

# Work on Preparatory studies for implementing measures of the Ecodesign Directive 2009/125/EC

ENER Lot 29 – Pumps for Private and Public Swimming Pools, Ponds, Fountains, and Aquariums (and clean water pumps larger than those regulated under ENER Lot 11) – Task 6: Technical Analysis BAT

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## Task 6: Technical analysis of best available technology (BAT)

A Best Available Technology (BAT) for a product in this study is a technology or change in design that leads to less environmental impacts and is already available on the market, or whose technical feasibility has already been demonstrated (and expected to be introduced within 2-3 years). Best Not yet Available Technology (BNAT) refers to a technology that has the potential to lead to further environmental performance improvements, but still is subject to research and development. BNAT is rather a future option or long term trend.

The identification and analysis of BAT and BNAT provides input for the assessment of the improvement potential in Task 7. The intellectual property, technical feasibility and the availability on the market of BATs in a strict sense are not judged here as the objective is to illustrate various technically available (or potentially available) options. However, Task 7 will consider these issues when suggesting possible improvement options applicable to clean water pumps. Note that this report covers the BAT and BNAT available around the world and not just in Europe.

The results of this task are predominantly based upon available literature, which includes technical journals, magazines and research publications, as well as other sources such as interviews with technology experts, research institutes and the stakeholders of this study.

### 6.1 State-of-the-art at component level

#### 6.1.1 Motors

Only the smaller pump motors (<120W), used in swimming pool/spa pumps, fountain & pond pumps and aquarium pumps, are considered in this study. The motors used on the other pumps are regulated under the Lot 11 or the upcoming Lot 30 motor regulations. The limit of the scope for the Lot 30 motor regulations is 120W

Brushless Permanent Magnet (BPM) Motors are rapidly becoming one of the most popular motor types. They differ from Brushed Permanent magnet motors in that the magnets are in the rotor instead of the stator, and in the commutation method, which is controlled electronically. BPM Motors, therefore, avoid use of a commutator and brushes.

Main characteristics:

- Medium construction complexity
- Moderate to high cost depending on magnet materials
- High reliability (no brush and commutator wear), even at very high achievable speeds
- High efficiency

- Low EMI
- Driven by multi-phase (output) Inverter controllers, which inherently offer variable speed control
- Sensorless speed control possible

These motors are still highly customized without suitable standards (e.g. dimensions, mounting, power, torque specifications, etc.) that would allow a commodity market to develop. Because of high volumes production for individual specialized applications, their cost has been decreasing and may become a key player particularly in the low power range. They are often used in conjunction with aquarium, pond and swimming pool pumps.

The motor sector is constantly developing and new, more efficient motor types are being brought to the market. Currently around 80% of all pump installations are fixed speed applications, and 20% are VSD-controlled because of the requirement of speed control. There is a possibility of additional reduction of power losses through speed control in some applications. According to EN 50598-2 Chapter 6 the motor starters have an efficiency of 99.9 %.

### 6.1.2 Centrifugal Pumps with intelligent controls

Pumps are also available which have built in diagnostics to identify possible causes of detected problems. This is useful in that it can both sound alarms and give maintenance staff ideas of what the technical problems might be. Early warning of problems can save cost and energy through making adjustments or repairs before failure of the pump.

The fitting of intelligent controls to pumps will give improved eco-performance in almost all applications, and so is to be welcomed. However, such controls would have no obvious impact on the design of the pump itself, and so are regarded as being beyond the scope of this study.

## 6.2 State-of-the-art for the product level

This section presents an overview of the BATs currently available on the market both at the component and product level for the Base Cases selected in Task 5. BATs are design options, which allow a product to operate significantly better in terms of environmental performance than the average product on the market (represented by the Base-Cases).

### 6.2.1 Improvements in Centrifugal Pumps

The centrifugal pump is a mature product, which has been under development for over 300 years. However, it was not until high-speed turbines and electric motors became available in the late 19<sup>th</sup> century that real improvements became possible. By the 1880's pump's efficiencies of 80% were achieved. Today, efficiencies well over 90% are achieved in larger clean water pumps. It is very important to note while reading the following section that the issues affecting the efficiency of pumps, such as hydraulics, surface friction and leakage are all interlinked to some extent and improvements made in one area may have a consequential effect on another. Also, the size and



geometry of each pump will have play role in the extent to which these factors affect the pump's efficiency. All this makes it difficult to accurately attribute an efficiency improvement % to any one specific measure.

