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

Lot 24: Professional Washing Machines, Dryers and Dishwashers

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Washing Machines and Dryers

Task 6: Technical Analysis
Best Available Technologies

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

The report at hand covers ***professional washing machines and dryers***.

The Task 6 report on *professional dishwashers*
is published separately.

Part: Professional Washing Machines and Dryers

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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 to 3 years. It provides input for the identification of the improvement potential (Task 7), i.e. especially relating 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 washing machines and dryers. The technical analysis carried out in Task 4 serves as an input for this purpose.

1.2 Methodology and assessment of data quality

The information used in this report was gathered from a number of different sources. Based on a questionnaire (see Annex 5.1) important inputs were provided by major European manufacturers (see also Task 3). Other sources as data sheets and research studies were also analysed. These sources permit a detailed insight into the current state of the art in professional laundry equipment technology. Stakeholders also contributed to the assessment of not yet available technology due to their own research and development efforts.

We start the technical analysis of best available technologies with a general overview over the energy flows and losses of professional washing machines and dryers (see Sections 2.1 and 3.1). This analysis provides an initial insight into the environmentally most important areas and improvement potentials.

In Sections 2.2 and 3.2, several design options are described at component and product level leading to a reduction in water and energy demand during the use phase.[1] Additionally, state-of-the-art product technology outside the EU has been analysed. In order to analyse possible trade-offs through additional environmental impacts in the production, distribution or end-of-life phase, the differences in material composition between a standard product and a product with integrated design option(s) are presented for each design option. 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 questionnaire.

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[1] As the detergent consumption is related to the water consumption, a reduction in water consumption thus also leads to a decreased detergent consumption.

In Sections 2.3 and 3.3, we describe which combinations of different best available technologies are possible and which design options are actually applicable to the different washing machine and dryer types (as many, but not all of the listed improvement options can be used within every category).

Moreover, we looked for best not yet available Technologies (BNAT) which are currently not introduced in the market but under development (e.g. in a prototype stage).

After these more general analyses of several possible design options, in Sections 2.4 and 3.4 we asked manufacturers to describe the components of currently best available products on the market for each washing machine and dryer category.

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 no commonly applicable European standard measurement methods for quantifying the energy and water consumption of **professional washing machines and dryers**, and there are likewise no eco-design or efficiency minimum requirements or a labelling scheme requiring manufacturers to define the measurement procedure for potential savings (see Task 1).
- Energy, water and detergent (the latter only for washing machines) savings depend on many different factors such as: ambient air temperature and humidity, water temperature, type of laundry textile, condition of soiling, type of machine, customer segment, type of energy heating and, last but not least, the base case or reference case to which savings are compared.
- Little or no systematic independent research is carried out on the potential saving impacts of improvement options.
- Manufacturers use varied terms for their improvement options and assess their innovative systems to their competitors in different ways.
- 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 to some extent diverge considerably. Therefore, the data presented in the Task report at hand are average values of the responses and inquiries.

2 Professional washing machines

2.1 Main areas of environmental improvement potentials

The factors influencing the energy consumption of professional washing machines can be mainly subdivided into energy for heating the water, and energy for mechanical action and the functioning of other electronic components. Approximately 90% of the energy consumed can be allocated to the heating of the water (compared to around 10% electricity used for the motor and electronic components).[2] The energy necessary for mechanical action depends on the total washing time. The energy necessary for heating the water is influenced by the amount of water, the wash load, and the temperature difference between the cold water inlet and the washing temperature to be reached. The entire washing cycle can be divided into the following phases:

1. Water (+ detergent) intake;
2. Heating (to the set water temperature);
3. Pre-wash phase (temperature depending on the kind of soiling);
4. Main wash phase (temperature depending on the kind of soiling and the temperature of the pre-wash phase: For instance, the test cycles defined in ISO 9398-4:2003(E) require temperatures between 60 - 85°C);[3]
5. Rinsing phase (with cold water);
6. Neutralisation (reduction of textile pH-value for the purpose of preventing a yellowing effect during the drying or ironing process by addition of laundry aids like e.g. starch, textile softener, acid);
7. Final spinning phase (extraction of water from the laundry).

Water acts as heating medium, transport medium and solvent for the detergents and soil, and as wetting agent for the textiles.[4] It is a main component of the washing process and is used for the pre-wash, main wash and rinsing phase. For the washing process, only the pre- and main wash phases operate with warm or hot water. Although the rinsing phase needs the highest amount of fresh water, this phase is using cold water. Contrary to professional dishwashers, where the final rinse of the washware requires the highest temperature (usually between 80 and 85°C) to accelerate the following drying period for the items.

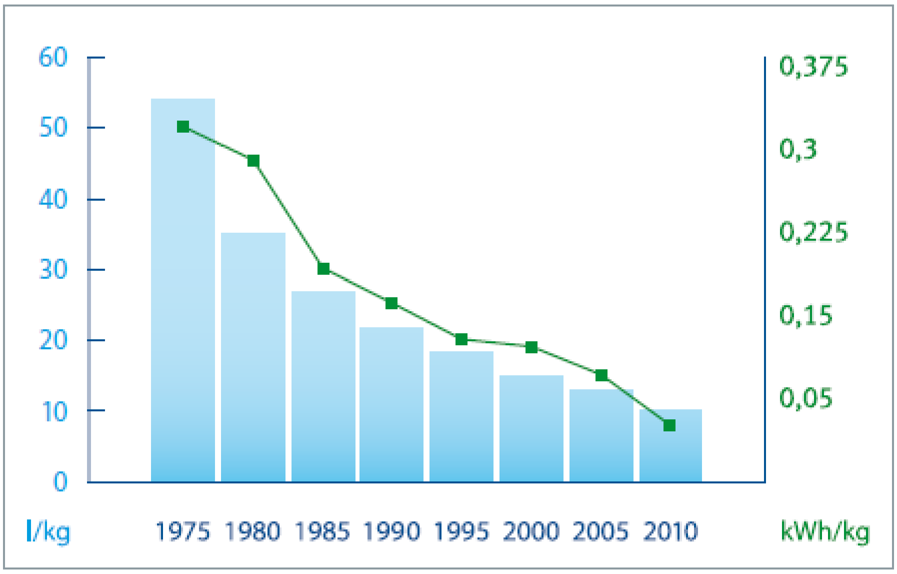
[2] For details, see Task 4, section ratio of energy use.

[3] This temperature is not fixed for the categories WM4, WM5 and WM7; however, a thermal disinfection requires a temperature > 85°C

[4] http://www.laundry-sustainability.eu/en/html/module_1__water.html

During the washing process, the energy used to heat the water also flows to other parts of the machine, for example to the steel drum or the glass door. The major part of this energy, however, is lost to the environment. These heat losses depend, for example, on the temperature of the heated water, the insulation of the machine, and the ambient temperature. In contrast to professional dishwashers, where energy losses due to absorption of heat by the wash ware play a significant role, this fact is negligible for washing machines with regard to heat absorption by the washed laundry. Consequently, the greatest improvement potential for professional washing machines lies in the reduction of energy for heating the water in the pre- and main wash phases.

Figure 1 shows the development of the water and energy consumption of professional washing machines over the past decades; it reflects that a major reduction has already been realised. For example, professional appliances of Schulthess[5] that used more than 50 litres per kg laundry around 30 years ago, now only use about 10 litres or even less per kg laundry (see Figure 1 further information in Task 2) mainly achieved by solutions for the re-use of rinsing water. Compared to current appliances in the stock, manufacturers expect further possible reductions of the overall water consumption in the coming years (cf. Task 2).



(Source: Schulthess)

Figure 1 Development of the water and energy consumption of commercial appliances from the Swiss manufacturer Schulthess (this figure is comparable to categories WM2 and WM3)

There are no specific options listed with regard to the reduction of the detergent consumption. From the perspective of laundry 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

5 http://www.schulthess.ch/de/produkte/gewerbe-industrie.html

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. Furthermore, according to A.I.S.E,[6] there are some market trends promoting a reduced consumption of detergents:

- 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 the washing process to a minimum, a great variety of detergent products is offered, by adjusting the components of each product to the individual requirements of the various types of laundry. The mixture of different detergent components can be tailored to fit the customer’s needs, thus avoiding chemical waste and unnecessary disposal into the environment.
- The institutional laundry detergent segment has developed towards a higher acceptance of concentrated detergents, both for granular and liquid detergents. This development has moved forward faster in the last few years and is expected to continue.
- The industrial laundry market uses mostly concentrated granular detergents and liquids. ‘Paste-type’ products or anhydrous liquids can also be found. The use of concentrates reduces the amount of packaging and of chemicals (mainly bulking agents) and therefore the total environmental impact of a product (cf. Task 4). However, highly concentrated products necessitate adapted dosage behaviour, as the dosage units (volume, weight) differ compared to conventional detergents.
- Finally, there is a trend towards lower wash temperatures and a shorter cycle duration. At lower temperatures, a special composition of detergents is needed to be applied for the same high level of cleaning and to guarantee hygiene.
- Enzyme applications have increased in recent years since research developments have allowed their use for very diverse applications. The largest reduction in environmental impact that enzymes have contributed to, is the lowering of wash temperatures with corresponding energy savings. In order to tailor the use of chemicals to the specific needs of commercial and industrial applications, enzymes are mainly used as boosters. Enzymes are needed in order to carry out high chemical reactions under mild conditions (temperature, pH).

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

- Design options considered best available technology (BAT),
- Improvement options outside EU,
- Best not yet available technologies (BNAT).

[6] International Association for Soaps, Detergents and Maintenance Products

2.2 Best available technologies at component and product level

In this section, first the state of the art at component level will be described. The 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 input from manufacturers based on a working paper (see Annex 5.1).

2.2.1 Design options

In general, the market has changed towards professional washing machines with reduced energy and water use in recent years (cf. Task 2 – market trends). These reductions in energy and water are caused by several technological features like optimal mechanical action or innovations such as new control or management systems for improving the efficiency and environmental performance. The most relevant technological options are described below.

2.2.1.1 Description of the design options

M 1.1 Increased motor efficiency

An option to reduce the energy consumption of the professional washing machine is to enhance the efficiency of the motor. Consistent with other appliances, washing machine manufacturers are continuously looking for methods to improve the operational efficiency while simultaneously reducing costs. In the past, various types of motors have been used in washing machines whereas nowadays nearly all machines use a three phase alternating current (AC). According to stakeholders, especially for the larger washing machine categories (WM4 and WM7), a three-phase system is more economical compared to a single- or two-phase system or a direct current motor (being more efficient for household washing machines) at the same voltage.[7] Although the heavier machines of WM4 and WM7 require more power for starting the filled drum, the three-phase motor is more efficient due to the fact that it requires less conductor material to transmit the electric power. According to the stakeholders, no further saving potential could be realised with another motor technology.

