Quantitative data provided by manufacturers with regard to the savings potentials are only rough estimations.
- Due to the above reasons, estimations and quantitative data of the different manufacturers diverge considerably.
- The data presented in the Task report at hand are average values of the responses.

2 Main areas of environmental improvement potentials

Based on obtainable data with regard to the energy flows of different types of professional dishwashers (cf. Task 4), the following illustration summarises the shares of heat losses and main areas of environmental improvement potentials respectively.

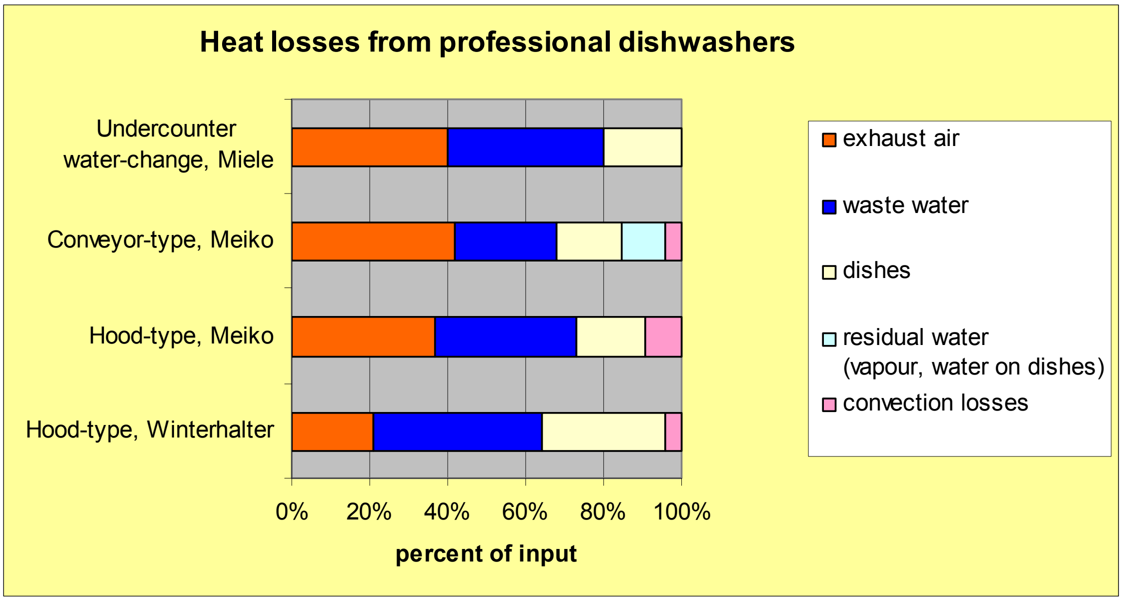

Figure 1 Heat losses from different professional dishwashers

Although data vary between the different categories and sources, Figure 1 generally shows that the most important losses occur in the following areas:

- Exhaust air,
- Waste water,
- Hot, clean dishes.

Approximately 90% of the energy losses can be allocated to these three areas. Consequently, the greatest improvement potential is in these areas. Typically, the losses through exhaust air and waste water are in the same range and totally represent about two thirds of the losses.

Of course, the magnitude of the losses is related to the overall input volume of water and energy. If the input (shown in the illustration as 100%) can be reduced through water-saving measures – without reducing the cleaning performance of the dishwasher – this subsequently leads to energy savings and reduced consumption of detergent and rinse aid[1]. Systematic work on achieving more efficient professional dishwashers will consequently also focus on reducing the overall water consumption. The according measures will be analysed in Section 3.1.

Another option to increase the efficiency of dishwashers can be realised by recovering the heat from either the exhaust air, waste water and/or the cleaned dishes. However, recovering

1 Within Lot 24 it was assumed that the concentration of detergent in the dishwashing process and the concentration of rinse aid in the rinse-process will be constant (see Task 3).

heat from waste water is limited because it has to have a minimum outflow temperature.[2] Possible design options are described in Sections 3.2 and 3.3.

Besides reducing the overall water consumption and recovering heat, in Section 3.4 we analyse and discuss further improvement options which might be able to reduce the energy and water consumption of professional dishwashers.

There are no specific options listed with regard to the reduction of detergents. From the perspective of dishwashing operators, a sole reduction of the detergent consumption is not reasonable as optimal *concentration* of the detergent is needed to reach the desired cleaning result. The detergent concentration depends on the overall amount of water used for the cleaning process. Thus, the detergent consumption is correlated to the water consumption, and the consumption of detergents will decrease if the overall water consumption can be reduced (see Section 3.1 for design options on reduced water consumption).

Further, according to A.I.S.E[3], there are some market developments promoting a reduced consumption of detergents (cf. also Task 2):

- Suppliers of detergents for professional applications place emphasis on the improvement of formulae and avoidance of components with a high environmental impact. To keep the use of raw materials in a dishwashing process to a minimum, a great variety of products if offered, which makes it possible to narrow down the components of a product to the exact requirements. The mix can be tailored to fit the customer's needs, thus avoiding chemical waste and unnecessary disposal into the environment.
- Products are more and more concentrated and the promotion of powder systems (currently the majority of the market uses liquid detergents) means that more concentrated products with less water can be delivered to the customers.
- First products are entering the market in which the rinse aid function is build into the main wash detergent. Besides simplicity, this offers product, packaging and transport savings to the customer.

The description of improvement options is structured according to the following categories:

- Reducing the overall water consumption (resulting in detergent and rinse aid savings),
- Reducing energy losses through exhaust air and dishes,
- Reducing energy losses through waste water,
- Other improvement options, and
- Improvement options outside EU.

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2 Waste water contains a high amount of grease and fats that may solidify if too much heat is extracted from the waste water; this material can build up in drainage pipes and cause severe problems for operation.

3 International Association for Soaps, Detergents and Maintenance Products

3 Best available technologies at component and product level

3.1 Reducing the overall water consumption

In dishwasher category 1 (water-change system), fresh water that has to be heated is used for each step of the dishwashing process. Consequently, any design option to reduce the water consumption in the wash and final-rinse phases would lead to a corresponding reduction of energy and thus also a reduction of detergent and rinse aid consumption.

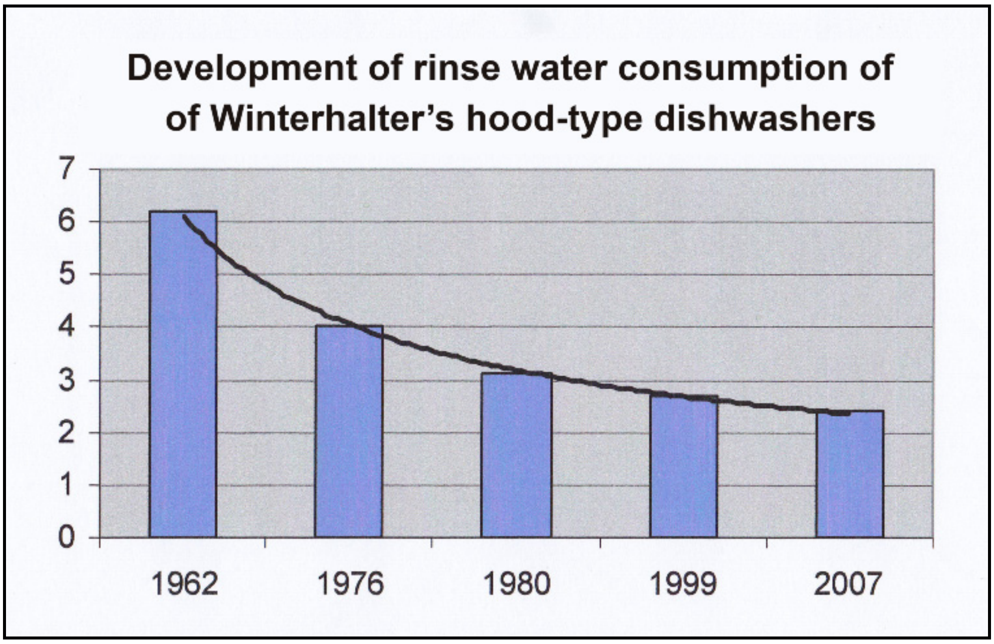
In all other dishwasher categories based on a tank system, rinse water is used to regenerate the detergent solution circulated in the wash tanks. The greater the amount of rinse water used the more water has to be heated up to the temperature of the rinsing process. Therefore, almost any measure which reduces this water consumption will also lead to a reduction in energy consumption.

Calculative, a reduction of 20% in water use (for example from 2.5 litres to 2 litres per cycle) will lead to a reduction in energy consumption of around 0.8 kWh per hour (basis: 30 cycles per hour and a temperature difference of 45°C).

3.1.1 Description of the design options

3.1.1.1 M 1.1 Optimised water-rinsing systems

Optimised water-rinsing systems have special precision nozzles that disperse rinse water like a curtain and form a thin film of water on items of wash ware. The more precisely the water is steered towards the dishes the less water is needed. Water consumption could be reduced in previous decades; e.g. pass-through dishwashers that once used more than 6 litres per cycle currently use only about 2.5 litres per cycle or even less (see Figure 2).



(Source: Winterhalter)

Figure 2 Development of the water consumption of hood-type dishwashers from the manufacturer Winterhalter

In addition to the conventional top-down and bottom-up rinsing system, some conveyor-type dishwashers (category 5 and 6) also rinse wash ware with lateral rinsing systems (see Figure 3) which, according to manufacturers, enables even more effective removal of soil and detergent. For instance, one manufacturer claims that his fresh-water rinse system reduces the water consumption up to 50%. However, as the reference case is not described and could be based on a rather low efficient appliance, the value does not help to quantify possible savings compared to an average model.

(Source: Winterhalter)

Figure 3 A micro-thin water film from four sides optimises the distribution of water

In the case of a hood-type dishwasher from another manufacturer, additional sprayers have been installed at every corner of the dishwashing machine so as to achieve uniform rinsing of all wash ware (see Figure 4). Newly designed racks shall optimise the water flow from below the rack, thus leading to improved washing and rinsing results.

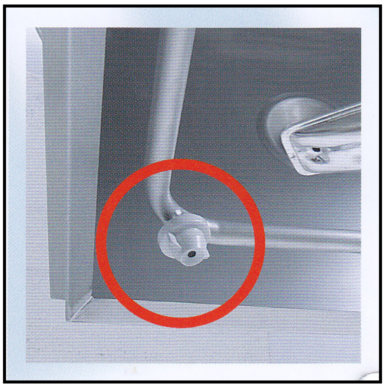

(Source: Meiko)

Figure 4 Additional water nozzles at the corner of a hood-type dishwasher

Another manufacturer uses a system with reverse spray arms in order to achieve improved cleaning results for hood-type dishwashers.

In general, optimised water-rinsing systems are an important measure for reducing the water consumption of all categories of professional dishwashers. However, differing from the above stated reduction potentials of individual machines, manufacturers estimate the average reduction potential of water savings to be around 10%. For other manufacturers it is very difficult to quantify individual design options like spray arms as the system has to be seen as a whole – the pump rating, water consumption, spray arms, etc. Further, comparing reductions of water consumption cannot be undertaken without taking the hygienic and optical dishwashing result into account as well.

The overall reduction potential is dependent on the water-rinsing system of the specific machine and the improvement options that can be installed. In most up-to-date machines, the water-saving potential seems to be already exhausted; only lower-end dishwashers on the market might still achieve water savings by implementing unexploited improvement options.

As it is not possible to identify any specific reduction potential for water and energy consumption in the different categories, we didn't further analyse this improvement option under cost-benefit aspects.

3.1.1.2 M 1.2 Steam rinsing

For this process, detergent is first rinsed off with water. The ensuing steam rinse completely fills the washing chamber with steam which then forms a very thin film on the wash ware and removes residual alkalinity. "Steam reaches every part of the wash ware, and spray shadows are avoided. The self-drying effect of the wash ware is further enhanced by the increased temperature penetration into the wash ware."[4]

For the steam-heating process, a small quantity of water (relative to the traditional process) is heated up to 85°C and only a fraction of the rinsing water (approximately 100 ml) is heated up to 100°C; overall, less water is needed for steam rinsing compared to water rinsing.

The steam rinsing system was first introduced in a category 2 dishwasher (undercounter, one-tank). For instance, one manufacturer claims that the rinse program uses 1.4 litres of water followed by an additional steam rinse of only 0.1 litres, leading to a final rinse-water consumption of 1.5 litres per cycle[5]. Compared to machines with water rinsing, this represents a saving of up to 55 percent in water as well as up to 70 percent in rinse aid.[6]

The use of steam rinsing in categories 3 to 6 is more difficult because the additional pressure of the steam has to be kept in the machine. This is currently not possible for the categories 5 and 6 (because of the open entrance and exit of these machines). For categories 3 and 4 it is possible in principle but the washing chamber would have to be sealed very well.

Steam rinsing is effective regarding reducing water consumption. However, the rinse performance has to be taken into account as water has its advantages regarding rinsing off debris and residues of chemicals. The energy required for the generation of steam by heating water up to 100°C reduces the energy savings gained from decreased water consumption. Some manufacturers doubt that energy savings can be achieved with steam-rinsing systems at all. .

3.1.1.3 M 1.3 Optimised filter systems

Another possibility to reduce the amount of rinse water is to improve the filter system of the dishwashing machines. As more soil can be removed from the water during the dishwashing process, less water is needed for the final rinsing.

Two possible options are described here:

- Centrifugal systems (cyclone filter)
- Integrated pre-scouring system.