Increasing the pipe diameters used on pump systems can reduce the overall system losses and therefore reduce energy consumption. Although this is not something that can be directly affected by pump manufacturers, they can provide guidance to purchasers on this front.

## 6.2.2 BC-1 & BC-2: Domestic swimming pool pumps with built in strainer

Domestic swimming pool pumps are produced by a variety of companies, but the overall design of a centrifugal pump with an integral inlet strainer is common to them all. The inlet strainers are responsible for a significant proportion of all the inefficiency associated with swimming pool pumps. The losses associated with the strainer will depend on the type of strainer being utilised, with those with the largest open area being the most efficient. This has to be balanced against the fact that strainers with larger open areas, may not be able to filter smaller solids or may be structurally weaker.

Swimming pool pumps generally have good hydraulic performance as the body is made from plastic materials, which are smooth and can be made with tight tolerances. The impellers are typically closed, multi-channel types to provide maximum efficiency.

Most domestic swimming pool pumps are physically located above the water level in the pool for ease of access and maintenance. This means that they need to have a self-priming function. Self-priming pumps are inherently less efficient than standard centrifugal pumps. Removing the need for self-priming pumps would necessitate a significant redesign of the way pumps are installed in domestic settings, including the provision of a pump sump, which would introduce an unnecessary health and safety risk. Therefore, it is felt that maintaining a self-priming function is worth the addition inefficiency caused.

### ► Controls

Significant energy savings can be made in swimming pool pump systems that use variable speed drives to match the flow rate to the requirements of the various water treatment systems within the pool. This allows finer controls allowing the heating, filter backwashing, disinfection and general circulation all to have different operating flow speeds. The theory is that each process is operated as efficiently as possible. This allows flexibility in the sizing of the components, for example, the heating system does not have to be sized for the peak flow conditions, allowing it to be undertaken at lower speeds. This has the effect of reducing pump power consumption and improving filtration efficacy. It should be noted however that in new European standards for domestic pools the minimum backwashing flow rate is the same as the filtration rate for all pumps. The savings are only expected to be possible in 35% on the in ground pool market and 0% of the above ground market.

The running time of domestic swimming pool pumps is often dictated by the need to turn over the pool volume in a fixed period of time, for example there may be a requirement to turn over

the pool volume in 8 hours. Pool pumps have to operate against different head conditions depending on how clean the filter is. The head difference between a clean and dirty filter can be in the region of 5 – 8 metres. Pool pumps are often sized to provide the duty flow rate at high head conditions, when the filters are dirty. When the pumps are working against a clean filter the actual flow rate may be significantly higher than is needed to achieve the stated turn over requirement. In this case, the potential exists to use variable speed drives to reduce the flow rate and benefit from the associated reduction in power consumption and friction losses.

Friction loss in domestic swimming pool pipework system can be relatively high due to the limited pipe sizes available for use. The pipe sizes used tend to be 40 – 50 mm (1½" – 2"), and the flow rates typically varying between 5 m<sup>3</sup>/h and 20 m<sup>3</sup>/h, during filtration condition. This can result in some pipework flow velocities being as high as 3 m/s. Friction losses in pipework are proportional to the square of the flow velocity. For example, the friction loss at a flow velocity of 3 m/s are 9 times greater than the losses at 1 m/s therefore there are significant savings to be made from reducing pump speeds (not lower than 0.5m/s). Savings in friction could also be done by fixing the maximal speed in pipe as proposed in CEN-TC402-WG2\_No096\_WI\_00402005.

It is important to note that many manufacturers believe that the market for domestic variable speed pool pumps is small, as it is perceived the savings potential is small. Variable speed pool pumps are certainly not appropriate for all domestic pool pumps, for example there is a growing market for 'hobby pools' which are small, above ground pools which retail for approximately 500€. Adding a variable speed drive to these pools may not provide any tangible energy savings and could increase the overall price to the point where market is adversely affected.