Another option to optimise the motor would be to use less amount of construction material. Although this has no direct impact on the energy or water consumption of the washing machine, it reduces the overall material composition of the machine and the costs for manufacturers and customers. Furthermore, an optimised motor can lead to a reduction of machine vibrations and noise emissions.

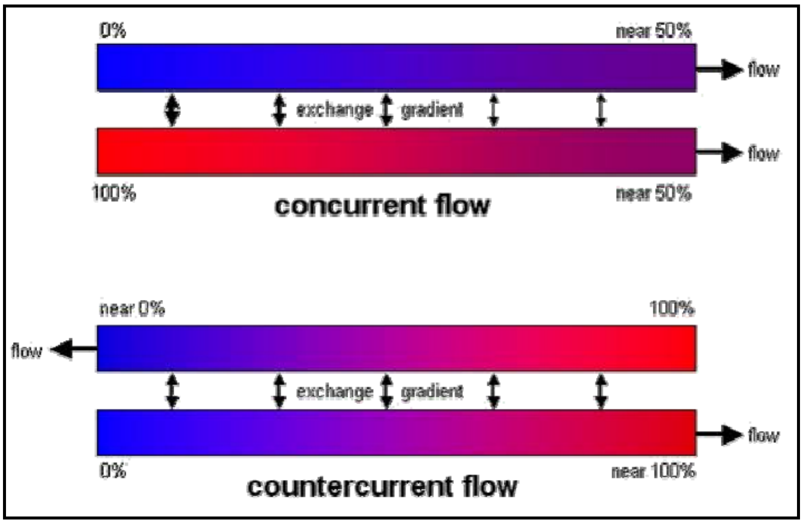
[7] http://www.allaboutcircuits.com/vol_2/chpt_10/2.html

The European Commission has recently taken steps to further regulate the energy performance of electric motors;[8] however, these requirements currently do not apply to professional washing machines. The Regulation No. 640/2009/EC is not applicable 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.

M 1.2 Heat exchanger

Depending on the pre-wash temperature, approximately 10-40% of the energy can be recovered by using a heat exchanger. Two different alternatives of the flow can be distinguished: "concurrent flow" and "counter current flow". As for a concurrent flow system, warm and cold liquids flow along the heat exchange surface in the same direction. In the counter current heat exchanger, hot and cold liquids flow along the separation wall in opposite direction. The energy loss of the counter current heat exchanger is significantly lower compared to that of a concurrent heat exchanger, as a larger proportion of the heat of the warmer liquid is transmitted to the colder liquid.

The principle of a heat exchanger is illustrated in Figure 2.



(Source: Laundry Sustainability)

Figure 2 Concurrent and counter current flow in heat exchangers

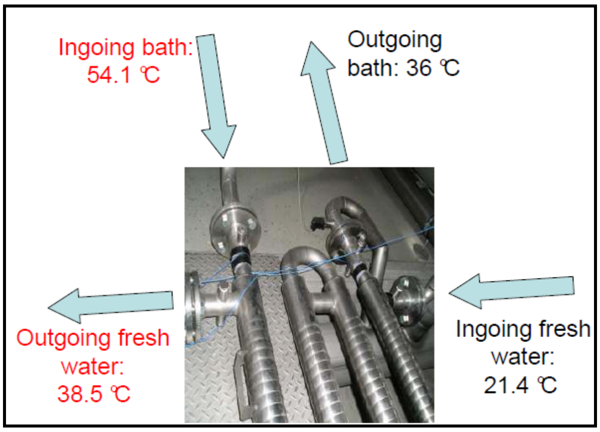
The different flow characteristics depend on the flow speed, the flow rates and the viscosity of the liquid (expressed in the so called Reynolds number[9]). As flow speed and flow rates are limited, turbulences.might occur in the heat exchanger leading to a reduced heat transfer.

8 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:191:0026:0034:EN:PDF

9 The Reynolds number is a dimensionless number a measure of the ratio of inertial forces to viscous forces

On the market, there is a variety of heat exchanger types with different technical and economic advantages and drawbacks. The following construction types of heat exchangers are mainly used in laundry equipment:

- Shell and tube heat exchanger;
- Corrugated pipe heat exchanger (see Figure 3);
- Plate heat exchanger;
- Rotating discs heat exchanger;
- Panel heat exchanger.



(Source: Laundry Sustainability)

Figure 3 Corrugated pipe heat exchanger of Kannegiesser

M 1.3 Water recovery systems

Washing machines with a water recycling system collect the wash water from all previous rinse cycles for a re-use in the next prewash and main wash cycle, thus decreasing the amount of fresh water required.

This system consists of a filter unit cleaning the water of coarse impurities. The water filtrate is then heated to operating temperature ready for the use in the prewash and main wash cycle. Fresh water is only needed for the rinse cycle.

Figure 4 shows a water recovery module that can be installed optionally on the washing machine.

(Source: Miele)

Figure 4 Washer extractor with an additional water recovery module

Figure 5 presents a similar system with several recirculation tanks for washer extractors.

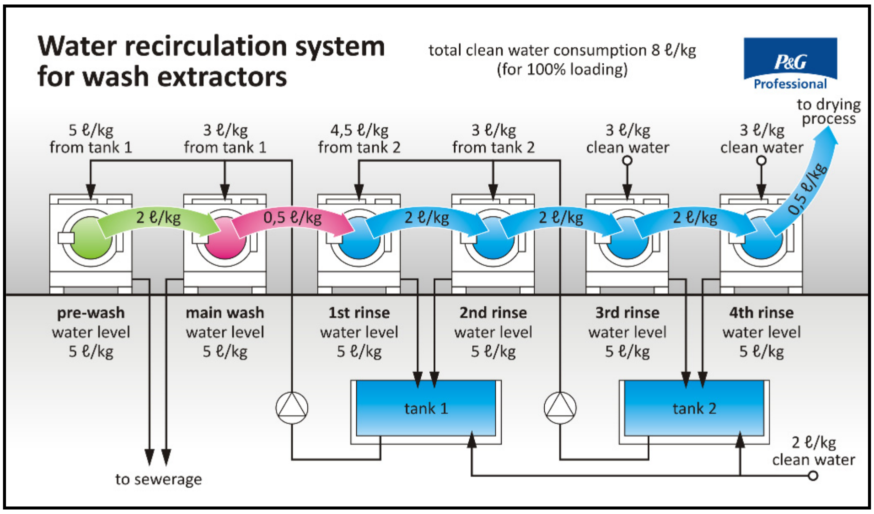


Figure 5 Various washer extractors in a water recirculation system [10]

This design option is often used in washing tunnel machines (WM7). Through a “balanced water management system” wash water is recycled and reused from previous wash cycles to decrease the amount of new required (hot) water. The water quality from the extraction process (i.e. press machine or centrifugal machine) is sufficient for rinsing the laundry, and the water quality from rinsing is sufficient for the pre- and main wash.

[10] http://www.pgprof.info/Water-and-energy-saving.html

M 1.4 Load control

Partial load of washing machines causes additional energy, water, and detergent consumption (cf. Task 3) when evaluated on the basis of a per kg laundry.[11] Sensor technologies (e.g. through an automatic weighing-machine or an algorithm based on the motor speed) can be implemented to evaluate the real load weight and consequently adapt the amount of water, detergent and time. For example, according to A.I.S.E., the most advanced washer extractors are equipped with load cells which weigh each batch of wash ware and automatically adjust the water level and dosage of detergent/chemicals to that weight.

This design option may result in a reduction of water consumption and energy as less water has to be heated. The absolute saving potential depends on the difference between the machines' capacity size and real-life workload. Note that for cleaning half load, the relative water reduction is far less than 50%, thus even with load control sensors the washing process is not as effective as washing at full load.

M 1.5 Further control systems

In terms of detergents, control systems are tailored as closely as possible to the specific requirements of individual users to minimise the generation of waste. Over-dosage directly increases the environmental impacts while under-dosage may lead to a non satisfactory result with regard to the cleaning performance, resulting in an additional washing cycle (which also leads to additional water, energy and detergent consumption). To reduce maloperation which depends on the respective consumer behaviour (e.g. in Coin & Card laundries, cf. Task 3), detailed dosage instructions might be given.

From the technical point of view, there is a broad variety of dispensers in the market to dose liquids, powders, pastes and even solids automatically. According to A.I.S.E[12], increasing use is made of sensors, which measure the amount of product actually dispensed, so that a central control unit is able to stop the dosing equipment as soon as the required detergent concentration is reached in the machine. The semi-automatic dosing devices of the 1970s and early 1980s in laundry equipment were based on flushing chambers or stock solutions, filled by hand and started by card systems in the washing machines. Card systems were simple mechanical readers that had to be changed and corrected by hand whenever changes to the washing process, used in the machine, were necessary.

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[11] On average, the real-life workload – depending on the washing machine category – is assumed to be between 60 to 85%, resulting in additional consumption (energy: +10%; water and detergent: +20%; cf. Task 3).

[12] A.I.S.E. "Industrial and Institutional Sector – Environmental dossier on professional laundry" (2000)

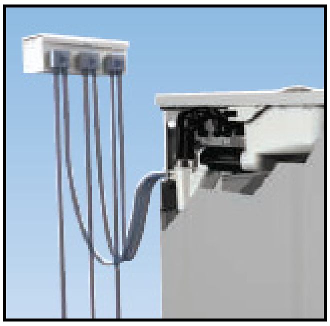
(Source: Electrolux)

Figure 6 Automatic detergent dosing feature

Sensors to measure and regulate the dispensed amounts of detergents are not yet used everywhere. The quantity dispensed is still most commonly measured by the running time of the dosing equipment. For this it is necessary that the dosing unit delivers a constant amount of product per time unit. A variation in the quantity dispensed leads to over- or under-dosage. The sensors measure the amount dispensed and then send that information to a control unit.

A modern controlling system offers a number of additional functions that might also be able to contribute to the careful use of resources, e.g. pH- and conductivity-controlled dosage. Modern automatic control units are also able to dispense the required product quantity per litre of fresh water used. This is an important aspect, e.g. with regard to disinfection of the laundry or partial load of the machine, as in the case of conventional dosage, which is usually indicated for one kg of textiles, a suitable concentration of washing liquor might not be achieved. Further, most large industrial laundries have a central water softening system integrated in their infrastructure reducing the water hardness and therefore the requirement of “builders”[13] in the detergent formulation and/or the overall detergent dosage which is usually indicated for a certain hardness of water.