The **centrifugal system** (see Figure 5) works in the following way: suspended soil in the wash water passes through a small unit which causes a vortex effect, separating out suspended matter in the water. Some manufacturers use this technique in undercounter and hood-type dishwashers. For category 2 and 3 dishwashers, the improvement potential by the means of a cyclone filter applying the centrifugal principle is estimated by manufacturers to be 40 up to 70%.

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4 Source: Hobart; http://www.hobart-export.com/wExport_en/news/news_records/488060762.php (21.7.2010)

5 http://www.premax.de/en/media/prospekte/web_PR-599-K-e_FP.pdf (11.8.2010)

6 http://www.hobart-export.com/wExport_en/news/news_records/488060762.php (11.8.2010), the "standard machine" is not specified however.

Another manufacturer has also used a vortex-action filtering system on larger conveyor-type machines of category 5 and 6.

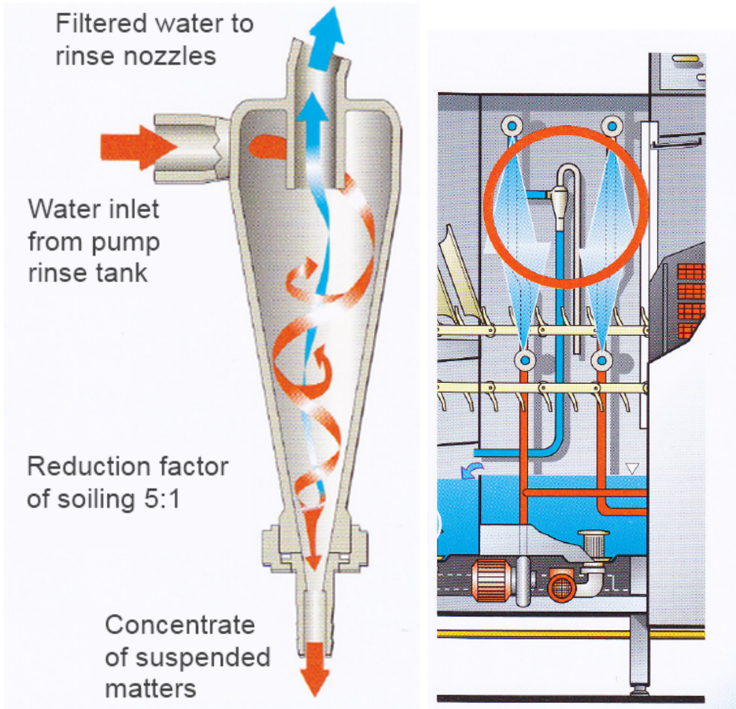

Figure 5 Cyclone filters system

Another possibility used in conveyor-type dishwashers (categories 5 and 6) is the installation of an **integrated pre-scouring system** with intermittent rinsing with fresh water from the 'pumped final-rinse zone'. The water from this process is filtrated via two cyclones. With this system, it is possible to rinse away food particles from dishes even before they reach the main wash tanks and final-rinse zone (see also M 1.5). According to one manufacturer, such a system could result in a reduction of up to 20% in fresh-water use.

In principle, it can be stated that in all dishwasher categories (apart from category 1 which is based on a water-change system), advanced filter systems are already available on the market. In these cases, there will be no significant water savings by improving advanced to the best filter systems. However, also machines with more primitive filter systems are offered on the market. These filter systems might be sufficient if the machine are used less frequently (e.g. 10 times a day) and the accumulation of dirt in the tanks is limited.

On the basis of those primitive filter systems (which are not assumed to be the base case) the possible water-saving potential by installing advanced filtering systems might be 10% to 20% of the total water use..

3.1.1.4 M 1.4 Automatic load adjustment systems

Partial load of dishwashing machines causes additional energy, water, and detergent consumption (cf. Task 3).[7] To adjust the water and thus the energy consumption automatically to the actual load of dishwashers, sensor technologies can be implemented in dishwashers.

For conveyor-type dishwashers (categories 5 and 6), the systems detect the amount of wash ware as well as empty conveyor-belt sections and then adjust water consumption accordingly.[8] It should be noted that only the final rinsing process will be adapted to the load.

Figure 6 shows the adaptation of fresh-water rinsing to empty conveyor-belt sections.

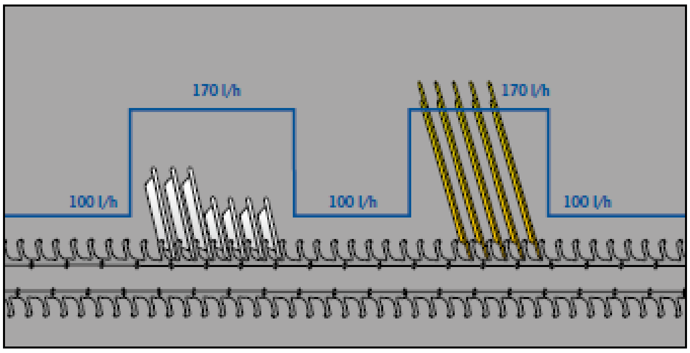

Figure 6 Automatic water regulation to minimum level on detection of empty compartments[8]

Some manufacturers offer conveyor-type dishwashers with an automatic system that works in a different way. A photocell activates the dishwasher when the incoming items are recognised, and the final rinse does not start until the load reaches the final-rinse zone. If no extra items are loaded, the machine stops automatically. The machine restarts once the photocell is reactivated.[9] Although this system works in a similar way, the effect may depend on the special design and programming of the systems. Consequently, a similar configuration may be programmed differently (e.g. timing of the deactivation of the washing zone) and will result in a different impact on energy and water savings.

On the other hand, automatic load-adjustment systems might also have disadvantages: in case the machine is stopped the vapour in the machine might collapse and the water would be drained away. This even results in additional water and energy consumption after the stop. Further, the washing process might be disturbed during the reactivating phase, resulting in a poor washing result.

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[7] On average, the real-life workload – depending on the dishwasher category – is assumed to be 60 to 80% (75% for conveyor-belt dishwashers), resulting in additional consumption (energy: 7.5 to 15%, water and detergent: 10 to 30%; cf. Task 3)

[8] See e.g. http://www.hobart-export.com/wExport_global/p_warewashing/documents/literatures/flight-type/web_PR-705-K-e_SENSOTRONIC.pdf

[9] http://viewer.zmags.com/publication/0e45a329#/0e45a329/8

Until now, technology for adjusting water consumption to the machine load technology has only been used in conveyor-type dishwashers (categories 5 and 6). In case of category 1 dishwashers, sensors could detect if the machine is only loaded half-full (i.e. only upper or only lower basket). For cleaning half load, the water reduction could possibly be 20%, thus it is not as effective as washing at full load. Dishwashers from categories 2 to 4 have not incorporated any automatic load adjustment systems. In principle this would be possible, but it would be very complex and expensive as it is only possible with a special matrix system which can recognise the position of the wash ware and which routes the water directly to these places.

The water and energy savings of the automatic load adjustment system strongly depend on the use of the dishwashing machine.[10] If the conveyor belt is loaded to full capacity, there will be no savings. In practice, however, empty spaces or gaps between the dishes or baskets can hardly be avoided. Rinsing those empty spaces or even frequently interrupted dishwashing processes have a huge effect on the consumption.

As there is no survey about the average load and no scientific report about the saving results in relation to the partial load for the different dishwasher categories we didn't further analyse this improvement option under cost-benefit aspects.

3.1.1.5 M 1.5 Auxiliary rinsing processes

For conveyor-type dishwashers (category 5 and 6), lower fresh-water consumption can be reached through a two or three-step rinsing zone. The rinsing process is divided into a pre-rinse or intermediate rinse in which the rinse water is circulated via a small tank, and a fresh-water rinse without circulation. For instance, one company uses a triple rinse system, which consists of a pre-rinse nozzle, a re-circulated rinse and a fresh-water final rinse. The pre-rinse nozzle is positioned before the pumped rinse. It rinses off most detergent from the wash ware before entering the rinse zone. The water is directed back into the wash tank, minimising detergent addition into the re-circulating rinse water.[11]

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[10] For the base case calculations within this report, we assumed that conveyor-type dishwashers are running continuously during the dishwashing periods. There might be differences if e.g. rack type dishwashers are used discontinuously. In a dishwashing process which is frequently interrupted, an automatic load adjustment system might have higher savings results. However, there is currently no information on typical user behaviour and consumption data with regard to discontinuous operation. Thus, within Task 4 (recommendations on mandates) we suggest consideration of real-life use conditions (inter alia partial load) when developing a new standard on consumption and performance measurement.

[11] http://www.hobart-export.com/wExport_global/p_warewashing/documents/literatures/flight-type/web_FTN_PR-600-e.pdf

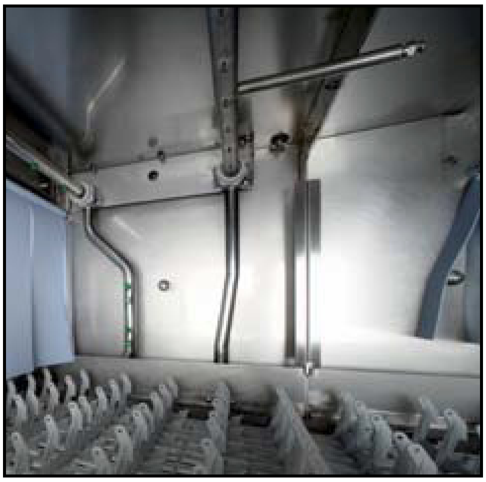

(Source: Hobart)

Figure 7 Inside of a triple-rinse chamber

An auxiliary rinse with recycled water from the tank helps reducing the water consumption for the final fresh-water rinse. For this reason, less water has to be heated up to the high rinsing temperature, thus resulting in reduced energy consumption. One manufacturer states that with an auxiliary rinse system it is possible to lower the water consumption for the final fresh-water rinse from approximately 400 litres per hour to 180 litres per hour.

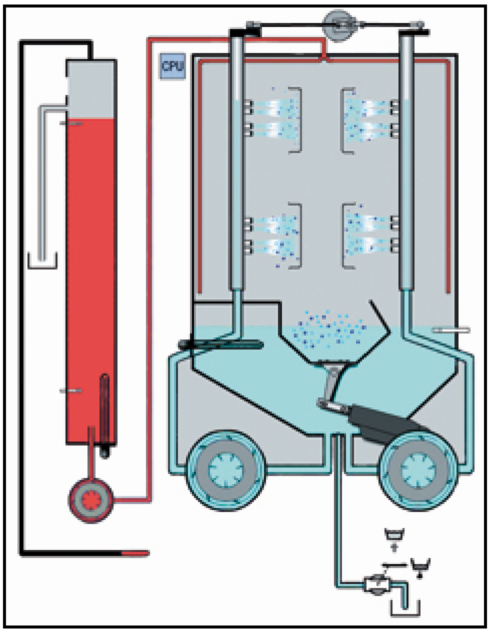
The auxiliary rinsing (with an additional tank) is used almost exclusively for conveyor-type dishwashers with more than one tank. Only one company is using the system for a hood-type dishwasher (category 3).[12] For category 1 dishwashers (water-change system), it is not applicable. The system is used in most of the high-end products but there are also multi-tank conveyor-type machines on the EU market which still do not make use of the advantages of an auxiliary rinse system.

3.1.1.6 M 1.6 Granule technology

For utensil/pot dishwashers (category 4), granule technology is applicable. It is a mechanical cleaning process where plastic granules and water are blasting the pots and pans clean without using pre-soaking and scrubbing. Even hard burnt-in pots and pans or dried-in soil is cleaned by the granules without soaking or scrubbing outside the machines.

Figure 8 shows the cleaning process of granule machines. The main characteristics of an exemplary granulate dishwasher have already been described in Task 4 (Technical Analysis Existing Products).

[12] http://www.wexiodisk.co.uk/Products/SingleTankDishwashingMachines/WD9/tabid/70/Default.aspx. Unfortunately, we did not get any data to provide a cost-benefit ratio of this improvement option for base case 3.



(Source: Granuldisk)

Figure 8 Principle of granule based utensil / pot dishwasher technology (category 4)

According to the manufacturer's feedback, through this process, which is used by more than 10 000 end-users, the following consumption values can be saved compared to conventional technology used in utensil / pot dishwashers:

- Water consumption: up to 70%
- Detergent consumption: up to 60%
- Energy consumption: up to 60%

This effect mainly is based on water savings in the external pre-cleaning phase prior to the cleaning within the dishwashing machine. According to the manufacturer's feedback, the water consumption in the external pre-cleaning phase is with around 8 litres hot water per item 5 to 8 times higher compared to the water consumption within the machine. For utensil / pot dishwashers using granule technology this consumption would be avoided.

In order to give incentive to reduce the overall water consumption of dishwashing, the inclusion of the whole process from dirty to clean (including the pre-soak and pre-cleaning phase) would be rather desirable for all dishwasher categories with special focus on utensil / pot dishwashers. However, the water consumption for pre-cleaning is strongly dependent on the specific user behaviour and cannot be influenced by the technology of the dishwashing machine itself. Further, there is no standard measurement method and thus no reliable data to record the average consumption through external pre-cleaning of the wash ware for the dishwasher categories. Finally, as we already excluded the manually process steps outside the dishwashing machines from the scope of this study in Task 1, we didn't further analyse the granule technology under cost-benefit aspects in the following tasks.

3.1.2 Material composition

The improvement options M 1.1 to M 1.6 described above lead to a reduction in water and energy demand during the use phase. In order to analyse possible trade-offs through additional environmental impacts in the production, distribution or end-of-life phase, differences in material composition between a basic product and a product with integrated design options were investigated (see the following table).