Variable speed drives are by no means the only option available for altering. For example, two speed (full speed and half speed) controllers are available which operate the pumps at half speed when there is not a demand for full speed operation from the heating or filter backwash systems. These, tend to schedule the high and low speed periods based on assumed operation patterns for the heater and filter. An issue to be aware of with two speed pumps is that in some systems, running pumps at half speed does not provide sufficient head to overcome the system losses, resulting to very low flow conditions. This in turn may result in insufficient filtration occurring and an unacceptable reduction in water quality, along with an increase in operational power consumption.

### 6.2.3 BC-3: Fountain and pond pumps up to 1 kW

Fountain and pond pump are composed of integral pump, motor combined in a single unit. The filter is sometimes integrated into the pump casing or is provided as a separate satellite unit connected via a hose. The pumps with integral filters have a higher efficiency as they avoid losses associated with the connector hose, however they do not provide as reliable circulation of the entire pumped volume. As with swimming pool pumps, the losses associated with the filter will depend on the size of the filter being utilised being those with the largest open area the most efficient. This has to be balanced against the fact that strainers with larger open areas, may not be able to filter smaller solids or may be structurally weaker. Filters with large surface areas are used to reduce losses and minimise the chance of filters blocking.

Most pond pumps are made with plastic bodies and impellers with help to reduce the losses associated with surface friction. Some pumps have integral UV filters to assist with the treatment of the water without the need for chemicals. The UV lamps are typically in the range of 5W.

#### **6.2.4 BC-4 & BC-5: Aquarium pumps (domestic/small aquarium non-commercial) pumps up to 120W and aquarium power head to 120W**

The pump/filter plays a vital role in the aquarium ecosystem and must operate continuously 24 hours per day, 7 days per week. Any control of the rotation speed of the pump, from a ON/OFF option up to a variable speed drive (VSD), can be harmful for the livestock, therefore the pumps are designed to be operated full time.

Most aquarium pumps are circulating pumps connected to a device that works as a filter. Inside the filter water is forced to flow through different types of filtering materials, in such a way that water is cleared from dirt and detoxified from fish waste. Most Aquarium pumps use the technology of integrated motor with wet rotor. Since the 80's, the aquarium industry has seen a progressive technological shift with the replacement of traditional asynchronous motors with permanent magnet synchronous motors characterized by a much higher yield together with lower power consumption than asynchronous motors. Today, aquarium pumps exclusively employ high efficiency permanent magnet motors.

In addition, over the last decade, the industry has made great efforts to optimise the hydraulic design with a view to improving the performance and get further reduction of energy consumption. Today are widely available on the market hydraulic solutions characterized by an high yield such as oriented blades impellers, flexible blades impellers, closed impellers; thanks to the very low hydraulic power the above mentioned design solutions are able to guarantee the correct direction of rotation without using electronics that controls the start-up phase of the pump. On models with higher performance, although they represent a niche market (salt-water aquariums), they are also used with electronic controls that ensure the correct direction of rotation of the impeller.

The market is further complicated by some pumps that are connected to additional devices, for example, a heating element, a UV-C lamp or a particular filtering unit. At this stage, it is suggested that any Minimum Efficiency Performance Standards that might be defined are based on the pump alone, but the test standard will need to take account of the need to remove these other elements (when not necessary to the functionality of the pump itself, for example some aquarium filters as shown in Figure 6-1). While this is a shift from the pure 'extended product approach' that aims to consider as much of the system as possible, it is likely that trying to define 'standard' to fit within regulations would be difficult and give little real benefit.