M 1.6 Ozone technology

Ozone works as bleaching agent (it kills bacteria 3 200 times faster than chlorine bleach[14]) at low temperatures and furthermore shortens wash time cycles so that potential energy and detergent savings are possible.
When using ozone technology in commercial laundering system, ozone must be dissolved into the wash water where the ozone breaks down by oxidation of $2O_3$ to $3O_2$. Thus, the main technical difference between a conventional washing machine and an ozone washing machine is the addition of a pump and piping loop. Water from the washer drum is circulated through this loop. Ozone laundry systems use an ozone generator and compressed air is forced through a high voltage electrical arc, which results in the conversion of oxygen

[13] Association Internationale de la Savonnerie, de la Détergence et des Produits d’Entretien (2000), Professional laundry and the environment

[14] http://www.schiff-consulting.com/Ozone_in_laundry_washing.html

molecules into ozone. The ozone is then dissolved in cold laundry wash water where it exerts its cleaning action. Ozone reacts with fatty and other soils attached to clothing, destroying them rapidly. Ozone is capable of degrading organic soil into compounds such as carbon dioxide and water.
There is a variety of ozone using solutions on the market as well as different methods for dissolving ozone into the wash water. The most common technologies are[15]

- Direct Water Injection – Ozone is directly dissolved into the cold water supply line by injection.
- Air Injection – Ozone gas is injected directly into the integrated drip pan of the washing machine. This approach could be applied also to a single ozone air injection system. Being a gas in solution, ozone penetrates and opens individual garment fibres, allowing faster cleaning and bleaching of garments with the use of fewer chemicals.
- Recirculation Injection – The rinse water is continually cycled back to the ozone system (generator) for re-oxidation of the rinse water and a predetermined amount of dissolved ozone is sent back to washer for sanitizing of the laundry.

The installation of ozone technology inside laundries requires particular water and steam quality to protect the material of the machines as well as special health and safety management aspects to protect workers potentially exposed to ozone[16] (e.g. sensors and detectors continually monitoring the exposure levels of ozone within the laundry room).
The generation of ozone itself requires energy[17] and causes additional costs; heating of the wash water is still required although washing is possible at lower temperatures; and there is a greater risk of damaging the textiles[25]. According to one stakeholder, due to lower washing temperatures increasing the ratio of suspended solids in the washing solvent, the ozone gas might not reach the textiles anymore. Especially in open systems as tunnel washing machines, the use of the highly volatile ozone is questionable as it can easily escape through the inner drum.

In the North American market, ozone technology is commonly applied in laundries, whereas according to stakeholders in Europe this technology is currently not so prevalent except for UK. Unfortunately, we did not receive any detailed information on the washing effects, savings potential and additional material composition of ozone-based technology.

M 1.7 Drum construction

In recent years, the drums of washing machines had cylindrical perforations resulting in an inter-fibre friction caused by the rough edges (see Figure 7).

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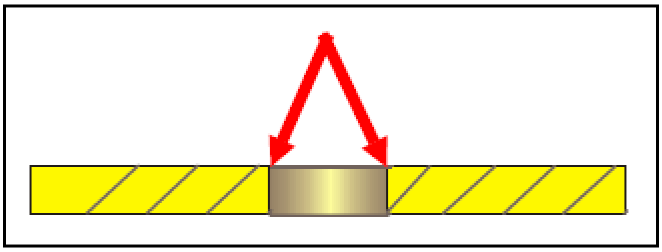
15 http://www.cwtozone.com/index.php?page=ozone-in-the-laundry-industry---practical-experiences-in-the-uk

16 Due to the strongly oxidizing properties of ozone, ozone is a primary irritant, affecting especially the eyes and respiratory systems and can be hazardous at even low concentrations

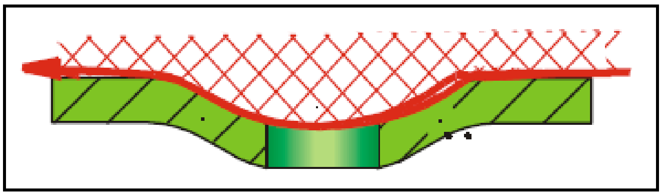
17 Due to its instability, ozone can not be stored for long periods or used as other industrial gases are purchased in ozone cylinders. Prior to his commercial application it must be produced on the premises.



(Source: Laundry Sustainability[18])

Figure 7 Cylindrical perforation of washing machines' inner drums

Funnel perforation, shown in Figure 8, is gentler on the fibres.



(Source: Laundry Sustainability[19])

Figure 8 Funnel perforation of inner drum surface

One manufacturer offers a patented honeycomb drum, in which the laundry glides on a thin film of water caused by a hexagonal relief pattern. This drum design particularly preserves delicate textile fibres.

This design option might not be relevant with regard to energy, water or detergents savings (improvement options cf. Task 7), but rather in terms of protective treatment of fabrics.

M 1.8 Wash process with lower temperature

If users of household appliances wash their clothes at 30°C instead of 40°C, the savings of energy consumption could reach about 12%. For the semi-professional appliances (WM1), lowering the used washing temperature could also be more efficient than increasing the washing machine's performance.[20]

The use of lower temperatures during the washing cycles, however, might promote the development of bio-films within the machines (bacteria and fungi), resulting in the need for regular routine services at higher temperatures to provide necessary hygienic cleaning

[18] http://www.laundry-sustainability.eu/en/Microsoft_PowerPoint_-_Module_2-2_Washer_Extractors.PDF, sighted on 12.11.2010

[19] http://www.laundry-sustainability.eu/en/Microsoft_PowerPoint_-_Module_2-2_Washer_Extractors.PDF, sighted on 12.11.2010

[20] BIO Intelligence Service / Giraffe / Intertek (2009), "Reducing the environmental impacts of clothes cleaning", for DEFRA

results. Therefore, some end users (especially in the medical sector) may require even compulsory high temperature washing in their activity area (e.g. health care market).

According to A.I.S.E, the large majority of professional washing processes take place at 80°C to 90°C or 60°C to 70°C. This washing temperature is critically important for cleaning performance and hygiene claims. Professional users need to be sure about the washing hygiene because of the claims they promised to their customers (the situation for professional use might be different compared to the household use due to specific cleaning requirements of the different kinds of stains, e.g. oil in the industrial and blood in the medical customer segments). At temperatures lower than 55°C, adequate reformulation of detergents may be needed to guarantee hygiene.[21]

Finally, washing with lower temperatures might result in a longer washing time to achieve the same required cleaning performance (cf. Task 3, principle of Sinner's Circle). As, in contrast to household applications, shorter wash cycles play a major role in professional laundry processes, washing at lower temperatures might be a limited solution in the professional context.

2.2.1.2 Material composition

The improvement options M1.1 to M1.8 described above may 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 and between a basic product and a product with integrated design options were investigated (see following table). Furthermore, the implementation of certain design options might require another material composition or a change in (the proportion of) the constituent parts of the appliance possibly inducing a better durability or a reduction of noise emissions.

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21 A significant germ reduction is achieved at temperatures higher than 40°C; at temperatures higher than 55°C most germs are killed off. To achieve a comparable result at lower washing temperatures, other factors like cycle time or composition of the detergent have to be adapted (cf. Principle of Sinner's Circle, Task 3). (Source: http://www.forum-waschen.de/doc/files/16199/WagnerNachhalitgesWaschen.pdf)

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

Design Option / Material category	M 1.1	M 1.2	M 1.3	M 1.4	M 1.5	M 1.6	M 1.7	M 1.8
	Increased motor efficiency	Heat ex-changer	Water recovery	Load control	Further control systems	Ozone techno-logy[22]	Drum con-struc-tion	Wash process with lower temp
	[g]	[g]	[g]	[g]	[g]	[g]	[g]	[g]
Bulk plastics								
PP					+ 200			
Ferrous metals								
stainless steel	- 100	+ 8 000	+ 15 000		+ 2 500		- 200	
Non-ferrous metals								
copper wire								
Al diecast		+ 3 000			+ 750			
Electronics				+ 200	+ 250			+ 100
Misc.					+ 100			

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

Stakeholders only provided information on a change in material composition with regard to the improvement options "heat exchanger" and "water recovery". The material composition of the further design options is an own estimate. Anyhow, the additional material consumption of the options described would 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 5 we concluded that the environmental impact resulting from the production (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 93 to 99% of the total GWP over the lifetime of professional washing machines.
- The material with the highest influence is stainless steel for the containment and frame of the washing machines (50 to 80% depending on category). Even if stainless steal would be substituted by another material with no environmental impact, the influence on total environmental impact over lifetime of the washing machine would be lower than 3 %. Nevertheless, there is no alternative for stainless steel for now.
- Due to the absence of a commonly applied standard measurement method at EU level and reliable results from other analyses the range of uncertainty of the consumption data is significantly higher than the influence of all materials.

[22] No input from stakeholders available, no own estimations possible

2.2.1.3 Market penetration

The above described technological options result in saving potentials in the following fields:

- Water consumption;
- Detergent consumption;
- Energy consumption;
- Program efficiency and cycle time.

The expected energy saving potential and the estimated additional costs for the users are further elaborated in Task 7. The following table shows the current (year 2010) market share of the BAT options, their economic and practical advantages as well as the drawbacks of all the design options are listed.

Please note, that the values regarding the market share are not differentiated with regard to the different product categories or the respective key customer segments. A thorough analysis will be undertaken in Task 7.

Table 2 Design options for professional washing machines

Design options for professional washing machines		**Application to the market in %**[23]	**Details or Comments**	
			Advantages	Drawbacks
M 1.1	Increased motor efficiency	~30-80	Process flexibility, better motor efficiency	Electromagnetic compatibility; more components
M 1.2	Heat exchanger	5-60	Reduced energy consumption	Customized solutions, high costs
M 1.3	Water recovery	5-80	Saves water and energy	hygiene risk, bioaccumulation in system, high costs
M 1.4	Load control	30-80	Reduced energy, water, detergent consumption, faster wash time	n.a.
M 1.5	Further control systems	20-50	Better dosing, selection of right programme	n.a.
M 1.6	Ozone technology	n.a.	Reduced energy, water, detergent consumption	Additional costs, health & safety risk; higher ratio of suspended solids in the washing solvent
M 1.7	Drum construction	20-40	Better clemency of the textile fibres.	n.a.
M 1.8	Wash process with lower temperature	35-50	Reduced energy consumption	Lower wash performance, hygiene risk, bio accumulation within machine, longer cycles

n.a. = no information available (Source: manufacturers' feedback)

[23] Depending on the different customer segment and washing machine category

2.2.2 Improvement options outside the EU

According to the stakeholders no further improvement options for professional washing machines outside EU are known.

2.2.3 Best not yet available technologies (BNAT)

In this section, best not yet available technologies shall be provided. To obtain an overview of future developments and long-term saving potentials in the professional washing machines sector, stakeholders were asked to name further technologies (see questionnaire Annex 5.1) which are currently not yet available on the market but expected to be introduced in the coming years (BNAT).

Unfortunately, we did not receive comprehensive information from manufacturers. It should be noted that, for competition reasons, manufacturers are rather reluctant to talk about inventions, ideas and strategies which are not yet available on the market. Competition between the manufacturers is quite fierce and the circle of leading manufacturers is rather small. Nevertheless, we found one BNAT option based on own literature research and subsequent personal communication with the manufacturer.