Table 1 Differences in material composition through implementation of the design option described

Design Option / Material category	M 1.1	M 1.2	M 1.3	M 1.4	M 1.5	M 1.6
	Optimised water rinsing systems	**Steam rinsing**	**Optimised filter systems**	**Automatic load adjustment systems**	**Auxiliary rinsing processes**	**Granule technology**
	[g]					
Bulk plastics						
PP			+500		+500	
Ferrous metals						
stainless steel		+10 000	+500		+10 000	
Non-ferrous metals						
copper wire		+1 000	+1 500		+1 500	
Al diecast			+500		+500	
Electronics		+100	+100	+100	+100	

Note: empty fields = not applicable or no response by manufacturers

3.2 Reducing energy losses through exhaust air and dishes

As mentioned in Section 2, roughly two thirds of heat losses occur through exhaust air and waste water. Approximately another third leaves the dishwashing process through the hot dishes. One improvement option might be to lower the overall process temperature of the cleaning process as this would reduce the losses of exhaust air, waste water and the wasted heat from dishes as well. However, the overall cleaning and hygienic performance has to be taken into account. This reduces the possibility of lowering process temperatures.

Another alternative to reduce the energy consumption is a process management that leads to lower heat-output flows or through the recovery of heat from these flows. The different design options for heat recovery from exhaust air and dishes are described in the following sections. Generally, for undercounter water-change dishwashers (category 1) the volume of (heated) air within the machine is relatively low compared to the other categories; thus for this dishwasher type it is difficult to achieve significant improvements.

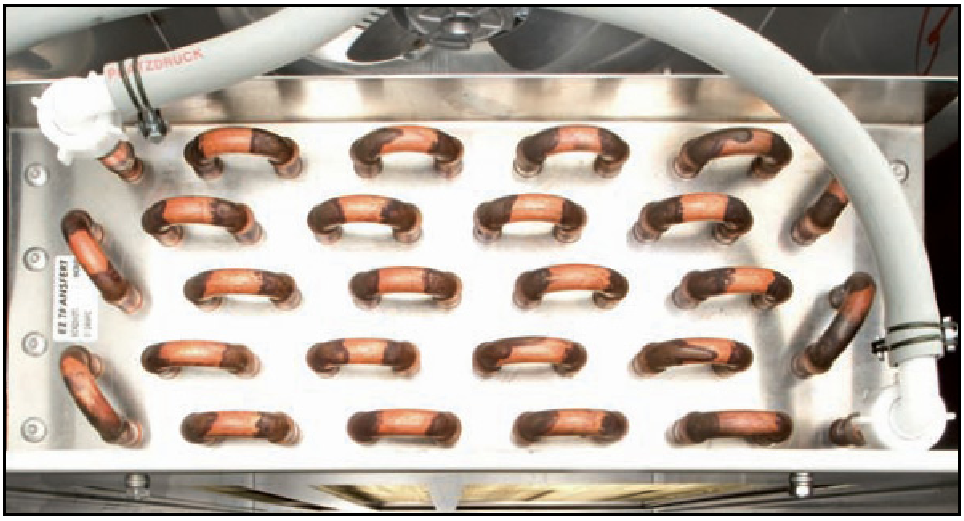
3.2.1 Description of the design options

3.2.1.1 M 2.1 Heat recovery from exhaust air

M 2.1.1 Heat recovery through a heat exchanger

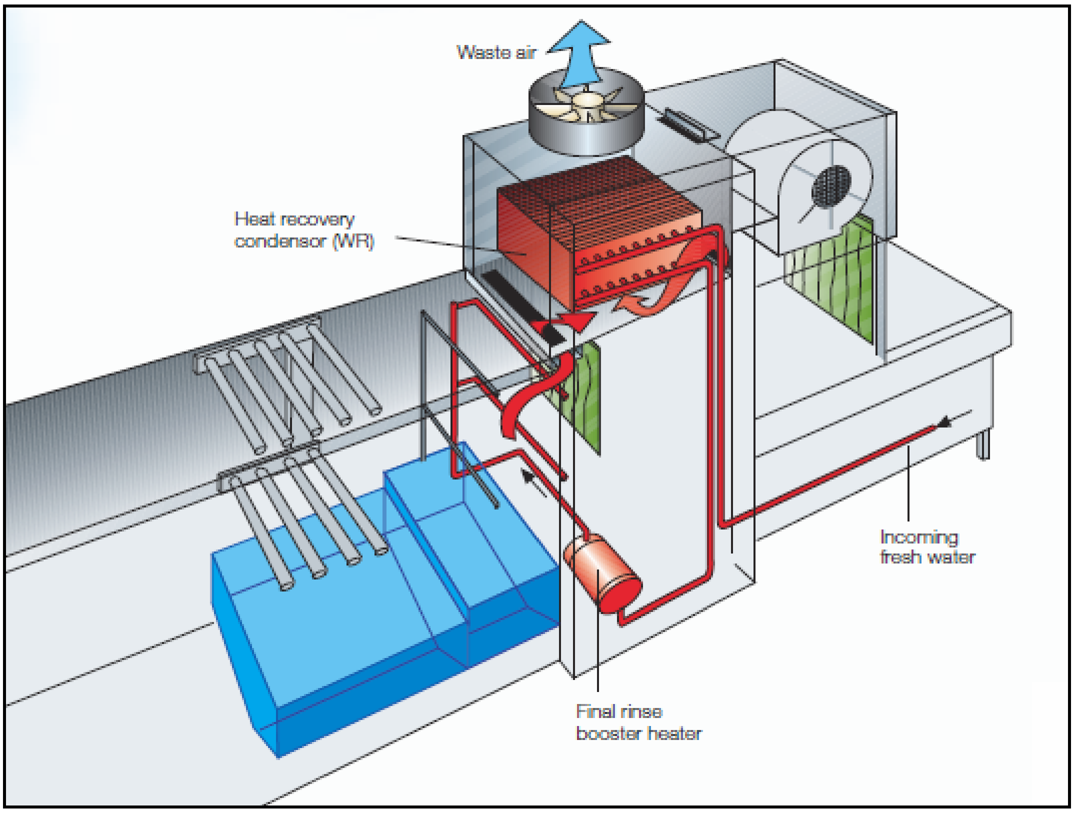
The heat from the exhaust air can be used to preheat the incoming water of the machine through a counter-flow heat exchanger. The exhaust air, which still has a remarkable energy content (35°C and 68% of humidity) is cooled down and dried before it is expelled. Using the heat gained from this process, the incoming water can be preheated to around 40°C.

The following illustration shows a heat exchanger.



(Source: Hobart)

Figure 9 Heat exchanger of a flight-type dishwasher



(Source: Meiko)

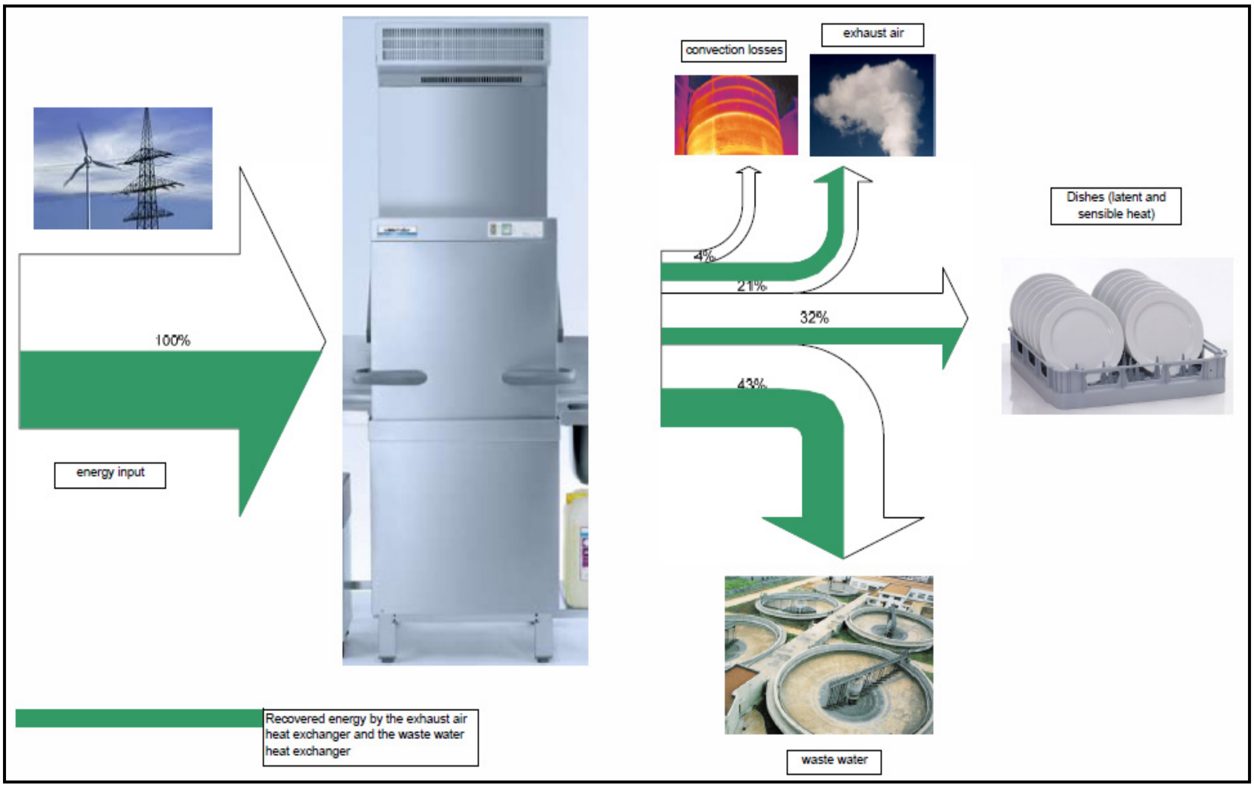
Figure 10 Heat recovery from exhaust air through a heat exchanger

Figure 10 above shows the working principle of an exhaust-air heat exchanger. The warm and humid air is ventilated through the heat recovery condenser. There, the heat is taken over by the incoming fresh water flowing in pipes through the air stream. The preheated water will then also be heated up through the final-rinse booster heater.

A good counter-flow heat exchanger can achieve an efficiency of approximately 90%, which means that 90% of the temperature difference between outgoing and incoming fluid can be used to heat up the incoming water. According to manufacturers, the temperature difference between the exhaust air and the hot water outflow of the heat exchanger will be about 5°C, while in older models the temperature difference may be up to 20°C.

By using a heat exchanger, more than half the losses of energy from the exhaust air can be recovered. Manufacturers stated that energy savings of 15% to 25% are possible related to the overall energy demand of a reference product without heat exchanger. An additional advantage of the heat recovery process is that the outgoing (exhaust) air will be cooled down and thus includes less humidity.

In the figure below, showing again the principal heat losses, the exemplified hood-type dishwasher is equipped with a heat exchanger to reduce the heat losses from exhaust air and an additional heat exchanger to reduce the heat losses from waste water. By these measures, the overall energy consumption can be reduced about 40% percent. The illustration also shows that the absolute amount of energy which can be saved is dependent on the total water consumption and energy input.



(Source: Winterhalter)

Figure 11 Energy balance of a hood-type dishwasher

M 2.1.2 Heat recovery through a heat pump

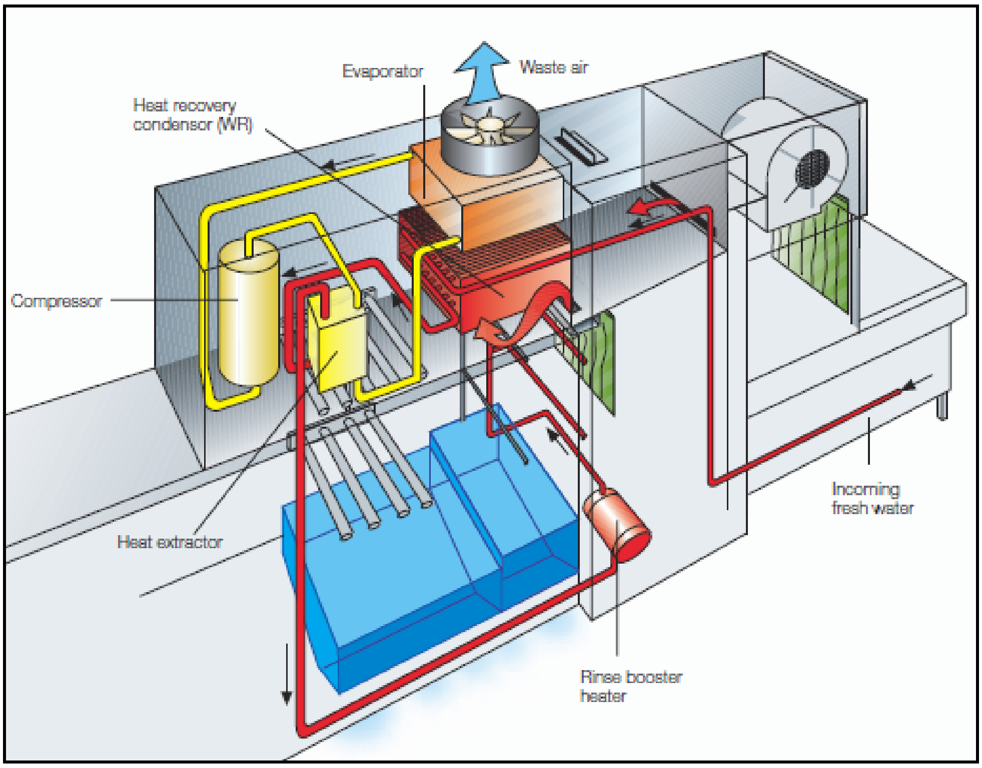
With the addition of a heat pump, the energy remaining in exhaust air can be used more efficient than with a counter-flow heat exchanger alone.