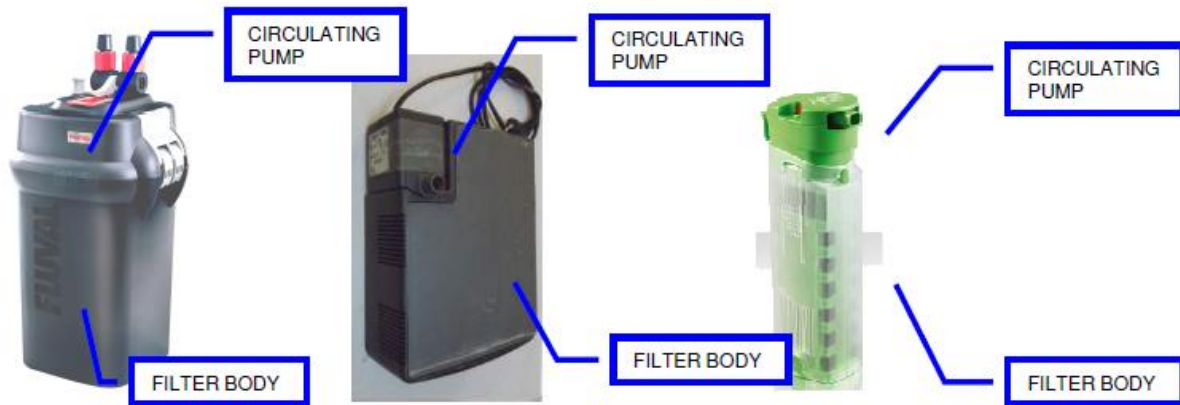


Figure 6-1: Aquarium filters - As described above the circulating pump forces the water through the filter body

Most Aquarium pumps use the technology of integrated motor with wet rotor: the older style pump set comprising separate motor and pumps can be considered obsolete.

### 6.2.5 BC-6 & BC-7 Countercurrent pumps and spa pumps

Countercurrent pumps and spa pump are essentially the same as swimming pool pumps and therefore have the same hydraulic performance. Countercurrent pumps are generally not provided with an inlet filter basket, however they do have strainers on the upstream end of the water inlet pipework, which does reduce the overall efficiency of the pumps. Countercurrent pumps are generally bigger and more powerful than the pumps used for domestic pools – typically domestic pool pumps are less than 1kW and countercurrent pumps are typically around 2kW.

Spas could have three or four pumps. Often the circulation pump is a fractional HP pump and the booster are considerably larger. These pumps have relatively low running hours.

### 6.2.6 BC-8 & BC-9: End Suction Close Coupled Pumps

The mechanical loss in the seal will be well below 1% for larger pumps, but for the smaller ones of the sizes considered in this study this loss might be much higher. The remaining power losses are considered below.

**Hydraulic design** The geometry of the impeller and the casing affects the hydraulic losses. Each manufacturer will have their own (confidential) method of choosing this geometry. With many years of feedback, an established manufacturer should have arrived at close to the optimum impeller vane number, vane shape, impeller inlet diameter, impeller cross-sectional profile, and casing geometry. This should produce an effective compromise between the various curve shapes for head, power, efficiency, and Net Positive Suction Head Required (NPSHR) against flow.

However, in most cases efficiency could be improved by sacrificing one or both of the ideals of head stability at low flows (e.g. by using a smaller diameter impeller), or NPSHR at best efficiency

flow (e.g. by using a smaller impeller inlet diameter). The increased sales resulting from higher efficiency would have to be balanced against the loss in sales due to the reductions in performance in the other areas.

▶ **Surface friction**

▷ **Impeller**

The outer surfaces should be fully machined to a hydraulically smooth finish, but in practice this is rarely done. The inner surfaces should be as smooth as possible. Mechanical methods of smoothing the rough cast interiors of impellers in iron or bronze are time-consuming and not entirely effective due to inaccessibility. Precision casting methods can give a good finish, at a high cost, but this is not possible with cast iron. Cast iron should not be used on cold water pumps unless precautions are taken against corrosion, due to the formation of rough corrosion products. Where good access is possible, a cast iron impeller can be coated with a smooth resin. This is costly and is rarely, if ever, done on pumps of this size. For a good finish, the impeller could be made from plastic or pressed sheet steel is viable for smaller pumps, although it is rarely, if ever, done.