<u>*Polymer beads*</u>

The following Figure 9 shows the general process of cleaning with polymer beads.[24] By contact and friction of the polymer beads with the laundry, the stains are more easily removed; the stains are transported to the beads, and afterwards absorbed by and diffused into the beads.

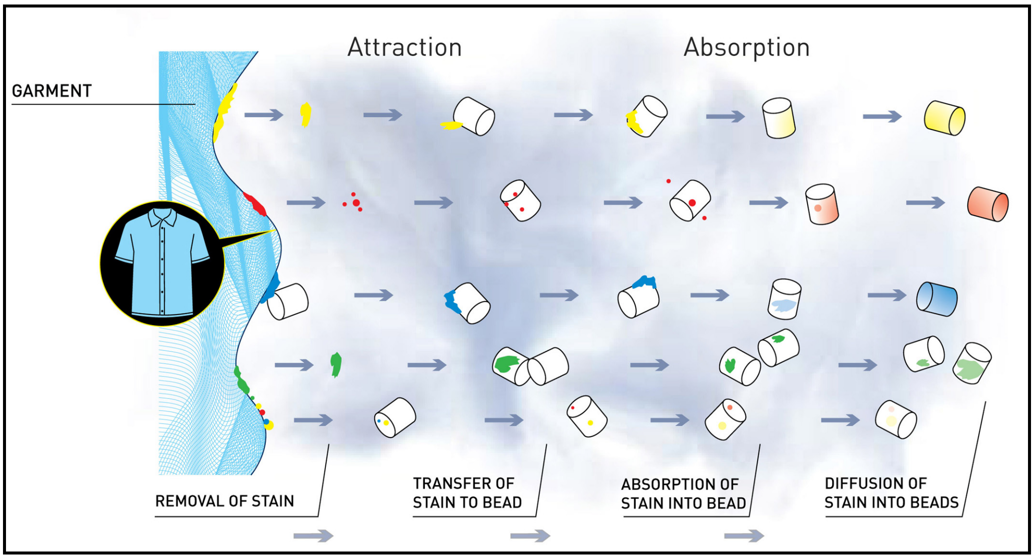


Figure 9 Polymer cleaning

[24] http://www.xerosltd.com/nylon-polymer-technology.htm

Whereas conventional washing processes use a dip wash which needs a high level of water, the polymer bead process only needs to wet the wash load by spraying water into the drum.
According to the manufacturer, the estimated savings during the main wash phase represent about 60% for energy, water and detergents compared to the consumption of conventional washing machines. Further, with the reduced level of detergents less rinse water is needed. The technology could be combined with additional recycling of the rinse water.
The bead system is not applicable in conventional washing machine technology: new designs or modifications of existing designs are needed before a polymer bead system can be introduced.[25] The polymer bead technology is currently under development and expected to be introduced in the market in 2011/2012.

2.3 Possible implementation and combinations

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 washing machine category. Only few exceptions exist which cannot be combined with other options:

- Heat recovery systems are not applicable in washing processes with lower temperatures as a certain temperature difference between outgoing and incoming water is required.
- Improvement options helping to reduce the overall water consumption are reasonably not combinable to water recovery systems.
- The implementation of some improvement options requires space. For instance, in the case of semi-professional machines, it would be difficult to integrate a water recovery system or a heat exchanger due to the compact nature of these washing machines.

2.4 Best available washing machine products on the market

In Sections 2.1 and 2.2 we provided a more general technical description of possible design options and – if available – a first rough quantification of the improvement potentials by manufacturers. In Section 2.3 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 most important design options and combinations thereof for each washing machine category shall be derived.

[25] BIO Intelligence Service / Giraffe / Intertek (2009), "Reducing the environmental impacts of clothes cleaning", for DEFRA.

Table 3 Technologies built into currently best available products on the market

Washing machine categories, base cases	Most efficient energy source to heat up the water	Contained improvement options
WM1 Semi-professional washer extractor	Alternative heating (mainly external heating through warm water input)	electronic stop controls, high extraction, drum construction, water and temperature sensors
WM2 Professional washer extractor, <15 kg	Alternative heating (mainly external heating through warm water input)	electronic stop controls, drum construction, water and temperature sensors
WM3 Professional washer extractor, 15-40 kg	Alternative heating (mainly steam heating)	electronic stop controls, drum construction, automatic weighing system, water and temperature sensors
WM4 Professional washer extractor, >40 kg	Alternative heating (mainly steam heating)	electronic stop controls, drum construction, load control, intelligent water and temperature sensors, high extraction, control system (with an industrial programm-able logistic controller for the whole laundry process)
WM5 Professional washer dryer	Electric heating	electronic stop controls, drum construction, load control
WM6 Professional barrier washer	Alternative heating (mainly steam heating)	electronic stop controls, drum construction, load control
WM7 Washing tunnel machine	Alternative heating (mainly steam heating)	Control system (with an industrial programmable logistic controller for the whole laundry process),

(Source: feedback from manufacturers and own research)

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

3 Professional dryers

3.1 Main areas of environmental improvement potentials

The drying process needs hot air which is usually generated by an electrical heating system and blown to the wet laundry, thus taking up humidity from laundry and drying it. The humid air is then either vented to the ambient air or condensed by cooling it down in a heat exchanger. The energy demand of the drying process inter alia depends on the residual moisture of the laundered wash ware. The wet laundry with a designated residual moisture coming from a washing process is loaded into the tumble dryer (manual or automatically) and affects the operation of the tumble dryer. The more water is removed by mechanical treatment (usually through spinning in the washing machine) the less thermal energy is required for the subsequent drying.

Another factor influencing the energy consumption is the duration of the drying process. In case the drying process is too short the laundry is still wet and an extra drying step would be necessary increasing the energy consumption. Whereas in the case the drying process is too long the textiles could be over-dried with a higher energy demand than necessary and a possible damage to the linen.

The whole drying process needs energy. Typical heat losses occur through exhaust air (process air), evaporation of the water and radiation losses (see Figure 10 for condenser dryers). Air vented tumble dryers need additional energy as the warm and humid air is blown outside and is replaced by cold air that has to be heated up by the space heating system. In a typical drying cycle of an air dryer the heating of the air represents approximately 90% (cf. more detailed for each category in Task 4) of the energy demand, about 10% is used for the electric motor and electronic controls, as shown in Figure 11. Therefore, the most effective approach for improving energy efficiency would be to focus on the aim to decrease the amount of heat input per kg of laundry.

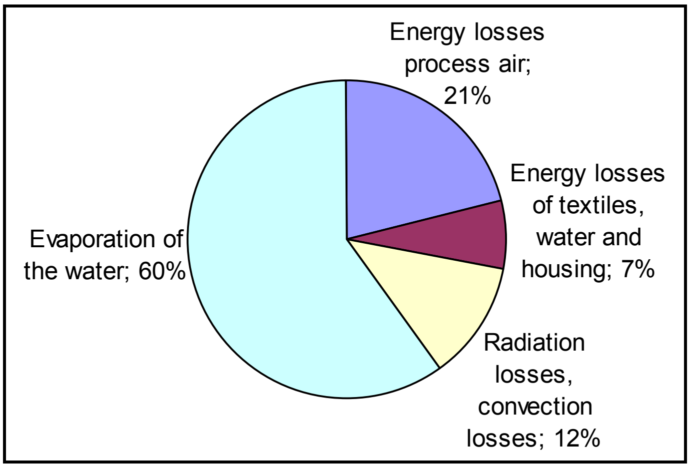


Figure 10 Energy use for a typical professional condenser dryer [26]

[26] Own illustration according to following sources: Universität Bonn / Haushaltstechnik and Electrolux/AEG

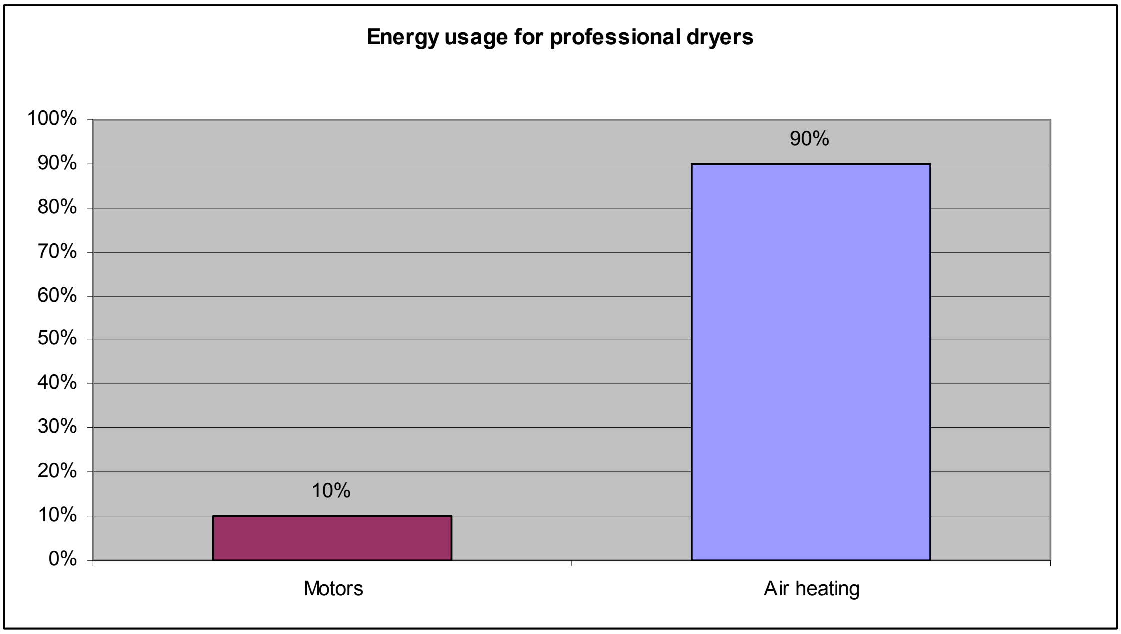


Figure 11 Energy use for a typical professional air dryer cycle[27]

The following sections describe various energy saving technologies for professional dryers. The description of improvement options is structured according to the following categories:

- Design options considered best available technology (BAT),
- Improvement options outside EU,
- Best not yet available technologies (BNAT).

3.2 Best available technologies at component and product level

In this section, first the state of the art at product and component level is described. These best available technologies (BAT) as well as indicative quantitative data were derived from manufacturers' brochures supplemented by personal communication with input from manufacturers based on a questionnaire (see Annex 5.1). A couple of design options applicable to domestic appliances were also identified for (semi-)professional dryers.

3.2.1 Technological options

The reductions in energy could be achieved by several technological features offered by manufacturers. The most relevant technological options are described below.