A heat pump is an electric device with both heating and cooling capabilities. It extracts heat from one medium (for example exhaust air) at a lower temperature and transfers it to another (for example rinse water) at a higher temperature, thereby cooling the former and warming the latter. Thus, the energy gained – which is transformed to a higher temperature level – can be used to heat up the wash tank and the rinsing water.

The following three examples show different ways in which heat pumps can be used in dishwashers (see also Figure 12 to Figure 14).

a) The heat pump (yellow circuit) initially recovers the heat from the exhaust air, which leaves the heat exchanger (heat recovery condenser) at a temperature of about 35°. The exhaust air is then cooled down further by the heat exchanger of the heat pump (in the illustration: evaporator). After passing this heat on to a gas medium, the heat pump mechanism compresses the gas medium in the compressor in order to increase its temperature. Following this compression pumping process, the heat pump transfers heat to the cold incoming fresh water (red pipes), while the now condensed cooled medium cycles back to recover more heat from the exhaust air. In this manner, incoming fresh water for the fresh-water rinse can be preheated to about 60 to 70°C, thereby saving initial water heating energy.

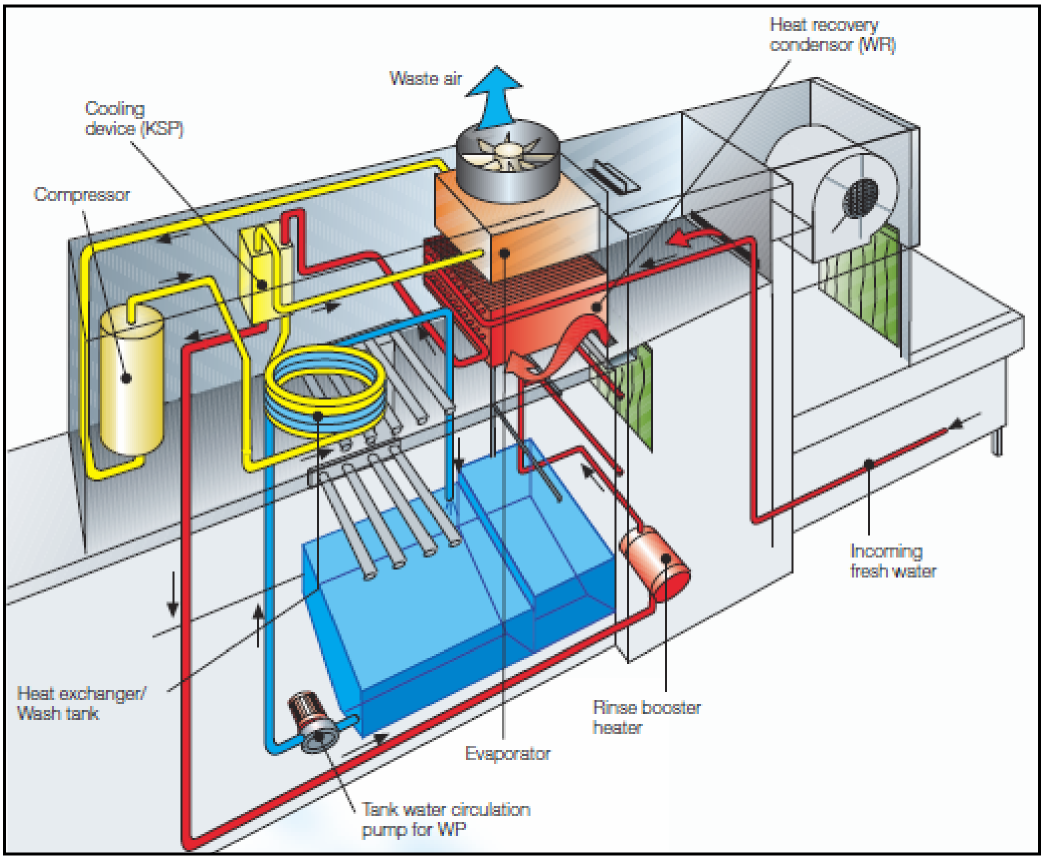
An additional advantage of the heat-pump process is that the outgoing (exhaust) air will be cooled down to 18-22°C. This results on the one hand in improved ambient conditions in the kitchen or in additional savings. On the other hand, under certain conditions, the air from the dishwashing process can be released to the room and reduce cooling requirements for the kitchen or operating facility.



(Source: Meiko)

Figure 12 Heat recovery from exhaust air through a heat exchanger and heat pump

b) The second possibility is similar to the first, however the heat from the heat pump (yellow circuit) is used to pre-heat the detergent solution in the *wash tanks* (blue pipes) in addition to heating the rinse water (red pipes). The advantage of this arrangement is that a larger part of the energy from the exhaust air can be reused, which saves additional heating energy.

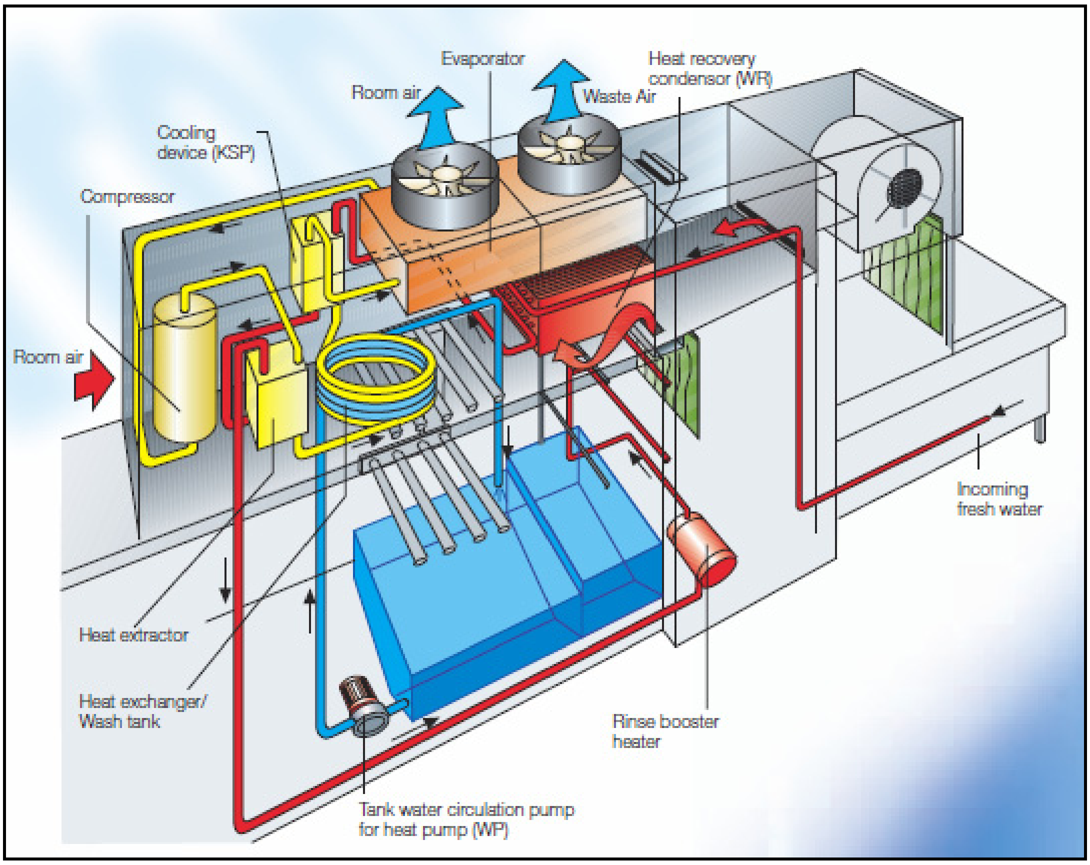


(Source: Meiko)

Figure 13 Heat recovery from exhaust air through a heat exchanger and heat pump

c) In the third case, not only the exhaust air from the dishwashing process is used for the heat pump, but also the air of the room. The advantage of this arrangement is an additional heat gain and further climatisation of the kitchen. In the example below, the total heat requirement of the dishwashing machine can be reduced by 62% (cf. stage 4 in figure 14).[13]

[13] Meiko: B-Tronic, K-Tronic, Heat recovery: a system with high benefits



(Source: Meiko)

Figure 14 Heat recovery from exhaust air and from kitchen air through a heat exchanger and heat pump

Figure 15 below shows the energy savings (green) in relation to the total heat demand for the four different heat recovery options described above. The installation of a counter-flow heat exchanger (design option M 2.1.1) saves about 27% of the heat required for the dishwashing process (i.e. only the heating energy, not the total energy of the dishwashing process including energy for pumps, transport belt and electronics).

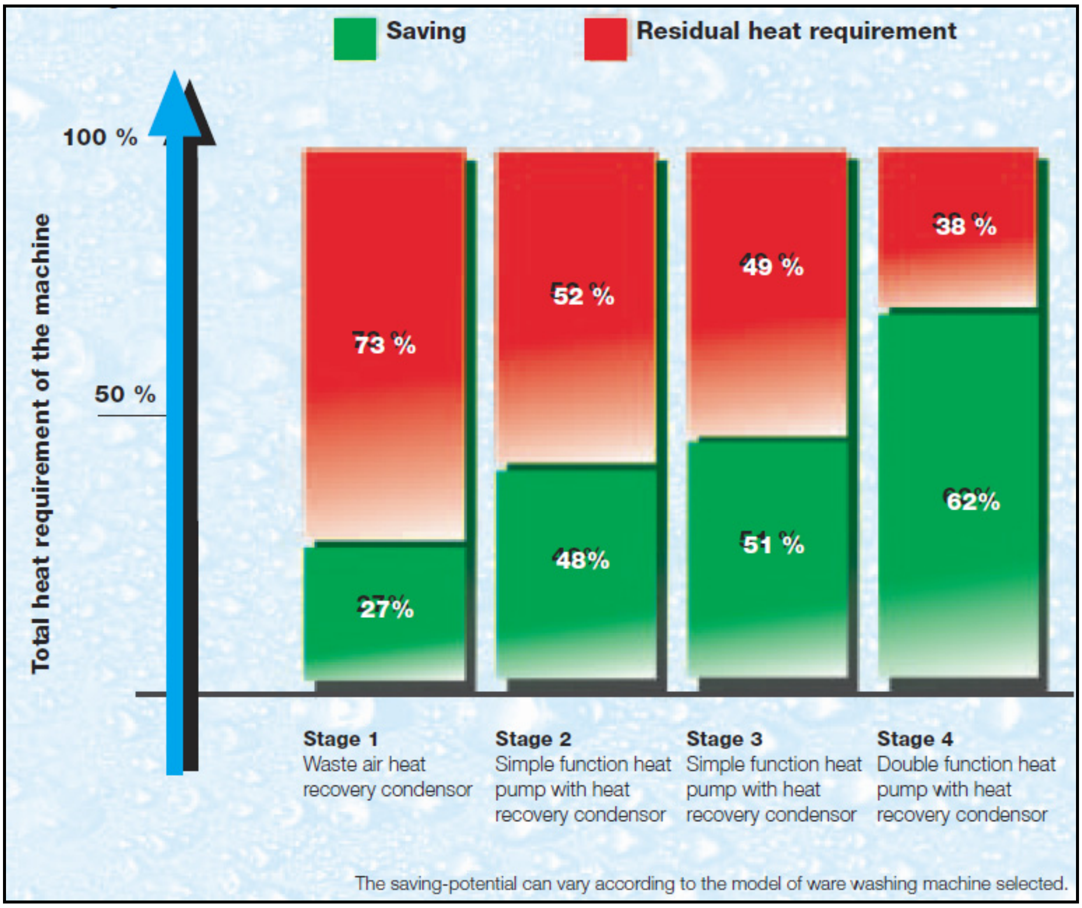
In stage 2 (design option M 2.1.2a) a heat pump is added to enhance the heat recovery process. Preheating of the rinse water increases the heat savings to 48%. If the heat pump is used to preheat both rinse water and wash tanks (stage 3, design option M 2.1.2b), the savings increase to 51%. Finally, if the heat pump system utilises warm air from the kitchen (in addition to hot exhaust air from the dishwasher), savings can reach 62% (stage 4, design option M 2.1.2c).

However, these potential savings depend on the assumed base case under consideration[14] as well as on the specific conditions in situ. Especially for stage 4 the possibility to install this

[14] The base case for categories 5 and 6 are assumed to be 75% partial workload, while the dishwashers are operated in a *continuous* process. For discontinuous operation (which has not been analysed within this study

technology is depending on the type and total energy consumption of the dishwasher and the local infrastructure (available space and ventilation).

The savings results are depending on the specific conditions (fresh-water temperature, air temperature in- and outside, air volume, and humidity of the exhaust air).



(Source: Meiko)

Figure 15 Energy savings through a counter-flow heat exchanger and different methods of heat pump integration.

According to manufacturers' information, more than 75% of multi-tank conveyor-type dishwashers (category 6), are already equipped with a heat exchanger; within multi-tank conveyor-types (category 5) just over the half of the dishwashers already use this technology; heat pumps are usually offered as optional/additional equipment.

due to a lack of data), the situation would be different. As exhaust heat pumps will suffer if they are switched on and off frequently, the dishwashing operators might not turn them off e.g. in a discontinuous operation. Thus, the rinse process will continue although there is no wash ware in the rinsing sector, resulting even in additional consumption values.