▷ **Casing**

The side walls should be fully machined to a hydraulically smooth finish. This is, at best, only partially done at present. The whole casing interior can then be coated with a smooth resin. This is very rarely done on pumps of this size and tends to only offer a benefit in the first years of operation. The theory behind the use of resins is the not only does this improve efficiency appreciably, but, more importantly, it enables the improvement to be maintained by avoiding the build up of corrosion products. (There have been objections in the past to the use of resin coatings on drinking water pumps, but coatings do now exist, which satisfy the regulations. However, a coating is only as good as the operator who applies it, so a reputable supplier is essential.) For an indication, based on many real pump tests, of the effect of coating the inside of a new cast iron pump casing, see Figure 6-1 below. It can be seen that, for the small pumps involved here, the efficiency improvement can be quite substantial.

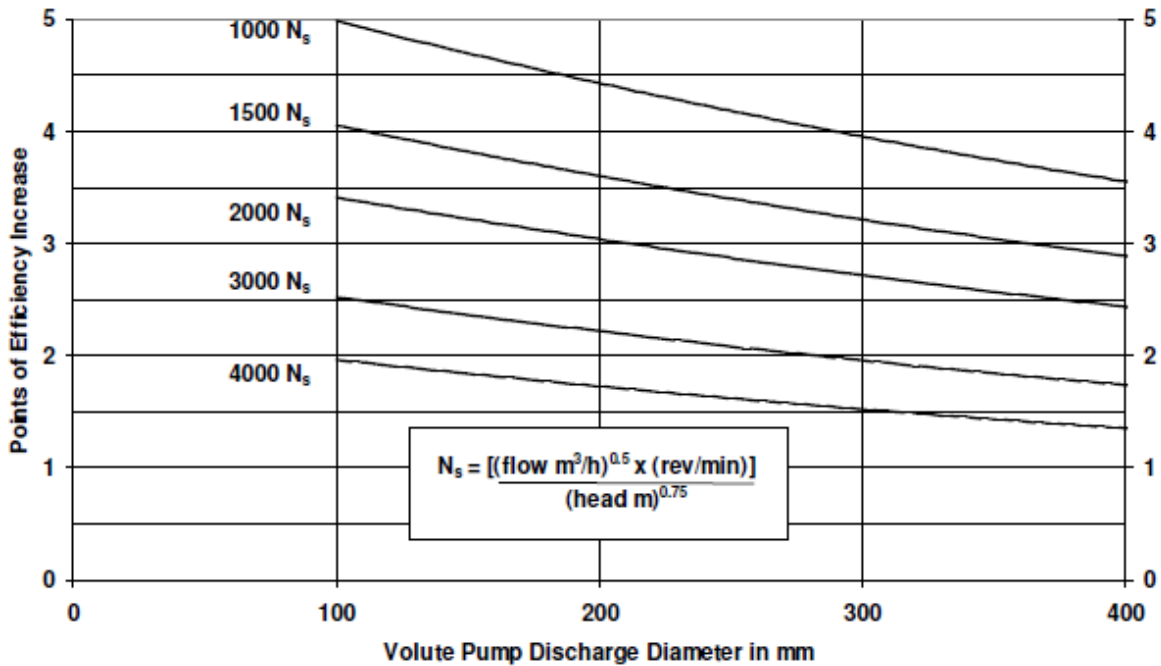


Figure 6-2: Effect on efficiency of coating the inside of a pump casing

### ► Leakage

Pump efficiency could be improved by reducing the leakage at the wear rings, by reducing the clearance.

This would require most or all of the following, all of which would increase cost:

- Tighter manufacturing tolerances
- Increased shaft diameter to minimise contact and wear at reduced or increased flow, which would also require the fitting of larger bearings and seals
- Very hard but compatible wear ring materials (e.g. Tungsten carbide).

Alternatively wear ring geometry could be changed, e.g. non-plane surfaces. However, the effect would be small and would be offset by reducing the small but beneficial hydrostatic centering force.

The back wear ring and the associated 'balance holes' could rarely be eliminated to reduce leakage, since this could overload the motor thrust bearing.

The bleeding of water from the casing to cool the mechanical seal could be eliminated by using a large conical housing for the seal (already done on some pumps).

## 6.2.7 BC-10: End Suction Own Bearings Pumps

The mechanical losses in the two anti-friction bearings and the mechanical seal will be between 2% and 10% of the input power to the pump, depending on the pump size. These are not capable of significant reduction without resorting to very sophisticated (and expensive) solutions, such as water lubricated journal and thrust bearings.