[27] Own illustration according to: DOE 2008 laundry equipment report, page 265

3.2.1.1 Description of the design options

M 2.1 Increased motor efficiency

The efficiency of the motors can be optimised. Electric energy is preliminary needed for the functioning of the dryer's drum that provides the mechanical agitation of the laundry to be dried: depending on the type of dryer, electric energy is also needed for the air flow and pumping out of the water (condenser dryer). Most of the dryers' categories use a three phase alternating current (AC) motor. Most gas heated dryers especially in the range up to 20 kg[28] are working with single phase motor systems. Optimizing the motor control strategy (adaptive acceleration, speed, positional control, and rotation patterns) would provide possible decrease of the energy consumption, the uniformity of drying and a gentler treatment of the laundry. Also material savings would be possible.

The European Commission has recently taken steps to further regulate the energy performance of electric motors;[29] however, the requirements currently do not apply to professional dryers. The Regulation No. 640/2009/EC is not applicable 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.

M 2.2 Heat pump

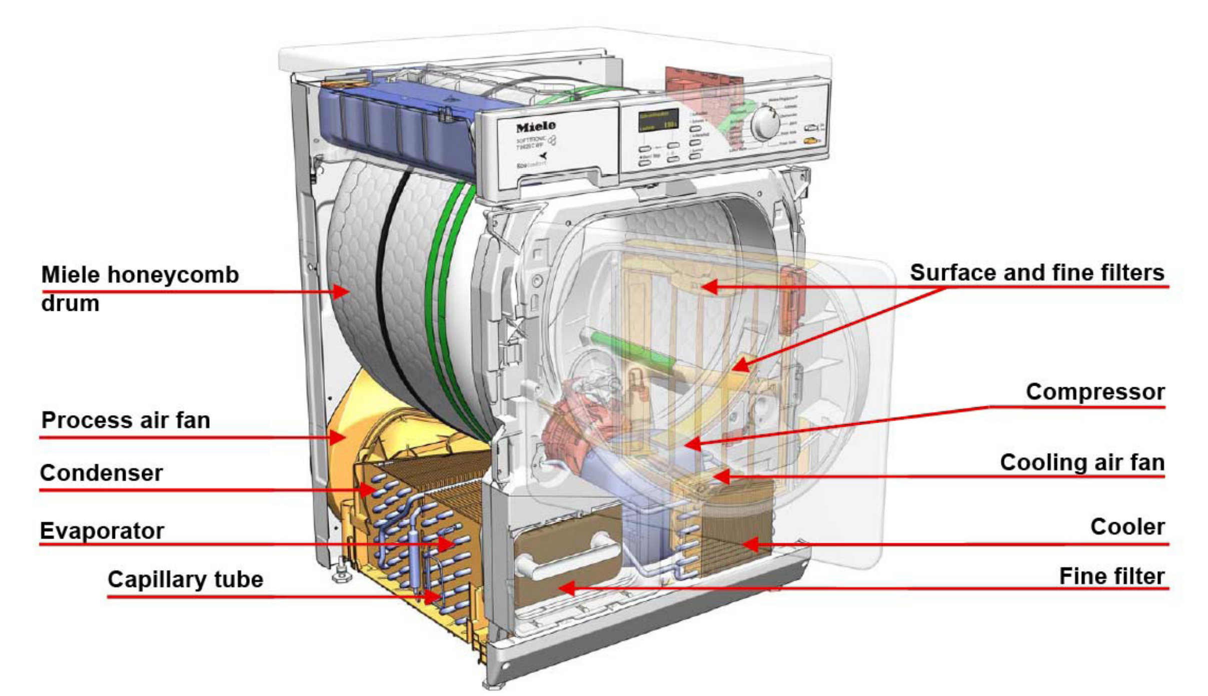
The heat pump consists of a refrigeration loop containing a refrigerant steam compressor, an evaporator heat exchanger, a condensing heat exchanger, and an expansion valve.

Hot, dry processed air enters the rear of the drum and interacts with the laundry. Inside the dryer, the residual moisture of the laundry evaporates into the hot, dry air, thereby generating warm moist air which exits the drum. In the evaporator, heat from this air is transferred to the refrigerant inside the evaporator coils. This decreases the temperature of the warm moist air and causes the moisture in the air to condense. The condensate is drained from the dryer. The cool dry air flows from the evaporator back to the condenser heat exchanger where the heat is transferred from the high-temperature refrigerant to the cool dry air. The resulting hot dry air enters the drum and the cycle is completed.

The design of a heat-pump dryer is shown in Figure 12.

[28] Source: Personal information by Miele

[29] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:191:0026:0034:EN:PDF



(Source Miele: http://www.miele.com.au/media/haushalt/VG_AUS/T_8627_WP_information.pdf)

Figure 12 Design of a heat pump dryer

Heat pump driers use refrigerants in their vapour compression cycles. Refrigerants as well as the heat pump units are not designed and manufactured by the manufacturers. Typical refrigerants used are R-134a (tetrafluorodichlorethene), R-407C[30] (a hydrofluorocarbon blend of R-32, R-125, and R-134a) and others with an average filling of 1 to 3 kg depending on the dryer categories.

The electricity consumption of a dryer with heat pump can be reduced by approximately up to 60% compared to a conventional condenser dryer. Besides the energy saving potential heat pump tumble dryers provide further advantages compared to conventional condensing dryers:[31]

- Waste heat dissipation into the operation room is about 50% lower as the heat is regained for the drying process and the outgoing exhaust air has temperatures of about only 18-22°C (conventional dryers: heated exhaust air). This is advantageous especially in summer as extending the possible operation hours of the appliances in hot periods (as conventional condensing dryers only limited operate at temperatures

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30 Source Electrolux data sheet: http://skalbimas.com/pdf_files/ts4180.pdf

31 Jürg Nipkow, Eric Bush: Promotion of energy-efficient heat pump dryers. Swiss Agency for Efficient Energy Use (S.A.F.E.), Topten International Group; http://www.topten.info/uploads/File/Efficient%20Heat%20Pump%20Dryers%20-%20EEDAL%2009.pdf

above 30°C) and reducing the additional energy demand for cooling the operating facility.

- Compared to conventional air vented dryers, there is no smelling and steaming exhaust air.
- Vented dryers blow the warm exhaust air outside the building being compensated by cold incoming air which has to be heated. For heat pump dryers, this cooling down of the operating room in winter is of no relevance, as the exhaust air is not blown outside but recycled within the heat exchanger.

On the other hand, there are also some disadvantages by implementing a heat pump[32]:

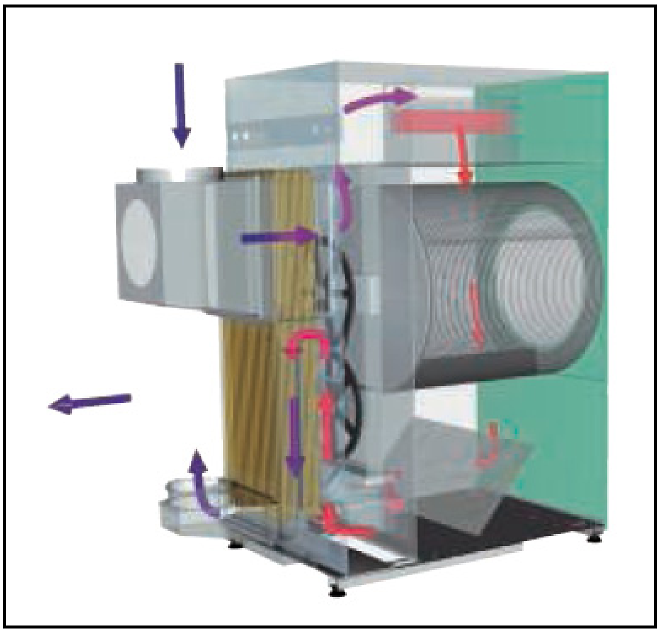
- additional costs are significant for the components and process integration;
- heat pumps need additional inspections to control whether or not the refrigerant circuit is leaking; thus it will cause additional maintenance costs.

M 2.3 Heat recovery systems

In general the same aspects described for the heat pump apply to heat recovery systems.

Heat recovery systems are usually based on a heat exchange that uses the warm exhaust air produced by the tumble dryer to preheat the cold inlet air. This system leads to energy savings, especially when the cold incoming air to be preheated is not exceeding 24°C. Furthermore, the drying time can be shortened, as less time is needed for preheating the incoming air. In a launderette (Coin & Card Laundry), for each dryer heat recovery units can be installed, or a number of tumble dryers can be connected to a central heat recovery unit.

[32] http://www-cep.ensmp.fr/francais/innov/pdf/ICR0143SLV%20_IIR_IIF%20Conf.pdf



(Source: Electrolux[33])

Figure 13 Air flow of the heat recovery system

Laundry dryers normally exhaust large amounts of warm, moist air. After having been circulated through the clothes, the air is exhausted along with moisture and heat. This can be avoided by installing a heat recovery system. In order to recover the exhausted heat, an air-to-air heat exchanger is installed, the incoming air thus being preheated by the hot exhaust air. The thermal contact surface of the heat exchanger should be optimized in order to guarantee the best transport of thermal energy from the hot to the cool side, thereby allowing vapour to condensate without inducing excessive heat transfers.

Since the hot process medium is humid air coming from the drum which is filled with laundry, it sometimes happens that lint covers the surface and makes the heat exchange less efficient. To avoid this effect, user-accessible air filters are in place, which have to be cleaned time and again to ensure optimal operation.

Figure 14 illustrates the energy consumption of a tumble dryer, with and without a heat recovery system.

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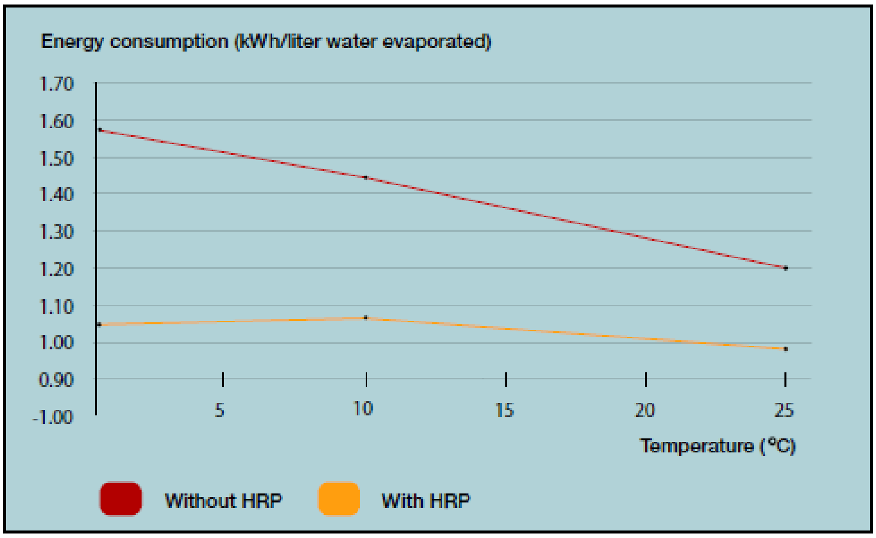
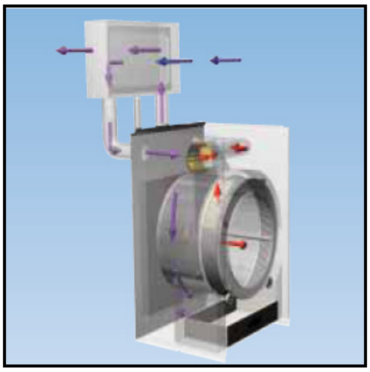
33 http://www.laundrysystems.electrolux.com/Files/Pdf_files2/Ljungby/Brochures/Heat_recovery_pipes_GB.pdf, sighted on 06.12.2010)



(Source Electrolux:
http://www.laundrysystems.electrolux.com/Files/Pdf_files2/Ljungby/Brochures/Heat_recovery_pipes_GB.pdf *)*

Figure 14 Energy consumption with and without heat recovery pipes (HRP)

A further possibility is an air preheat condensing unit with an effective heat exchanger. A condensing unit (see Figure 15) is required for installations where a normal dryer exhaust connection to the outside is not possible. The condensing unit is connected to the dryer air exhaust and the air inlet. The warm moist exhaust air passes through the condensing unit. The condensing unit condenses the humidity of the exhaust air by using the ambient room air for cooling. The condensed water is led to the drain. For optimal performance the room temperature should not exceed 25°C.