It should also be pointed out that the possibilities described above are only appropriate for cold-water inlets and cannot be used in combination with warm water supply of the rinse water. The decision whether to use a heat exchanger, a heat pump or none of these options also depends on the ambient conditions in the establishment where the dishwasher is used: if there is already a central heat recovery system installed, it might be more cost-effective to use the central system to recover heat from the exhaust air of the dishwasher.

Four other aspects should be mentioned:

- Commercially available heat pumps have a limited temperature level with regard to the medium after the compressor. Furthermore, since the overall water consumption is already low in high-efficiency dishwashers, the capacity for transferring recovered heat to incoming fresh water is correspondingly reduced. The effect of these two factors is that not all of the heat recovered may be used and returned to the washing circle.
- Double-step heat pumps could be used to increase the temperature of the supply line to a higher temperature level (more than 90°C), but they require a lot of space and create additional costs. Further, the additional saving potential is very limited (see previous bullet point).
- Heat pumps need an annual inspection to establish whether or not the refrigerant is leaking; thus it will cause additional maintenance costs.
- Due to a lack of space it is more difficult to integrate heat pumps into smaller under-counter dishwashers[15].

3.2.1.2 M 2.2 Alternative temperature profile

In particular in the case of conveyor-type dishwashers, heat losses in the loading and unloading areas may be reduced by concentrating the heat-intensive processes in the mid section of the machine (see Figure 16). The high-temperature wash zone is embedded between the pre-wash and the fresh-water rinse zones which are supposed to act as a temperature barrier.[16] The temperature equalisation takes place within the machine and energy losses are reduced.

[15] As one manufacturer stated

[16] Hobart, Flight-Type Dishwasher Premax FTP

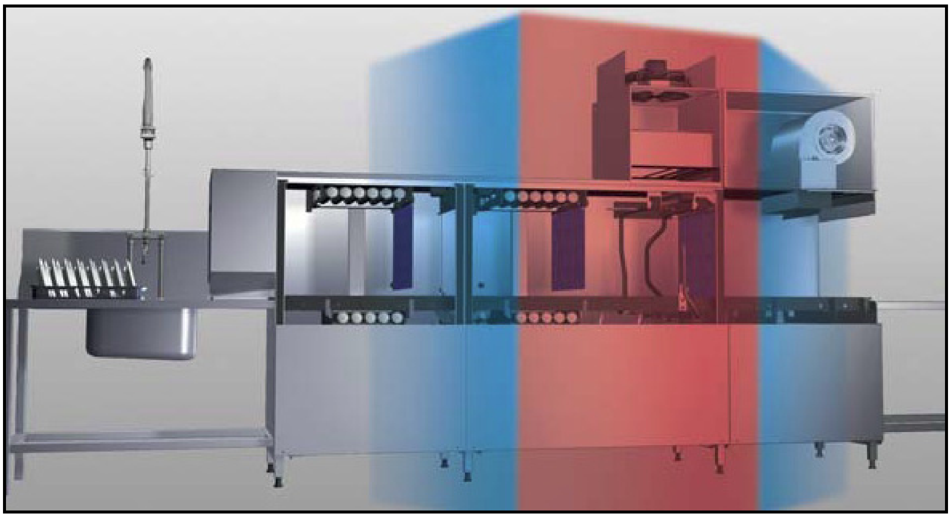

(Source: Hobart)

Figure 16 Energy Management – the hot zone is embedded in colder zones

The temperature barrier between the zones may also be enhanced by the use of specially designed thermal-layered curtains hung in the loading and unloading areas. One manufacturer claims that thermal-layered curtains reduce temperatures in the loading and unloading areas by 2 to 3 degrees.[17]

In addition to the effect described, the temperature in the washing zone is slightly increased (from typically 55°C to 65°C) while the rinse temperature is slightly lowered (from typically 85°C to 75°C). The energy-saving potential of this system is estimated by the manufacturer to be 10 to 15%. In contrast, other manufacturers question whether this innovation leads to quantifiable and reproducible energy savings at all. Additionally, there are doubts that the hygienic result can be achieved in every case because the rinsing temperature is lower than in the traditional system.

While the spatial embedding of the wash zone is only applicable for conveyor-type dishwashers (categories 5 and 6), an alternative temperature profile of the wash and rinse process could also be used for dishwashers of categories 1 to 4 in principle. However, there is no information available with regard to the possible savings potential of this design option, thus we didn't further analyse this improvement option under cost-benefit aspects.

3.2.1.3 M 2.3 Reuse of the heat from drying dishes through active drying zone

The heat stored in the dishes or other wash ware is substantial but it can only partly be used and regained without disturbing the drying process. It seems difficult to achieve a high efficiency of this system (low savings potential accompanied by comparably high investment).

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[17] Hobart. Hobart CLe Warewashers. 17 August 2010. Retrieved from: https://feg.hobartcorp.com/resourcecenter/Marketing%20Literature/F40077%20%2806-08%29%20broCLeWareWash.pdf

For example, heat losses through china could be reduced by using dishes with less weight or heat capacity and through heat recovery from the outgoing china. However, the reduction of weight or heat capacity might be limited as this affects the drying performance (if the dishes contain less heat, the remaining water might not evaporate completely).

For category 2 and 3 dishwashers, the heat stored within the hot and humid air and the dishes can be reused during the drying process. Dry air from outside the dishwasher can be ventilated through the machine to accelerate the drying process and the hot dishes will transfer heat to the incoming air stream. This heat can then be transferred via a heat exchanger and/or concentrated with a heat pump in order to preheat the rinsing water or wash tanks (similar to improvement options M 2.1.1 and M 2.1.2).

As for conveyor-belt dishwashers, one manufacturer is advertising a fresh-air drying zone. In this case, the drying process is supported by a blower and an air heating system. To reduce the humidity in the drying zone to 10%, fresh dry air from the kitchen is drawn into the drying chamber. The humid and hot air is then directed through the machine and gives its heat to the washing process. At the entrance to the machine, the air is drawn into the exhaust system by a ventilator. Usually, the residual heat of the exhaust air will be recovered through a heat exchanger or a heat pump (see options M 2.1.1 and M 2.1.2).

Another concept makes use of heat recovery through an active drying zone: heat is extracted from dishes by an incoming air flow; at the same time, warm air from the machine's fresh-rinse zone is directed through the colder areas of the machine (against the transport direction of the belt) and then transfers the residual heat to a heat exchanger situated near the entrance to the dishwasher. The advantage of this arrangement is a smaller heat loss throughout the whole machine. In some cases, the effect of this technique is that no additional, active drying (additional heat) of the dishes is necessary. Proponents of this system claim that the directional air flow (from the clean to the dirty sectors) also helps to avoid contamination of clean dishes. The manufacturer estimates the overall energy savings for conveyor-type (category 6) dishwashers to be up to 30%.

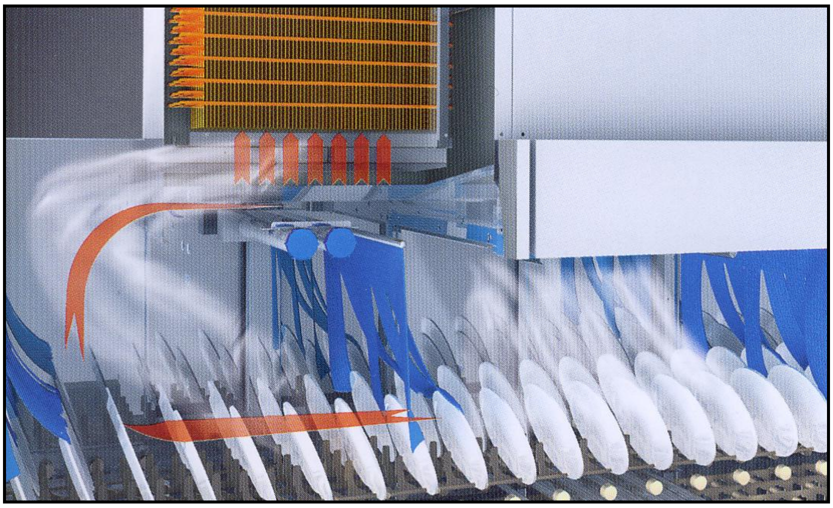

(Source: Meiko)

Figure 17 Air flow concept

3.2.2 Material composition

Table 2 Differences in material composition through implementation of the design option described

Design Option / Material category*	M 2.1.1	M 2.1.2	M 2.2	M 2.3
	Heat recovery of exhaust air through heat exchanger	Heat recovery of exhaust air through heat pump[18]	Alternative temperature profile	Reuse of heat from hot dishes through active drying zone
	[g]			
Bulk plastics				
PP		+500	+500	+500
Ferrous metals (stainless steel, steel sheet, steel tube/profile, cast iron, ferrite)				
stainless steel	+5 000	+35 000	+10 000	+5 000
Non-ferrous metals				
copper	+5 000	+55 000		+6 500
Al diecast				+500
Electronics		+500		+100
Misc.				
refrigerant[19]		+2 500		

Note: empty fields = not applicable or no response by manufacturers

[18] Note: Although the addition of a heat pump increases the volume and weight significantly, it is expected that the influence of this on the overall environmental impacts will be negligible (cf. Section 3.4.2 and Task 7).

[19] Note: About 5% of the refrigerant will get lost during the life cycle of the dishwashing machine. (Source: E-mail from Miele, 22.12.2010)

3.3 Reducing energy losses through waste water

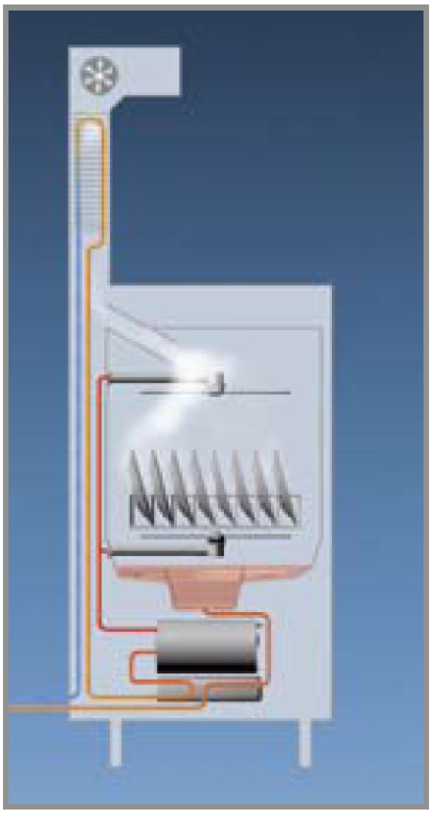
As described in Section 2, a large share of energy is lost through waste water leaving the dishwasher, which usually has a higher temperature than the inlet water. Heat from waste water can either be reduced through reduced rinsing-water consumption on the one hand, or through heat recovery from the waste water.

3.3.1 Description of the design options

3.3.1.1 M 3.1 Heat recovery from waste water

M 3.1.1 Heat recovery through heat exchanger

There are only a few companies recovering the heat from waste water of the dishwashing process. For example, one company offers a hood-type dishwasher with a combination of heat recovery from the exhaust air and heat recovery from the waste water.



(Source: Winterhalter)

Figure 18 Heat recovery from exhaust air and waste water

Since drainage water usually includes significant amounts of grease, removing heat from the water can lead to the dissolved grease solidifying in the piping downstream of the heat exchanger and thus creating a maintenance problem. For this reason, fresh water is first warmed up by the exhaust air (blue to orange pipes in Figure 18) and, in a second step, the warm water is further heated by the heat exchanger of the waste water (orange to red pipes in Figure 18). Using this concept, it is possible to ensure that the temperature of the waste water will not drop to a temperature of below 40°C.

With heat recovery from exhaust air (cf. M 2.1.1), the energy savings would be about 20% to 25%. By using a heat exchanger for the waste water, additionally 10% of the total energy consumption might be saved. In total, about 30 to 35% of the energy might be saved compared to a reference machine.

M 3.1.2 Heat recovery through heat pump

Using a heat pump, the residual energy of waste water can be used more efficiently than with a counter-flow heat exchanger alone. Specifically, the combined use of a heat pump and heat exchanger enables the wash tank and/or rinsing water to be heated to a higher temperature compared to using only a heat exchanger. However, currently no machine was found on the market that incorporates this feature, thus we didn't further analyse this improvement option under cost-benefit aspects.

The reason for this is the maintenance problem resulting from solidifying fats and grease in the drainage pipes – this occurs when too much heat is recovered from waste water. A second reason is that it is difficult to reuse the energy from the heat pump because the temperature level is not high enough to heat the fresh rinsing water to the required temperature (usually 85°C).

On the other hand, if heat is already recovered from exhaust air (cf. M 2.1) – which is easier to manage and has the additional advantage of dehumidifying and cooling down the exhaust air – the additional heat that can usefully be recovered from the waste water of the dishwashing process is limited.

3.3.2 Material composition

Table 3 Differences in material composition through implementation of the design option described

Design Option / Material category*	M 3.1.1	M 3.1.2
	Heat recovery of waste water through heat exchanger	Heat recovery of waste water through heat pump[20]
	[g]	
Bulk plastics		
PP		+500
Ferrous metals		
stainless steel	+10 000	+45 000
Non-ferrous metals		
copper		+35 000
Electronics		+500
Misc.		
refrigerant[21]		+2 500

Note: empty fields = not applicable or no response by manufacturers

3.4 Other improvement options

Finally, there are some further design options that might reduce the energy consumption or energy losses during the dishwashing process.

3.4.1 Description of the design options

3.4.1.1 M 4.1 Insulation of wash tanks or the dishwashing machine

The energy balances of different professional dishwashers show that convection losses are about 4 to 9 percent of the total heat losses (see Section 2).

The wash tank or the whole dishwashing machine (in category 5 and 6 the washing and rinse zone) can be insulated to reduce heat losses in the operating mode as well as in the ready-to-use mode. The insulation options include the insulation of:

- Doors,
- Pipes to external heat sources,
- Tanks,

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20 Note: Although the addition of a heat pump increases the volume and weight significantly, it is expected that the influence of this on the overall environmental impacts will be negligible (cf. Section 3.4.2 and Task 7).

21 Note: About 5% of the refrigerant will get lost during the life cycle of the dishwashing machine. (Source: E-mail from Miele, 22.12.2010)

- Walls (double walls can provide additional insulation),
- Bottom of the machine, and
- Screens (thermal-layered screens in loading and unloading zones).

Due to safety reasons, all walls and doors that can come into contact with the operator of the machine usually have a double skin with air insulation or foamed plastic between these layers (PVC, polystyrene, polyurethane etc.) to prevent excessive temperatures on these parts. The other components of the dishwashing machine such as tanks, motors, boilers and screens are usually not insulated with the exception of some multi-tank conveyor-type dishwashers (category 6).

For example, one manufacturer equips all machines with a closed bottom (via steel panel), which means that they have a layer of air insulation between the tanks and the outside of the machine. According to manufacturers' feedback approximately 1% energy could be saved by improved insulation compared to today's performance.

Undercounter water-change dishwashers (category 1) already have a double skin design. For hood-type dishwashers (category 3), another method for retaining heat is to insulate the hood with a double-walled design. Additionally, the hood of the machine can be sealed in such a way that steam cannot escape through the hood-lifting mechanism. In this way, the steam from previous cycles can be used for the next washing cycle. The energy savings of this system are estimated to be 3 kWh per hour.

3.4.1.2 M 4.2 High-efficiency pumps and motors

The efficiency of the whole hydraulic system (motors, pumps and pipes) can be optimised. Nevertheless, account should be taken of the fact that the heat losses of motors or other aggregates will heat up the machine, thus replacing a certain amount of energy needed to heat the wash tanks, and therefore not lost completely. In cases where the machines are equipped with a bottom panel, nearly all the energy losses of motor and pumps would be useful for heating up the tanks. Vice versa, if these losses would be smaller due to more efficient motors and pumps, the dishwasher would need more energy for heating up the process.

The European Commission has recently taken steps to further regulate the energy performance of electric motors and pumps; however, these standards currently do not apply to dishwashers. For instance, the EU Directive No. 640/2009/EC specifies energy efficiency standards and requirements for motors and pumps based on testing methods and limits in IEC 60034-2-1:2007 and IEC 60034-30:2008. However, the motors of professional dishwashers fall outside the scope of this Directive for several reasons:

- The Directive applies to motors with an output of between 0.75 and 375 kW. Smaller motors for as e.g. in undercounter dishwashers are not covered by this regulation.

- The Directive does not apply to motors completely integrated into a product (for example gear, pump, fan or compressor) and whose energy performance cannot be tested independently from the product.

Consultation with stakeholders has revealed that dishwasher manufacturers typically do not produce pump motors in-house, and they are primarily concerned with sourcing/selecting long-lasting and durable motors and pumps for their systems; energy efficiency is not a primary consideration.

Larger motors (above 0.75 kW) built into professional dishwashers are standard motors provided by suppliers that also produce EuP-conform motors. It is also to be expected that dishwasher motors will become more efficient, even though their improvement is not required under the Directive.

Attention should preferably be given to optimising the entire hydraulic system, including the pumps, in order to enhance the energy saving potential. Despite the potential for improvement outlined above, the energy savings from optimised hydraulic systems would be quite small. For instance, if the efficiency of the hydraulic system can be raised by 10% (which was the opinion of two manufacturers), savings of approximately 10 to 15% could be achieved in the electricity required to power the motor. In this case, the total savings from motors and pumps would be about 1 to 1.5% as only roughly 10% of the total energy consumption of a professional dishwasher is caused by pumps and motors (90% is needed for heating purposes).

3.4.1.3 M 4.3 Self-cleaning machine

Usually, dishwashing machines have to be cleaned regularly. In many cases, this will be done manually (the whole machine being hosed down with a water jet from the mains). However, there are some machines using a self-cleaning process. Two methods of self-cleaning can be distinguished:

- With the first type of automatic cleaning, the machine cleans itself after switch-off. For example, such operating principle was found in a hood-type dishwasher (category 3). After entering the self-clean mode by touching a button, the machine automatically cleans the interior and then switches off. Additionally, an integrated drain pump removes any remaining dirty water from the machine, eliminating both deposits and odours.[22] The automatic cleaning at the end of the day is a useful and water-saving feature, because the machine is cleaned with the residual water of the wash tank and the rinsing boiler.
- Another self-cleaning process involves the machine automatically cleaning itself after a certain water quality limit has been exceeded. For example, some machines have a

[22] Winterhalter. Winterhalter GS 500 Series. 16 August 2010. Retrieved from: http://www.winterhalter.co.uk/uploads/tx_whboxes/GS_500__e_D_04.pdf

sediment sensor that "monitors the dishwater quality and if necessary initiates step-by-step regeneration".[23] In theory, this method could lead to savings in energy and water consumption because the system can avoid additional dishwashing which would be necessary if poor water quality leads to inadequate cleaning performance. In practice, however, this situation would be very seldom. In most cases, even if the cleaning result may be insufficient, the dishes or utensils are not cleaned a second time. This means that the automatic detection of the water quality would not create any energy or water savings but would only improve the cleaning result.

For undercounter water-change dishwashers (category 1), this design option is not applicable as BAT as they basically clean themselves after each cycle.

As the reference cleaning of the machine is based on a manual process which is strongly dependent on the user behaviour and which is not within the scope of this study (cf. Task 3), we didn't further analyse this improvement option under cost-benefit aspects.

3.4.1.4 M 4.4 Alarms

Alarms, signals and prompts (visual and acoustic, via beeps, flashing lights or signals) can be an effective way of indicating the machine's status to operators and service personnel. Alarms can save water and energy by ensuring that proper levels of detergent/rinse aid are maintained within the machine, thus reducing the probability of unsatisfactory cleaning results and repeated dishwashing cycles.

In conveyor-type dishwashers (categories 5 and 6), alarms are most commonly integrated into the control panel's functionality, which, in turn, is connected to sensors throughout the machine. Alarms may indicate incorrect levels of tank temperature, water/detergent/rinse aid levels, malfunction (dosing-pumps, jams, ware blocking spray fields) or if the efficiency of the heat-exchanger unit goes down below a certain level (i.e. the time to clean the unit). Some machines automatically shut down or stop the wash cycle depending on the error/alarm triggered. This step reduces the likelihood of repeat washes due to unsatisfactory cleaning results or damage to the machine.

Some of these features are used in category 1 to 4 dishwashers. In some conveyor-type dishwashers the dosing and alarm systems are outsourced to other companies such as detergent suppliers.

The saving potential from alarm systems is hard to measure. The difficult task is to define a base case or rather whether alarm systems would actually reduce the number of washes presumably associated with inadequate cleaning results (for instance, if the detergent or rinse aid runs out). Stakeholders indicated that, in practice, dishes and utensils will usually not be washed a second time even if the cleaning result is poor. Therefore, it is likely that

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[23] Winterhalter. Winterhalter undercounter dishwashing machines UC Series. 16 August 2010. Retrieved from: http://www.winterhalter.co.uk/uploads/tx_whboxes/UC-Broschuere-GB_23.pdf

alarm systems will not create any energy or water savings; however, they may help improve the overall cleaning results. Due to the unclear situation with regard to the overall improvement potential we didn't further analyse this option under cost-benefit aspects.

3.4.1.5 M 4.5 Customer-specific adjustment of the dishwashing process through electronic control of the whole process

Customer-specific adjustment of dishwashing parameters can lead to more appropriate dishwashing results and energy performance for different customer requirements. A number of manufacturers offer the possibility of accessing pre-programmed settings that adjust water temperature, cycle time and jet pressure depending on the wash ware and soiling conditions (see Figure 19).

Moreover, by providing a simple intuitive interface with access to programmable washing cycles, service operators can optimise dishwashing according to the type of wash ware and/ or the soiling level. For instance, one manufacturer provides an undercounter dishwasher that allows adjustment of the dishwashing cycle according to the requirements of the customer. For example, the machine requires a special detergent for some programs that operate at a reduced temperature. Another machine offers a similar feature through three selectable pump power levels that are appropriate for different wash ware.

(Source: Winterhalter)

Figure 19 Possible program types of an undercounter dishwasher

Programs are usually optimized by the manufacturer. Customised programs have advantages and disadvantages: on the one hand, the specialised programs could save water and energy if the dishwashing process is correctly adapted to the needs of the customers. However, it should be ensured that these adjustments cannot be carried out by the customer himself but only by the manufacturer's specialists to ensure a clean and hygienic result for every dishwashing process. When customers deviate from those programs, it might lead to a higher consumption of water and energy.

One manufacturer criticises that most applications are "standard" applications which could be handled with "standard" configurations. However, an optimisation of the dishwashing programs for every special application and customer is not feasible.

So far, energy, water and detergent savings achievable with customised programs cannot be quantified, thus we didn't further analyse this option under cost-benefit aspects.

3.4.1.6 M 4.6 Documentation of the dishwashing process and the dishwashing parameters

Machines with the ability to document the dishwashing process and its parameters have a small data storage device which saves the presetting data (temperature, power of the pump etc.) and the data of every dishwashing cycle. It is normally integrated into the control panel. Data and dishwashing parameters are often password (or PIN) protected, which allows management or service personnel greater control over the machine's operating parameters. Some manufacturers allow different levels of authorisation or access to their devices; in the case of one manufacturer the menu includes three options:

1. Operating Menu: allows the user to turn the machine on and off, and to select from a set of programmable cycles; provides basic information, e.g. temperature alterations
2. Chef Menu (PIN-protected): allows the head of the dishwashing section to access information that may be relevant for management, such as operating or hygiene data.
3. Service Menu (PIN-protected): allows an authorized user (service personnel, manufacturer of the machine) to change the machine's settings.

Some other parameters that may be documented include: time between servicing visits, device malfunctions (jams, blocked spray fields), water quality and dishwasher capacity.

The advantage of having different access levels is that service personnel can reconstruct which changes have been carried out in order to investigate the reasons for possible poor dishwashing results. On the one hand, this could be the basis for optimising the dishwashing process and, on the other hand, it can avoid unwanted intervention by the user in the dishwashing programs.

There are several options for linking documentation and monitoring systems with relevant diagnostic tools and dishwasher repair or service companies. A standard data-logging system would store information within a data-storage unit located inside the dishwasher. More recent data-logging techniques enable dishwashers to communicate operational information with customers' personal computers or PDA devices through wire or wireless connections.[24] With the help of software provided by the manufacturer, these systems can support logging, display and diagnosis system status in real time. In some cases, dishwashers may support

[24] Meiko. K-Tonic function description. 16 August 2010. Retrieved from: http://www.meiko.info/Produkte,45,106,en,Function_description&showID=105

direct communication with service companies, which can reduce processing time for service calls and reduce shut-down times.[25]

The documentation and information systems could help the kitchen manager to control the work of the operators and if necessary influence their behaviour. The customer at least gains indication on certain improvement potentials. But there is no experience how many customers use the information for this reason. Another advantage is that, in the long run, manufacturers can optimise the dishwashing process and machines based on the data obtained from the machines. In both cases there will be an additional saving potential but it cannot yet be quantified as it very much depends on the specific user behaviour,[26] thus we didn't further analyse this option under cost-benefit aspects.

3.4.1.7 M 4.7 Sensor systems to control the dishwashing process

Sensor systems can detect whether the soil is dissolved and whether the hygienic result achieved is sufficient. Thus the dishwashing cycles can automatically be shortened, e.g. a diffusion sensor might help to reduce water consumption by omitting a pre-wash step in case of lower initial soiling of the dishes.

Soil measurement in the wash liquid is possible using a turbidity sensor; however, this has not yet been widely integrated into dishwasher products currently on the market. Using soil measurement sensors, the duration of the wash cycle could be influenced and the quantity of regeneration water optimised. For instance, sensors could initiate total refilling of the tanks or even of one specific tank. Similarly to previous improvement options, the impact of such a system cannot be quantified. Savings could be achieved by prevention of a second run but in practice real savings depend on customer behaviour. Two manufacturers stated that a second run for dishes is rather unusual. In most cases, the results of the dishwashing process are accepted even if the results might be improved. The potential savings also depend on the initial soiling of the wash ware.

Due to the unclear situation with regard to the overall improvement potential we didn't further analyse this option under cost-benefit aspects.

3.4.1.8 M 4.8 Optimised tank volume

The consumption of professional dishwashers is classified into

- Energy and water consumption in operating mode,
- Energy consumption in left-on / ready-to-use mode, and
- Energy and water consumption for initial filling and heating of the wash tanks.

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[25] Meiko. FV 40.2. 16 August 2010. Retrieved from: http://www.meiko.info/index.php?scriptlet=Meiko/Web/ProductsBrowser&pID=10&pdID=200531

[26] One manufacturer quantified the savings to be between 0 to 20%, strongly depending on user behaviour with and without such a documentation system.

The consumption for initial filling and heating of the wash tanks depends on the volume and temperature difference between inlet water and wash tank temperature.