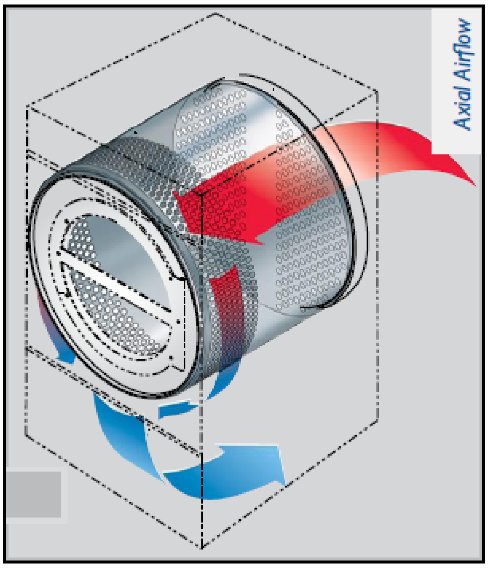
(Source: *http://www.waeschereitechnik-horstbalk.de/Waschetrockner.pdf* / Electrolux)

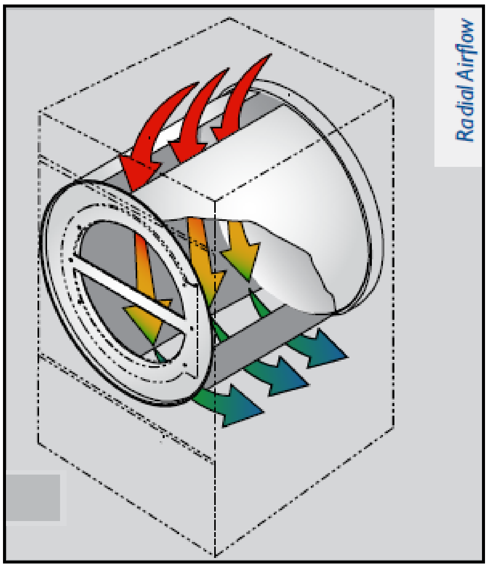
Figure 15 Condensing unit

Another manufacturer developed a plate heat exchanger which preheats the incoming air of the dryer by extracting heat from the hot exhaust air. The heat exchanger increases the heat of the air entering the dryer by about 30 to 35°C. If the ambient temperature is 15°C, the air transferred to the dryer is typically at 45 to 50°C.[34]

M 2.4 Improved air flow systems

Tumble dryers can be equipped with different air flow systems (axial, radial, mixed or others). With axial systems, the air flows through the drum from rear to front, rather than from top to bottom (see Figure 16). This means all the air passes through the load and increases the speed of the drying process. With radial airflow, the air flows from the bottom to the top (see Figure 17). In contrast to the axial airflow, part of the air does not come into contact with the linen but passes alongside the drum.





(Source: Girbau[35])

Figure 16 Axial airflow

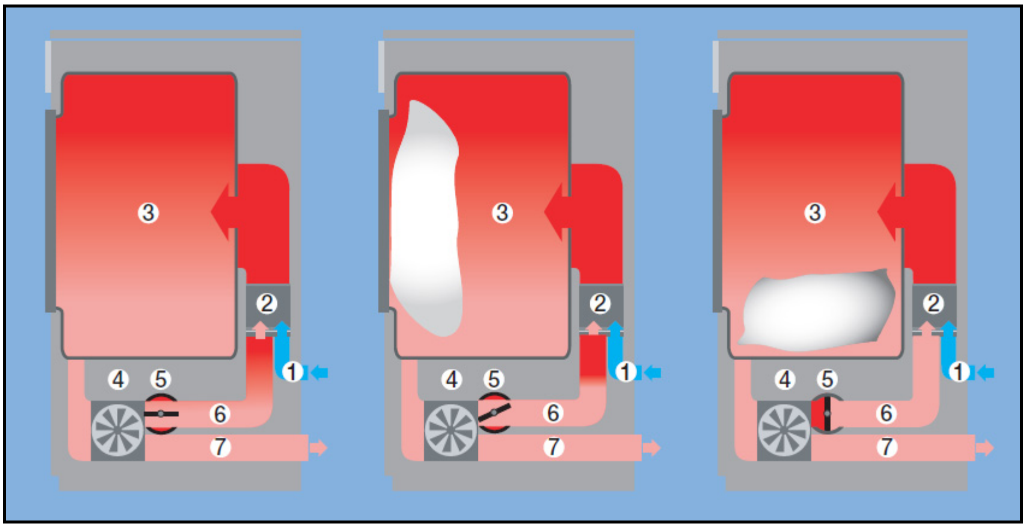
Figure 17 Radial airflow

In order to achieve an improved drying temperature, an alternative solution might be to use an air system as specified in Figure 18). A special air shutter controls the intake of the air via a fan. If the temperature inside the drum rises, this air shutter reduces the intake of hot air into the drum. Air-resistant fabrics can cover the perforations in the interior of the drum next to the door, creating an under pressure which causes the temperature inside the drum to rise. With a reduction of the air intake the laundry falls to the bottom of the drum, exposing the perforation and enabling the air/pressure balance to equalise.

These air and temperature controls result in shorter drying times, and therefore a better energy efficiency.

[34] http://www.resourcesmart.vic.gov.au/documents/BP_ProcessHeating_Case_Study.pdf

[35] http://www.girbau.co.uk/shopimages/products/extras/Pro_Series_II.pdf, sighted on 06.12.2010



(Source: Miele, http://www.miele-ebrochures.co.uk/professional/files/PT7801_Tumble_Dryer_2006.pdf, sighted on 06.12.2010)

Figure 18 Air control system

M 2.5 Load control

Weight sensors directly measure the weight of the load and could adapt the drying process in case of partial load. Dryers with integrated weight sensors sending a signal.to users that their dryer is only partially loaded, may influence their behaviour (optimizing the load and thus improving the energy efficiency).

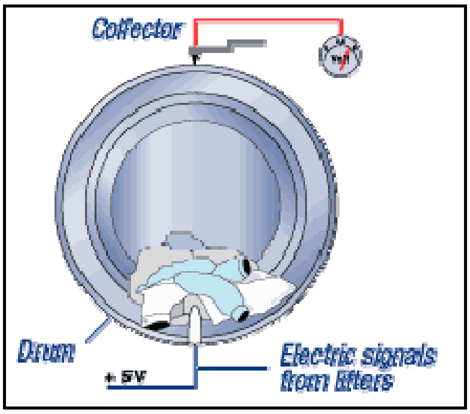
M 2.6 Residual moisture control – RMC

The residual moisture control system allows an optimal drying cycle end-point determination to avoid both still wet laundry as a result of too short drying and over-drying by extended drying. Is the drying too short the laundry is still wet and an extra drying phase is necessary which, in turn, leads to an increased energy consumption. When, however, the drying process is too long the textiles could be over-dried resulting in higher energy demand as necessary which might damage the linen.

Several end point determination methods are available on the market:

- Fixed drying time per article,
- Methods based on air temperature control, and
- Infrared sensors which measure the temperature of the linen.

Moisture-controlled dryers stop the drying process as soon as the preset residual moisture level is reached. Time-controlled dryers stop after a certain period of time set by the user. Usually the time-controlled dryers run longer than necessary resulting in higher energy consumption in comparison to moisture-controlled appliances.



(Source: http://www.wascomat.net/docs/sect03/inst_rmc.jsp)

Figure 19 RMC provides a direct electronic and accurate measurement of moisture content in the dryer load

M 2.7 Improved insulation

A further design option to reduce heat losses is to ensure optimal thermal insulation. Improved geometry and materials for the casing, drum, tubing, etc. ensure that a lower amount of heat is lost to the surroundings.

3.2.1.2 Material composition

The improvement options M 2.1 to M 2.7 described above lead to a reduction in energy and time demand during the use phase of professional dryers. 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 questionnaire in Annex 5.1).

Table 4 Differences in material composition through implementation of design options

Design Option / Material category	M 2.1	M 2.2	M 2.3	M 2.4	M 2.5	M 2.6	M 2.7
	Increased motor efficiency	Heat pump	Heat recovery from exhaust air	Improved air flow system	Load control	Residual moisture control – RMC	Improved insulation
	[g]	[%][36]	[g]	[g]	[g]	[g]	[g]
Bulk plastics		+ 1,5%	+ 1 400				+ 200
PP				+ 500			
Ferrous metals							
stainless steel	- 200	+75%	+ 21 000	+ 500			
Non-ferrous metals							
copper wire		+ 4,5%	+ 850	+ 1 500			
Al diecast		+17%	+4 700	+ 500			
Electronics		+ 1,2%		+ 100			
Misc.					+ 200	+ 100	
refrigerant		+ 0,8%					

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

Unfortunately, stakeholders only provided information on a change in material composition with regard to the improvement options "heat pump" and "heat recovery system". Thus, the material composition of the other design options are own estimations. Anyhow, the additional material consumption of the options described would 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. In Task 5 Report we concluded that the environmental impact resulting from the manufacture (including material), distribution and disposal of the appliances is negligible compared to the impact of the use phase: 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 dryers.
- The material with the highest influence is stainless steel for the containment and frame of the dryers (more than 60%, depending on the product 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 dryers would be lower than 2%. But there is no alternative to stainless steel for now.

[36] Size and additional material of heat pumps depend on the size of respective dryer category. Thus, additional material consumption of the heat pump is given as proportional to the material composition of the different base cases. The weight of the heat pump unit includes the cabinet, tubes, base etc (detailed calculations: see Task 7)

- Due to the missing standard measurement method and other reliable results the uncertainty of the consumption data is significantly higher than the influence of all materials.

3.2.1.3 Market penetration

The expected energy saving potential and the estimated additional costs for the users are further elaborated in Task 7. The following table shows the current (year 2010) market share of the BAT options, their economic and practical advantages as well as the drawbacks of all the design options are listed.

Please note that the values regarding the market share are not differentiated with regard to the different product categories or the respective key customer segments. A thorough analysis will be undertaken in Task 7.

Table 5 Design options for professional dryers

Design options for professional dryers		Application to the market %	Advantages	Drawbacks
M 2.1	Increased motor concept	30	Slightly better energy performance	n.a.
M 2.2	Heat pump	3–5	Saves a lot of energy	Longer drying time
M 2.3	Heat recovery	10	Saves energy more in cold climates	Maintenance, more difficult to clean
M 2.4	Improved air flow system	40–60	Saves energy Optimisation for different loads	More complexity Requires more front space
M 2.5	Load control	0–5	Can detect part loads	Complexity
M 2.6	Residual moisture control – RMC	30–90	Less energy consumption Better laundry economy.	Cost
M 2.7	Improved insulation	20	Saves energy	Cost

n.a. = no information available (Source: manufacturers' feedback)

3.2.2 Improvement options outside the EU

It was stated by all manufacturers that the most advanced dryer technologies and the most efficient professional dryers are produced in the European Union. According the stakeholders the state of the art is very similar all over the world. Thus no further improvement options for professional dryers from outside EU are known.

3.2.3 Best not yet available technologies (BNAT)

In this section, best not yet available technologies are provided. To obtain an overview of future developments and long-term saving potentials in the professional dryers sector, stakeholders were asked to identify further technologies (see questionnaire Annex 5.1) which are currently not yet available on the market but are expected to be introduced in the coming years (BNAT).

Unfortunately, we did not receive any information on BNAT from manufacturers; they stated that especially for the components used in dryers considered BNAT are still subject to research and development. It should be noted that, for competition reasons, manufacturers are rather reluctant to talk about inventions, ideas and strategies which are not yet available on the market. Competition between the manufacturers is quite fierce and the circle of leading manufacturers is rather small.

The following BNAT technologies were derived from Lot 16 (dryers for household use); it is expected that they could be applicable for semi-professional dryer categories as well. However, there is no indication that professional laundries are currently working on these technologies in Europe.

Modulating Gas Dryers

Most gas dryers on the market today operate with a single burner at fixed input rate and fixed airflow rate. The burner typically operates in an on/off mode as determined by the cycle chosen. One strategy for saving energy in a gas dryer is to modulate[37] the heat input rate to the moisture level of the load. This saves energy because the dryer requires less heat towards the end of the cycle. Modulating gas dryers have the ability to detect when the clothes are becoming dry, and to reduce the heat input rate accordingly as the clothes are approaching their dry state.

Microwave dryer

Microwave dryers employ electromagnetic waves in order to directly heat the water. The water vapour is removed by a stream of air and blown out to the atmosphere. Energy is transferred through the material electro-magnetically, not as a thermal heat flux. Therefore, the rate of heating is only limited by the power for the generation of microwaves; the uniformity of heat distribution is rather improved. Heating times can be reduced to less than one percent of those required using conventional techniques.

Because volumetric heating is not dependent on heat transfer by conduction or convection, it is possible to use microwave heating for applications where conventional heat transfer is inadequate. One example is in heterogeneous fluids where the identical heating of solids and

[37] U.S. Department of Energy Energy Efficiency and Renewable Energy Building Technologies Program. Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances, Navigant Consulting, Inc. December 21, 2009

liquids is required to minimize over-processing. Another application is to obtain very low final moisture levels for products without over-drying.

A disadvantage is the depth of penetration achievable using microwave energy. This is a function of microwave frequency, the dielectric properties of the material being heated and its temperature. As a general rule, the higher the frequency, the lower is the depth of penetration.

Vacuum dryer

A vacuum dryer uses vacuum condensation technology to dry laundry at lower temperatures. As the air pressure inside the drum is reduced (vacuum), water evaporates at temperatures lower than 100°C. This results in energy savings because less energy is needed to create a vacuum than to heat the laundry up to 100°C. Vacuum dryers have a completely different design compared to existing dryers and they need a complex structural design raising high research and development costs.

3.3 Possible implementation and combinations

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 dryer category except for the following restrictions:

- The air-flow design options cannot be implemented in condenser dryers (category D1).
- Heat pump technology is only applicable to condenser type dryers, but not to air vented dryers.
- An improved condensing unit can not be combined with an additional heat pump and also not within gas or steam operated machines.
- The implementation of some improvement options requires additional space. Thus, for example, for semi-professional dryers D1 and D2 as well as for the smaller tumble dryers it would be difficult to integrate a heat pump due to the compact nature of these appliances.

3.4 Best available dryer products on the market

In Sections 3.1 and 3.2 we provided a more general technical description of possible design options and – if available – a first rough quantification of the improvement potentials estimated by manufacturers. In Section 3.3 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 most important design options and combinations thereof for each dryer category can be derived.

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

Dryer categories, base cases	**Current best available energy source for the air heating**	**Contained Improvement options**
D1 Semi-professional dryer, condenser	Electricity heating	Control system,
D2 Semi-professional dryer, air vented	Electricity heating	Control system, improved air flow system
D3 Professional cabinet dryer	Electricity heating	Heat pump, control system (adjustable)
D4 Professional tumble dryer, <15 kg	Alternative heating (mainly gas heating)	Heat pump, exhaust duct not needed, RMC, improved air flow system
D5 Professional tumble dryer, 15-40 kg	Alternative heating (mainly gas heating)	RMC, improved air flow system
D6 Professional tumble dryer, >40 kg	Alternative heating (mainly gas heating)	Control systems, (with an industrial programmable logistic controller for the hole laundry process)
D7 Pass-through (transfer) tumble dryer	Alternative heating (mainly gas heating)	Infrared control, control system (with an industrial programmable logistic controller for the hole laundry process), heat recovery system

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

4 Infrastructure options and laundry system solutions

4.1 Infrastructure options

Apart from powering the motor and electronic controls, laundry equipment requires most energy for heating the water of washing machines and the air of dryers. Different heating options can be used depending on the existing local infrastructure: electricity, gas and steam (or thermo oil). Washing machines can also be heated by using externally heated water. Tunnel washing machines (category WM7) are mostly (more than 90%) operated by steam heating (see Task 3).

The existing infrastructure influences the choice of the heating source and accordingly the difference in environmental impacts. It is a general rule that only one method of heating supply is used. In order to achieve economies of scale, it would not make sense to install multiple heating systems like steam heating, thermo-oil or natural gas in parallel. Improvements by changing the heating source could be realised for example in case of new investments or re-planning of a laundry or a launderette.[38]

In the following sections, the further heating options besides electricity heating are described.

4.1.1 External heating with warm (hot) water

Heating with warm water might result in energy savings if heating the water outside of the washing machine (e.g. existing central or district heating system of the regarded customer segment) is more efficient compared to electric water heating within the machine. Next to the direct efficiency of the heat generation this mainly depends on the primary energy sources used for the energy supply.

To prevent reduced washing performance, for some laundry (some stains like e.g. blood require a lower initial temperature) the initial temperature of the hot-fill has to be limited to a starting temperature just below 40°C. To allow alternatively both hot-fill or lower initial temperatures, two valves (for each hot and cold water) are necessary and currently mostly implemented in the machinery.[39]

In general, warm or hot water connection leads to shorter programme times and lower energy consumption of the washing machine itself. However, the overall environmental and economic advantage of the connection to warm water supply strongly depends on the type of water heating outside the appliance and other infrastructural parameters, like length and insulation of the water line.

4.1.2 Internal heating with steam (or thermo-oil)

Washer extractors and dryers equipped with steam heating are mostly used in large commercial laundries (WM7 and D7) or in industries which basically need steam for their processes.

Some professional washing machines or dryers are equipped with special heating elements in which the heat, produced for example by district heating, is let in. A separate boiler produces high-pressure steam distributing it into all steam using appliances. This steam is used for heating up the water in the washing machine to the desired temperature. Thus, nearly no electricity is used for the heating process (only approx. 5% for the electronic components). Furthermore, in some large laundries a steam management is applied to prevent energy losses. Figure 20 shows the conversion of the energy input in a steam heating system

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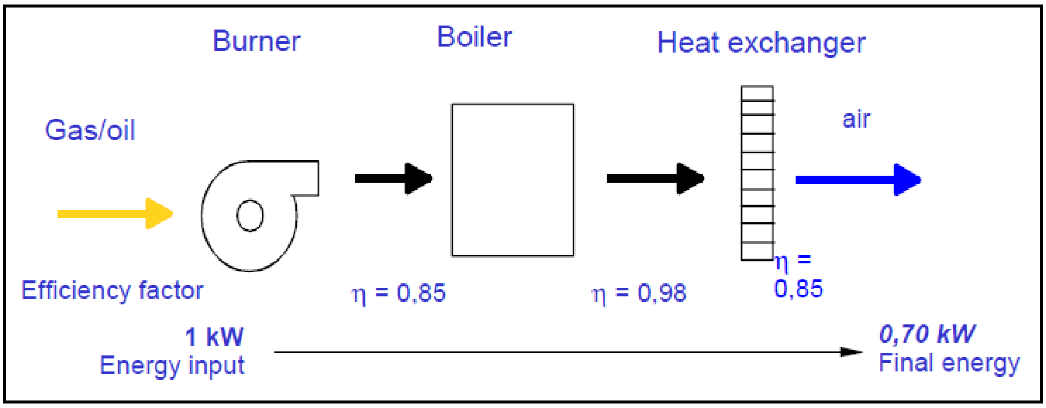
[38] It is a general rule, that only one method of heating supply is used. In order to achieve economies of scale it would not make sense to install multiple heating systems like steam heating, thermo-oil or natural gas in parallel in commercial or industrial laundries.