While two manufacturers state that the tank volume will not be a relevant factor in achieving a best available product, another manufacturer claims that the tank volume could be optimised to reduce energy losses and has specified how a best available product deviates from a standard product as shown in Task 3.

However, due to missing data with regard to the overall improvement potential we didn't further analyse this option under cost-benefit aspects.

Table 4 Tank volume and temperature of a best available product

Dishwasher category	Standard product (cf. Task 3)		Best available product	
	Volume of wash tank(s) (assumed average)	Operating temperature of wash tanks (assumed average)	Volume of wash tank(s)	Operating temperature of wash tanks
No 1 Undercounter water-change	not applicable	not applicable	not applicable	not applicable
No 2 Undercounter one-tank	15 litres	60°C	13 litres	60°C
No 3 Hood-type	40 litres	60°C	20 litres	60°C
No 4 Utensil/Pot dishwashers	100 litres	60°C	80 litres	60°C
No 5 One-tank conveyor-type	120 litres	60°C	120 litres	60°C
No 6 Multi-tank conveyor-type	230 litres	40°C pre-wash 60°C wash tank	230 litres	60°C

3.4.1.9 Effects of lower washing temperatures on composition of detergents

Currently in Europe the hygienic requirements during the dishwashing process are met by thermal means (as outlined e.g. in the DIN standards on food hygiene, cf. Task 1). In this case no special disinfecting agents are needed in the detergents or rinse agents. By reducing the dishwashing temperatures the detergent solution would not have to be heated up so much, thus being a possibility to reduce the overall energy demand of dishwashers.

According to the so-called "Sinner's circle" (see Task 3), there are four main factors influencing the cleaning process: Temperature, chemistry (detergency), time and mechanics. Only when these four factors match it is possible to achieve satisfying (dish-) washing results and to fulfil the requested hygiene conditions. If one parameter is reduced, other factors must be increased to compensate.

Thus, if the washing temperature (= energy consumption) is reduced, either the contact time with the detergent needs to be prolonged or the decontamination and disinfection performance of the detergent needs to be enhanced. In this context, the hygiene requirements given in DIN 10510 to 10512 are considered obligatory: by reducing the operational temperature within dishwashing machines, a thermal disinfection of the wash ware is not given anymore. Consequently, the use of chemical disinfection components is required to achieve the requested decontamination performance of $5\log_{10}$ stages for 90% of the wash ware.

For better understanding, in the following the differences between cleaning and sanitizing are described[27]:

- Cleaning is the process of removing food and other types of soil from a surface, such as a dish, glass, or cutting board. Cleaning is done with a cleaning agent that removes food, soil, or other substances.
- Sanitizing refers to the reduction of micro organisms to levels considered safe from a public health viewpoint.[28] It is done using heat, radiation, or chemicals. Heat and chemicals are commonly used as a method for sanitizing; radiation rarely is. The item to be sanitized must first be washed properly before it can be properly sanitized. Some chemical sanitizers, such as chlorine and iodine, react with food and soil and so will be less effective on a surface that has not been properly cleaned.

Generally, there are two possibilities for sanitizing.[27]

Thermal sanitizing

The thermal sanitizing involves the use of hot water, hot air or steam for a specified temperature and contact time.

- Hot water is the most common method used. The time required is determined by the temperature of the water. According to DIN 10510 and 10512, the final rinse must be 80 to 85°C (cf. Task 1). Cleaned items must be exposed to these temperatures for a certain time. Hot-water sanitization is a slow process which requires come-up and cool-down time; can have high energy costs.
- The use of steam as a sanitizing process has limited application. It is generally more expensive compared to alternatives, and it is difficult to regulate and monitor contact temperature and time.

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27 Schmidt, R. H. (2009): Basic Elements of Equipment Cleaning and Sanitizing in Food Processing and Handling Operations. FS14, Series of the Food Science and Human Nutrition Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu/fs077

28 The official definition (Association of Official Analytical Chemists) of sanitizing for food product contact surfaces is a process which reduces the contamination level by 99.999% (5 logs) in 30 sec. For comparison: **Sterilizing** refers to the statistical destruction and removal of all living organisms. **Disinfecting** refers to inanimate objects and the destruction of all vegetative cells (not spores).

Chemical sanitizing

An extreme form of shift to lower dishwashing temperatures (and consequently lower energy consumption) is the so called chemical sanitising which is more widely used in the USA. Chemical sanitizing machines often wash at much lower temperatures, but not lower than 49°C. Rinse water temperature in these machines should be between 24 and 49°C for the sanitizer to be effective. Here, the lower water temperatures during the final rinse are compensated by the use of an approved chemical sanitizer at a specified concentration and contact time. Chemicals that are approved sanitizers are chlorine, iodine, and quaternary ammonium. Table 5 gives an overview of the advantages and disadvantages of the different chemical sanitizers.[29]

Table 5 Advantages and disadvantages of different chemical sanitizers

Chemical	Concentration	Contact Time	Advantage	Disadvantage
Chlorine	50 ppm in water between 24 and 38°C	7 seconds	Effective on a wide variety of bacteria; highly effective; not affected by hard water; generally inexpensive	Corrosive, irritating to the skin, effectiveness decreases with increasing pH of solution; deteriorates during storage and when exposed to light; dissipates rapidly; loses activity in the presence of organic matter
Iodine	12.5-25 ppm in water that is at least 24°C	30 seconds	Forms brown colour that indicates strength; not affected by hard water; less irritating to the skin than is chlorine; and activity not lost rapidly in the presence of organic matter	Effectiveness decreases greatly with an increase in pH (most active at pH 3.0; very low acting at pH 7.0); should not be used in water that is at 49°C or hotter; and might discolour equipment and surfaces
Quaternary Ammonium Compounds	Up to 200 ppm in water that is at least 24°C	30 seconds	Nontoxic, odourless, colourless, noncorrosive, nonirritating; stable to heat and relatively stable in the presence of organic matter; active over a wide pH range	Slow destruction of some microorganisms; not compatible with some detergents and hard water

In Europe, chemical sanitizing as practiced in the US is available, but not widely accepted due to the high environmental impact of the heavy use of aggressive chemical detergents as well as due to the following disadvantages:

- Chemical decontamination is hard to measure with sensors. It is therefore more difficult to guarantee a certain washing result and hygienic performance.

29 Source: http://chinesefoodsafety.com/sections/pdf/section11b_clean.pdf

- Bleaching agents like sodium hypochlorite have only limited storability before loosing their full performance. It therefore might be that disinfectants are used that are not fully active anymore.
- Remainders of sodium hypochlorite on the wash ware can cause nuisances of odour or taste.
- Additional entries of chlorine-containing detergents could affect microorganisms in sewage plants and could have other harmful effects, e.g. the development of toxic organic chlorine compounds cannot be excluded.
- The drying efficiency might be problematic (poor drying results).

Some manufacturers, however, indeed seem to plan introducing low temperature dishwashing programmes, which are supposed to meet the hygienic requirements according to DIN standards and which are marketed with a compatible detergent. As outlined above some disinfecting component will be included in the detergent. However, the kind of disinfectant and amount is not known. As the whole composition of these detergents is not accessible it is not possible to quantify the environmental effects. An appropriate indicator would be the critical dilution volume which can be used to quantify the aquatic toxicity of chemicals.[30]

3.4.2 Material composition

Manufacturers did not state any change in material composition with regard to the improvement options presented in the above sections. The additional input has to be seen mainly in know-how and some electronics.

In general, the additional material consumption of the options described does not play a significant role due to the following reasons:

- The input of all material has only a minor influence on the energy-consumption and the total environmental impact. Within Task 4 Report we analysed that the environmental impact resulting from the manufacture (including material), distribution and disposal of the devices is negligible compared to that during the use period: For example the global warming potential (GWP) caused by the use phase accounts for 97% to 99% of the total GWP over the lifetime of professional dishwashers.
- The material with the highest influence is stainless steel for the containment and frame of the dishwashing machine (50 to 80% depending on category). Even if stainless steal would be substituted through another material with no (!) environmental impact, the influence on total environmental impact over lifetime of the dishwashing machine would be lower than 2%. But there is no alternative for stainless steel for now.

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30 Source: 2003/31/EC: Commission Decision of 29 November 2002 establishing revised ecological criteria for the award of the Community eco-label to detergents for dishwashers and amending Decision 1999/427/EC

- Due to the missing standard measurement method and reliable results from independent analysis the range of incertitude of the consumption data is essentially higher than the influence of all materials.
- There might be a possibility to reduce the energy-consumption of the dishwashing process by changing the material of the dishes with a lower heat capacity. However, this would have impacts on the drying process, the cleaning results and would also affect user preferences. As the material design of dishes is isolated from the design options of the machinery, this option is out of scope of this study.

3.5 Possible implementation and combinations

Implementation possibilities: From a technical point of view, i.e. not taking into account economic feasibility, in principle nearly all improvement options could be implemented in every dishwasher category. Nevertheless, the following practical restrictions apply:

- M 1.2: Steam rinsing is currently only applied to undercounter one-tank dishwashers (category 2) of one manufacturer. In principle, it could also be implemented in other automatic-program devices (categories 3 and 4). However, it is not possible to implement it in conveyor-type dishwashers (category 5 and 6) as these appliances have an open entry and exit area and thus the steam would escape from the rinse zone into the surrounding area.
- M 1.4: Automatic load-recognition systems are currently only offered for conveyor-type dishwashers (categories 5 and 6). Such systems could also be implemented in automatic-program devices, but would require a special matrix system which can recognise the position of the wash ware and route the water directly to these places.
- M 1.5: Multi-zone rinsing is, by definition, restricted to machines with different cleaning zones, which means that this system would be restricted to category 5 and 6 dishwashers. If an additional rinsing zone with pump rinsing is implemented, an additional tank is necessary. This means that in case an additional rinsing zone would be added to a one-tank conveyor-type (category 5) this machine would, by definition, belong to category 6. On the other hand, however, it is also a question of definition. Automatic-program devices do not have different cleaning zones. But they could also have a second tank for pump rinsing. Thus an auxiliary rinse could also be performed within dishwasher categories 2 to 4. This system is only used by the Swedish manufacturer Wexiödisk for a hood-type dishwasher. For category 1 dishwashers, this design option is not applicable.
- M 2.3: The special air-flow concept combined with heat recovery (see chapter 3.2) is applied to conveyor-type dishwashers (categories 5 or 6) and cannot be implemented in other categories.

Combination possibilities: In principle it is possible to combine nearly all kinds of options in one dishwasher except for the following restrictions:

- Heat pumps and heat exchangers cannot be combined with a warm water supply for the purpose of recovering energy from exhaust air and waste water as a certain temperature difference between outgoing and incoming water is required.
- The implementation of some improvement options requires space. For instance, in the case of undercounter machines, it would be difficult to integrate a heat pump due to the compact nature of these dishwashers. For the same reason, it would be even more difficult to install both a heat pump for the exhaust air and a heat exchanger for the waste water.
- It does not make much sense to install a heat pump for waste water when, on the one hand, a heat pump for the exhaust air may already be recovering most of the heat required for the dishwashing process and, on the other hand, the heat recovery from the exhaust air is more efficient than waste-water heat recovery because:
  - more heat can be gained from exhaust air than from waste water,
  - the humidity and temperature of the ambient air can be reduced, and
  - heat extracted from exhaust air will not cause grease to build up inside drainage pipes (as is the case with waste-water heat recovery if too much heat is extracted from the water).

3.6 Best available products on the market

In Sections 3.1 to 3.4 we provided a more general technical description of a broader spectrum of possible design options and a first estimated quantification of the improvement potentials by manufacturers. In Section 3.5 we narrowed the spectrum due to certain constraints with regard to implementation and combination possibilities. For this section, we asked manufacturers to specify those components or technologies being currently implemented in best available products on the market. From this inquiry, an impression of the most important design options and combinations thereof for each dishwasher category shall be derived.

Table 6 Technologies built into the best available products on the market (feedback from manufacturers)

<table>
<tr><th>Dishwasher category</th><th>Company 1</th><th>Company 2</th><th>Company 3</th></tr>
<tr><td>No 1
Undercounter water-change</td><td>--</td><td>--</td><td>--</td></tr>
<tr><td>No 2
Undercounter one-tank</td><td rowspan="2">Filter system and heat recovery from exhaust air</td><td rowspan="2">Optimised spray arms for washing and rinsing, filter system, exhaust air heat recovery,</td><td rowspan="2">Exhaust air heat recovery, optimised spray arms, double skin</td></tr>
<tr><td>No 3
Hood-type</td></tr>
</table>

Dishwasher category	Company 1	Company 2	Company 3
No 4 Utensil/Pot dishwashers		drain heat recovery	
No 5 Conveyor-type one-tank	Filter system, reversed air flow and heat recovery from exhaust air	Optimised spray arms for washing and rinsing, side nozzles, exhaust air heat recovery	Optimised spray arms, intelligent air flow, multi-zone rinsing, exhaust air heat recovery with heat pump, double skin
No 6 Conveyor-type multi-tank			

Naturally, the best available products currently on the market have not implemented all possible design options as the marginal savings are decreasing and therefore additional investments do not pay off. Nevertheless, from a sole technological point of view, it would of course be possible to implement most options in professional dishwashers.

In this case, if *all* available BAT components were used, the additional energy saving potential compared to the best available products as presented in Table 6 could be 2 to 5% according to two manufacturers. The water-saving potential was estimated to be 0 to 5% compared to the current BAT products. However, these figures were not differentiated according to the different categories.