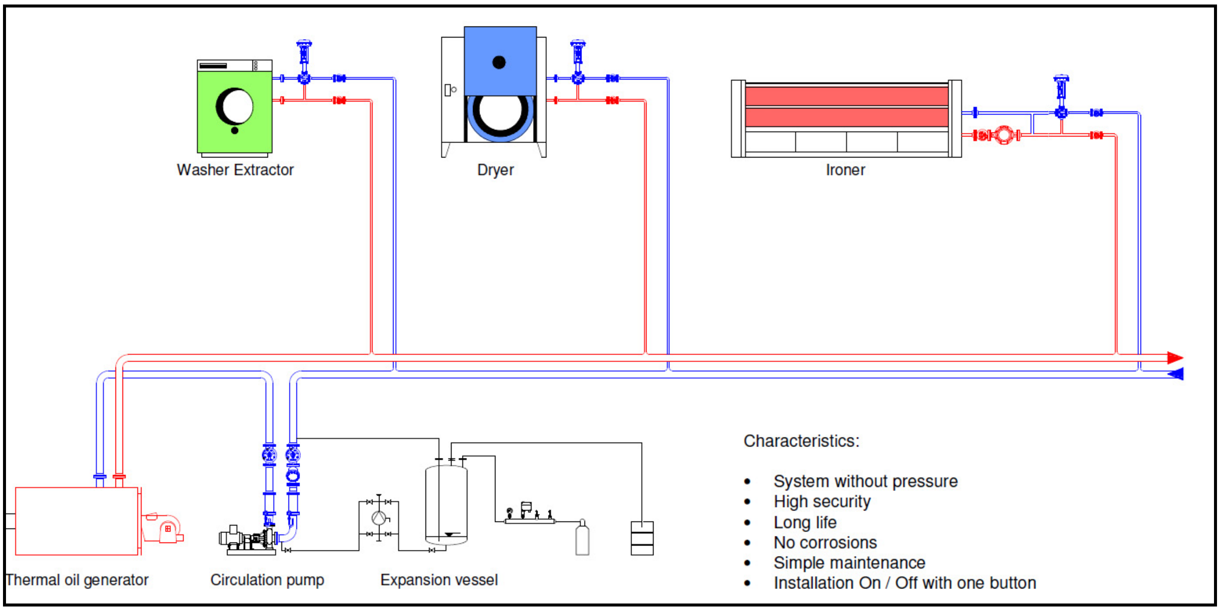
[39] Öko-Institut e.V.; Rüdenauer, I.; Gensch, C.-O.; Quack, D.; Eco-Efficiency Analysis of Washing machines – Life Cycle Assessment and determination of optimal life span (2004)



(Source: Laundry Sustainability)

Figure 20 Energy conversion process in a steam heating system

The laundry equipment machines could also directly be heated with thermo oil. Figure 21 shows an example of a thermal oil heating laundry.[40]



(Source: Regiomat)

Figure 21 Diagram of a thermal oil heating laundry

4.1.3 Internal (direct) heating with natural gas

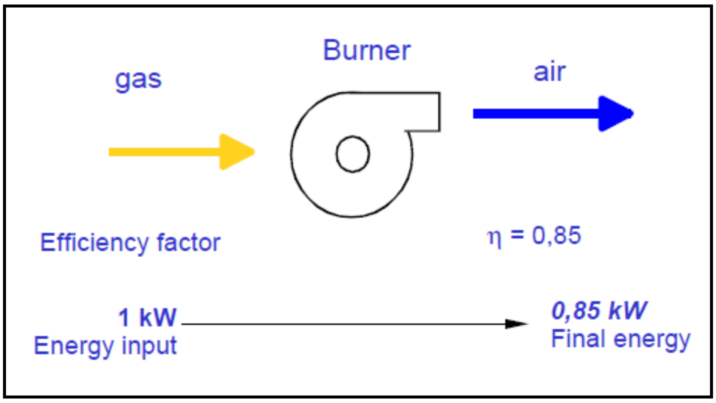
In some laundries gas is used for heating the water of the washing machines or the air of the dryers. The main environmental advantage is that natural gas burns almost free of particles

[40] http://www.regiomat.com/Regiomat_Homepage_English/pdf_english/Thermal%20oil%20or%20Steam.pdf

with much less CO_2 compared to electricity production; thus the carbon dioxide emissions are reduced by up to 50%.[41] With gas heating a faster heat-up and cost savings due to the cheaper purchase price of gas compared to electricity are possible. Further, compared to steam heating, the operation costs can be significantly reduced by the use of natural gas heating due to the following reasons:[42]

- Steam and condensate lines are hot and must be insulated separately.
- Heat-up times of gas-heated dryers are much shorter compared to those in (indirect) steam-heated dryers.
- The steam boiler plant has a loss in efficiency of 10 to 15%. These losses can be avoided by using a direct gas dryer. Gas dryers have an improved combustion efficiency compared to electricity because natural gas is burnt inside the dryer to produce heat. Thus, the drying performance of direct-heated dryers is significantly higher.
- Finally, gas dryers provide an improved temperature-controlling of the drying process.

The following figure shows the conversion of the energy input in a direct gas heating system.



(Source: Laundry Sustainability)

Figure 22 Energy conversion process in a direct (internal) gas heating system

The following table provides a brief overview of the different heating sources and their advantages and drawbacks.

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41 http://www.gewerbegas-online.de/

42 http://www.gewerbegas-online.de/index.php?id=270

Table 7 Information on different types of heating

	Advantages	Drawbacks	Details
Electricity	▪ Easy & economic ▪ installation ▪ Easy maintenance ▪ Clean	▪ Expensive operating cost	▪ Recommended for small units up to 100 kg/hour
Gas	▪ Cheap operating cost ▪ Any type of gas available ▪ Ideal for Tumble dryers (see Section 3.2.2	▪ Cannot be installed everywhere (ventilation) ▪ Requires strict maintenance ▪ Not available for WE except side loaded WE and for chest ironers	▪ For medium size installations up to 100 / 150 kg/hour
Steam	▪ Cheap operating cost ▪ Ideal for any type of ironer	▪ Additional cost for installation ▪ Requires additional room ▪ Safety norms	▪ Recommended for large laundries
Thermo-oil	▪ Simple installations and placements ▪ 30–40% less investment costs as a steam plant ▪ No losses of condensate and energy ▪ High security, Long life	▪ Additional costs for maintenance ▪ Operational hazards (e.g. leakage)	▪ Recommended for large laundries

The infrastructure options are differently applied in the various customer segments and product categories (cf. Task 3). The choice for a specific professional washing machine depends inter alia from the locally applicable infrastructure. In case of new investments or re-planning of a laundry, however, improvements by changing the heating source or implementing the following options could be realised.

- The existing energy supply system can be adapted to the state of the art or using BAT. For example an existing steam supply could be substituted by a new, more energy efficient steam supply in laundries.[43]
- Another approach aims at the conversion of the energy supply structure of laundries. For example: an existing central steam supply can be converted to a system with decentralised gas heating.

[43] E.g. Gläßer, B.; Energiy efficient steam supply in laundries. 44th International Detergemce Conference. Düsseldorf 2009

4.1.4 Smart portal display (changes to appliances operation)

Based on experiences from the household appliances sector another infrastructural option could be to manage the required power on the grid. By means of a smart portal display the available power on the grid coming from conventional and renewable resources could be harmonised with the respective demand. Thus, professional washing machines or dryers could be linked to cheaper energy sources, such as night charge. The machines could be started within a predefined time interval. The portal display is informed about the selected programme or at least the expected energy demand.[44] However, in the professional context, the use of this application is limited. In some market segments (e.g. Coin & Card Laundry), users expect to wash and dry their laundry directly and not delayed. In large laundries, the machines are already operated in several shifts during the whole day.

There is no information on a possible environmental saving potential of this application.

4.2 Laundry system solutions

In commercial or industrial laundries usually a wide range of machinery and options are used to process the different types of laundry. To optimize the laundry operation both under environmental and cost aspects, the machines used for washing, extraction, drying and finishing are often integrated into a comprehensive laundry system.

In addition to optimisation at the level of the single machines and process steps of the laundry process there are further improvement potentials which could be realised at system level. Basically, there are different approaches at this level for implementing measures:

- Improvement potentials can be achieved by a concept which is called “media integration”. The energy flow between different laundry process steps is optimised. Examples for this approach are the use of energy from the ironer’s exhaust heat for (pre-) heating the wash water or the filtration and recycling of waste water from tunnel washing machines for washer extractors. [45]
- Also, the spin speed of washing machines influences the energy consumption of the subsequent drying process. This is due to the physical fact that for the drying process, the water has to be evaporated by using thermal energy and removed through an air flow. The more water is removed by mechanical treatment (usually through spinning in the washing machine) the less thermal energy is required for subsequent drying. Water removal by an increased spinning in a washing machine needs about 100 times less energy[46] than thermal drying. The additional energy demand through higher spin

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44 University of Bonn, Synergy Potential of Smart Domestic Appliances in Renewable Energy Systems, Prof.Dr. R. Stamminger (Stamminger 2009)

45 E.g. Langer, A.; The green laudry. 44th International Detergence Conference, Düsseldorf 2009

46 http://www.topten.info/uploads/File/Efficient%20Heat%20Pump%20Dryers%20-%20EEDAL%2009.pdf

speeds of the washing machine is negligible compared to the reductions in thermal energy demand of the dryers.[47] However this design option is not suitable for all garments.

- Efficient Laundry Management Information Systems (LMIS) enable to spare resources: important machine and process data is easily available, including for example the machine load. The consumption of chemicals, water and energy to a large extent depends on optimal utilisation of the machine, and can be monitored with such a system.[48] With the help of LMIS it is possible to find out which machines are using more resources and therefore which ones could be replaced from the environmental point of view. Further, especially for hospitals where disinfection programmes are used this system serves as data documentation to comply with legislation.

Such concepts at system level could result in considerable savings. However, the infra-structural and systemic approaches are highly dependent on site-specific boundaries and side conditions like

- amount and kind of laundry,
- existing energy infrastructure,
- existing equipment to be integrated into an energy flow system and
- degree of on-premise laundry (OPL), i.e. need of internal logistics and differentiation of division of work respectively.

Thus, such concepts can not be considered more detailed in this study at a quantitative level.

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47 Öko-Institut e.V.; Rüdenauer, I.; Gensch, C.-O.; Quack, D.; Eco-Efficiency Analysis of Washing machines – Life Cycle Assessment and determination of optimal life span. Freiburg 2004.

48 Association Internationale de la Savonnerie, de la Détergence et des Produits d’Entretien (2000), Professional laundry and the environment

5 Annex

5.1 Questionnaires for stakeholders

These questionnaires are provided separately:

- EuP_Lot24_Wash_T6_Final_Questionnaire.xls
- EuP_Lot24_Wash_T2-T7_Questionnaire_for_Final_Report.xls

5.2 Stakeholder feedback to draft versions of Task 6

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

Feedback		Comment
Xeros Ltd.		
Comment on Draft Final task 6	Throughout the report: Change the word to 'pellet' to 'bead'	included
	Section 2.2.1 / T 1.13: Change the level of estimated savings to 60% for water, detergent and energy Change the date for coming to market to 2011/12	included
	Section 2.3 / table 3 / T1.13: Energy 60%, Water 60% Advantages: saves significant energy, water and detergent Drawbacks: technology not yet validated in the market	included
	Section 2.3 text and table 4: Should the polymer beads not be considered for Task 7 since we are able to quantify potential savings? I accept that it is a more radical change than the other technologies highlighted for inclusion and that independent verification of the wash performance and savings is not yet available to you or to other stakeholders.	included
	With reference to your table 3 in 2.2.1, is it really true in T 1.14 that Ozone is proven to have no influence on washing performance? We are not using ozone, but I do know that there are machines on the market that have ozone so it is somewhat surprising that it does not work!	noted