4 Best existing product technology outside the EU

According to stakeholders' feedback 30 to 40% of the US market washes with chemicals (chemical sanitizing, cf. Section 3.4.1.9). However, due to perceived inferior washing and drying results and the further described disadvantages, this approach has limited acceptance in the EU market.

In general, it was stated by all manufacturers that the most advanced dishwashing technologies and the most efficient dishwashing machines are produced in the European Union. Even the American dishwashing industry seems to be far behind Europe, as American dishwashers use more energy and water than European products. This is due to the fact, that on the US market sanitizing treatment of dishes is commonly applied (hot water sanitizing and chemical sanitizing respectively, cf. Section 3.4.1.9). These machines and processes generally require higher (sanitizing) temperatures compared to the (cleaning) temperatures of dishwashers in Europe. Thus, also the thresholds of the US ENERGY STAR label are not particularly ambitious compared to the performance of the European dishwashers. ENERGY STAR differentiates high and low temperature efficiency requirements for each hot water and chemical sanitizing machinery (see Task 1).

No further improvement options for professional dishwashers from outside EU are known.

5 Annex

5.1 Working paper "Task 6" for stakeholders

This paper is provided separately (EuP_Lot24_Dish_T6_Annex_Workingpaper.pdf).

5.2 Stakeholder feedback to draft versions of Task 6

Please note that the feedback refers to draft versions of Task 6 report; thus, the indicated numerations of chapters, tables, figures or pages might have changed.

Feedback		Comment
Granuldisk		
6.2.1	**Reducing the overall water consumption** The huge water consumption in pre-soak and pre-wash must be included in BC 4 in order to give incentive to reduce the overall water consumption. The whole process from dirty to clean must be covered.	Included in the text (cf. 3.1.1.6); In order to give incentive to reduce the overall water consumption of dishwashing, the inclusion of the whole process from dirty to clean (including the pre-soak and pre-cleaning phase) would be rather desirable for all dishwasher categories with special focus on utensil / pot dishwashers. However, the water consumption for pre-cleaning is strongly dependent on the specific user behaviour and cannot be influenced by the technology of the dishwashing machine itself. Further, there is no standard measurement method and thus no reliable data to record the average consumption through external pre-cleaning of the wash ware for the dishwasher categories. Finally, as we already excluded the manually process steps outside the dishwashing machines from the scope of this study in Task 1, we didn't further analyse the granule technology under cost-benefit aspects in the following tasks.
6.2	**Improvement options** A chapter describing utensil- and pot-washers using granule technology must be included. Granule technology = A mechanical cleaning process where plastic granules and water are blasting the pots and pans clean without using pre-soaking and scrubbing. This technology is today used by more than 10 000 end-users! M 1.6 Granule pot- and pan-washing machines. A mechanical cleaning process where	Considered in revision.

Feedback		Comment
	plastic granules and water are blasting the pots and pans clean without using pre-soaking and scrubbing. Through this process we can save: • Up to 70% in water consumption • Up to 60% in detergent consumption • Up to 60% in energy consumption • Up to 50% in man hours Even hard burnt-in pots and pans or dried-in soil is efficiently cleaned without any soaking or scrubbing outside the machines. The granules are taking over the hard job. Figure x (enclosed in the e-mail) shows the cleaning process of granule pot and pan-washing machines.	
JRC IPTS		
General comment to Task 6	With regard to Draft Task 6: 'Technical analysis of best available techniques' we consider that amendments on the quantification of the environmental savings potentials of BAT would improve the outcome of this task. This is important in order to ensure reliability on the forthcoming policy support issues (in Task 7 and 8).	This comment refers to the prior version of Task 6. In the revised Task 6 version of the draft final report published on 8 November 2010 this chapter has been improved essentially.
General comment to Task 6	The investigation of the BAT while broad remains rather qualitative. Based on the outcomes of Task 5 on the environmental assessment of the product base cases, the analyses of the BAT are mainly restricted to energy and water efficiency in the use phase. However, quantification of the technological improvements is not considered sufficient as it is solely left on stakeholders' estimations. From our point of view, a systematic approach using specific technical parameters which would eventually enable the quantification of the overall energy and water savings due to the application of BAT should be provided.	Within the study we also tried to collect usage data from different categories of end-users (e.g. large canteens). But it was not possible to get data which enable us to quantify the impact of BAT on water- and energy-savings. Regarding the consumption data we have to accentuate that there is no standard measurement method existing to quantify the consumption of energy and water for the dishwashing machines. Quantification based on information from independent side is also not possible as there is no scientific literature about the results of BAT in the professional dishwashing sector published.

Feedback		Comment
6.2.4 (page 38)	In this section it is stated that the changes of technological features in professional dishwashers 'has to been seen mainly in know-how and some electronics'. This could be true on this particular point however we would like to emphasise that one of the objectives of the current preparatory study is to provide the evidence for any consideration of material substitution which could result in environmental savings. As mentioned in the general comments above, the environmental investigation seems to be on a level that does not allow this issue to be captured. A greater level of detail in the analysis would provide the necessary information to unveil this aspect.	We did not put emphasis in the consideration of material substitution due to the following reasons: A) The input of all material has only a minor influence on the energy-consumption and the total environmental impact. Within Task 4 Report we analysed that the environmental impact resulting from the manufacture (including material), distribution and disposal of the devices is negligible compared to that during the use period: For example the global warming potential (GWP) caused by the use phase accounts for 97% to 99% of the total GWP over the lifetime of professional dishwashers. B) The material with the highest influence is stainless steel for the containment and frame of the dishwashing machine (50 to 80% depending on category). If stainless steal would be substituted through another material with no (!) environmental impact, the influence on total environmental impact over lifetime of the dishwashing machine would be lower than 2%. But there is no alternative for stainless steel for now. C) Due to the missing standard measurement method and reliable results from independent analysis the range of incertitude of the consumption data is essential higher than the influence of all materials. D) There might be a possibility to reduce the energy consumption of the dishwashing process by changing the material of the dishes with a lower heat capacity. However, this would have impacts on the drying process, the cleaning results and would also affect user preferences. As the material design of dishes is isolated from the design options of the machinery, this option is out of scope of this study.
6.5	The analysis of appliances implementing best available technologies is extensive. However precise quantitative features and technical performance parameters (which would result later in environmental savings calculations) of BAT are lacking or scarcely presented. Moreover, the option of applying on the same device one or more than one BAT is not evaluated. We consider it necessary that in this re-	The comment refers to the prior version of Task 6. In the revised Task 6 version of the draft final report published on 8 November 2010, the chapter has been improved essentially. We included the impact and costs of five improvement options. In the final report, however, this section has been moved to Task 7 to be coherent with the MEEuP methodology.

Feedback		Comment
	spect, the analysis of BAT should be further elaborated. A systematic approach which would allow for quantification and evaluation of the presented best available techniques should be applied and presented.	
6.5.2	Formatting error	Considered in revision.
CECED Italia		
General considerations	As a general comment on cold water machines we deem that any consideration on these particular kinds of products should be specifically assessed. These machines have a huge environmental impact due to the heavy use of aggressive chemical detergents. In other words, energy consumption for cold water and warm water appliances cannot be compared without considering the notable environmental impact differences.	Note: Be aware of the differences between dishwashers with cold and/or warm water supply (cf. Task 3) and the use of low dishwashing temperatures (chemical sanitising). Chemical sanitising has been presented in detail in Section 3.4.1.9. However, due to the portrayed disadvantages, this approach has limited acceptance in the EU market and thus has not been further analysed as BAT.
3.4.1.10	Chemical sanitizing: We would like to highlight that the US situation for chemical sanitizing is completely different from EU considering a totally different standard scenario (NFS for US). In Europe it could not be accepted this approach due to the high environmental impact of the heavy use of aggressive chemical detergents. Moreover, there could also be several problems in drying performance.	Included in revision.
Wexiödisk		
6.2.1, M 1.4 Automatic load adjustment system, page 15.	I find the estimated savings of water, energy and chemicals by far to low when it comes to "Automatic load adjustment systems" on BC 5 and BC 6. Enclose you will find a pdf document describing a test that was done together with a customer. Even though the test is rather old it clearly shows the impact the way of controlling the machine has. The machines in the test are one manufactured by Wexiödisk and branded Metos and the other one is from a competitor. What one shall have in mind is that the machine from the competitor has a	The section has been detailed accordingly; pointing out that the base cases were assumed to run continuously; discontinuous operation would lead to higher improvement potentials with regard to automatic load adjustment systems; however, for the purposes of the study, discontinuous operation could not be taken as basis as it strongly depends on user behaviour and could not be quantified. However, in Task 4 (recommendations on mandates) we ask for real-life usage (inter alia partial load / discontinuous operation) to be included in the development on a new performance standard.

Feedback		Comment
	very accurate control system with autotimer for the wash tank as well as the rinse tank. Meaning the zones does not start when there is no item in them. And for your information the control it has (had) was and is much more accurate than the one Hobart, Meiko and Winterhalter has today. In the technical data you can see that the rinse water flow rate was 20% higher on our machine. What even out the figure partly is that the machine was equipped with drying zones, without them the difference in percentage would be even bigger. Another thing worth to mention is that the place is the worst case for this type of tests, meaning that one wash rather intensively during a period of a couple of hours. I will tell you that we haven't done anything to make the test look better for us. Meaning nothing has been manipulated and the figures are correct. The disadvantages described in the text regarding collapsed vapour, additional water and energy consumption and poor washing result is by far exaggerated and does not exist, except in marketing material from the competitors not having this system.	
"Auxiliary rinsing"	Second thing is that I don't understand why you has excluded is the "Auxiliary rinsing" on BC 3 in Task 7. On hood type machines with this system we have the same rinse result with 1/3 of the rinse water volume compared with one without this system. The rinse result is not only tested with fenoftaline (meaning controlling if any chemicals are left on the rinsed items) it is also heavily tested with food soils such as mashed potatoes etc. 1/3 of the water consumption in the rinse does not only mean water savings but also huge savings in energy as well as chemicals. When calculat-	We didn't exclude "Auxiliary rinsing" on BC 3. In Task 6 we wrote: "The auxiliary rinsing (with an additional tank) is used almost exclusively for conveyor-type dishwashers with more than one tank. Only one company is using the system for a hood-type dishwasher (category 3). For category 1 dishwashers, it is not applicable." We could not provide a cost-benefit ratio for the base case 3 because we didn't get any data from the sole company who is producing this hood-type dishwasher.

Feedback		Comment
	ing overall consumption meaning standby consumption (ready-to-use mode) and continuous operation there is a 50% reduction of chemicals, water and energy.	
M 2.1.2 Exhaust air heat pump	Due to the way of working one want to minimize the on and of mode as much as possible to extend the lifetime of the exhaust air heat pump units. The result of this is that one doesn't turn of the rinse water when it's not needed. Just to give you one example: If one wash one basket in the state of the art model Premax with heat pump from Hobart the rinse water will be on for a length of 2 to 3 baskets, meaning 100% to 200% of the water will be used to just rinse empty spaces. And what this lead to is rather obvious when looking in the test from the Espoo school. In my opinion the figures for BC 5 and BC 6 should not be 100% but instead 120 to 130%.	It is correct that exhaust heat pump units will suffer if they are switched on and off frequently. In consequence the rinse process will continue for some time, even if there is no wash ware in the rinsing sector. As we describe above, the base case for category 5 (and 6) was assumed to be a *continuous* washing process with a workload of 75%. Under these terms and conditions no additional water consumption will occur.
M 4.4 Alarms	We have an alarm in our tunnel rack machines that goes on when the efficiency of the heat recovery unit goes down below a certain level. Meaning when it's time to clean the unit. This in my opinion does save some energy.	The described alarm system of your company makes sense and it will save some energy. Dishwashers from some other companies use a self-cleaning process of the heat-exchanger which will be activated after every working-day. The saving potential of the systems are dependent on the soiling of the dishes and other factors. As far as we know there is no scientific report or qualified measurements about the saving potential of such kind of alarm systems.
Overall comment	You had a note in one of the previous tasks regarding the difference in consumption stated in the brochures compared to real life operations. The hunt for lower consumption has lead to an increasing gap between those two figures. Overall has this made the machines more sensitive to cope with food soil. I have done a "simple" simulation of what could happen (see pdf-file enclose) in different scenario. One can see that just after 11 wash cycles the concentration of dirt in the water in simulation 2 is more than 100% higher	The mentioned graph is showing a plausible result. We agree that theoretically we should include the pre-treatment of the wash ware into the whole dishwashing-process to judge the efficiency of the whole process. But this is not possible because the pre-treatment process is strongly dependent on the behaviour of the service people, of the soiling of dishes, the existing infrastructure and other factors. Additionally there is no survey about water and energy consumption of the pre-treatment process in the EU on one side and the interrelation between pre-treatment of the wash-ware, the use of the dishwashing machine (program selection) and the washing-results of the dishwashing machines on the other

Feedback		Comment
	than simulation 1. Meaning when the rinse cycle starts the ware are twice as dirty in simulation 2 but the rinse has 29% less amount of water to cope with this, compared to simulation 1. As you can see the tank volume of simulation 2 is the same as the BAT Hood type machine shown in table 4, task 6. This has increased the demand for pre-washing the ware before it enters the machine. The measurement we have done shows that the consumption for pre-treatment in a typical hood type installation is between 3 to 6 litres/basket of 40 to 50°C heated water. Not an insignificant amount of cost in the whole washing process.	side. In this EuP-study we had to compare the efficiency of different dishwasher categories and to analyse the improvement potential of the dishwashers under ideal and typical use. An according explanation has been added to Task 6 (Section 3.1.1.6) and Task 3 (real-life user behaviour, influence of external process steps)