The remaining power losses are looked at theoretically for a specific pump in Task 4. These can be viewed as the hydraulic losses due to turbulence and surface friction, plus the leakage losses. These are considered below.

▶ **Hydraulic design**

The same comments apply as the previous section. Indeed manufacturers who make both types of pumps will use the same impeller and casing geometries.

▶ **Surface friction**

- Impeller - As for End Suction Close Coupled Pumps.
- Casing - As for End Suction Close Coupled Pumps.

▶ **Leakage**

- As for End Suction Close Coupled Pumps.

## 6.2.8 BC-11: Submersible Multistage Pumps

In some pumps the axial thrust from the pump is normally accommodated in the motor. There is a considerable portion of pumps where the axial thrust cannot be accommodated by the motor or an external ball thrust bearing, but where a balancing device is necessary. The losses in the water lubricated journal bearings can be neglected. There are no seal losses.

▶ **Hydraulic design**

The pump outside diameter is usually restricted by the diameter of the hole it is intended to work in. To reduce cost, for a given duty, the number of pump stages tends to be minimised and the stage length reduced. This results in relatively narrow impellers and diffusers. By increasing the number of stages and increasing the stage width, it would be possible to increase stage efficiency and, in many cases, increase the pump efficiency for a given duty. However it is important to note that the impeller geometry will play an important role in this context.

Some pumps use inward flow diffusers. Stage efficiency could be improved by using outward flow (or outward/inward flow) diffusers, but again stage numbers would increase.

▶ **Surface friction**

The pump hydraulic components are normally made from bronze or cast iron. Precision casting is an option where bronze impellers are used.

▶ **Leakage**

Wear ring (and interstage bush) clearance is mainly dictated by journal bearing clearance. However, very hard but compatible wear ring materials (e.g. Tungsten carbide) may allow reduced clearance. More importantly, hard materials would better resist the wear caused by the abrasive materials found in most wells, which increase leakage. By the same token, hard bearing materials would reduce the risk of wear causing wear ring contact. Rubber bushes and casing wear rings are resistant to wear but to be really effective they need to be run in conjunction with inner hard surfaces.

## 6.2.9 BC-12: Vertical Multistage Pumps

The axial thrust from the pump on some pumps is accommodated in the motor or an external ball thrust bearing. There is little that can be done to reduce these small thrust bearing losses or the small losses in the water-lubricated journal bearings. The loss in the single mechanical seal is negligible.

### ► Hydraulic design

In the smaller pump sizes, for a given duty the number of pump stages tends to be minimised and the stage length reduced. This results in relatively narrow impellers and diffusers. By increasing the number of stages and increasing stage width it would be possible to increase stage efficiency and, in many cases, increase the pump efficiency for a given duty. The impeller geometry is important in this context.

Some pumps use inward flow diffusers. Efficiency could be improved by using outward flow (or outward/inward flow) diffusers. Pump diameter would increase and, in some cases, so would stage length. If the pumps become taller, they may need to be made sturdier.

### ► Surface friction

The pump hydraulic components are normally made from bronze or cast iron. Where bronze is used, precision casting is possible.

### ► Leakage

Wear ring (and interstage bush) clearance is mainly dictated by bearing clearance. However, in order to reduce these clearances, very hard but and compatible wear ring materials (e.g. Tungsten carbide) could be used. Alternatively, providing the water is clean, PTFE casing wear rings could be used (and sometimes are).



## 6.3 Summary of BAT options at component and product level

In this section, the best available technology options at component level are summarised for each Base Case<sup>1</sup>. The improvements presented are generally high cost with relatively small efficiency gains, therefore there is likely to be a cost penalty for their implementation.

Note as stated in section 6.2.1, it is difficult to attribute energy savings to single pump improvement measures and so the 'pump/hydraulic improvements' shown here are indicative of the level of savings achievable when hydraulic, surface friction and impeller improvements are combined together effectively. Also, the improvement percentages shown in the following tables are the average improvements over all the stock for each base case. For example, if applying a VSD to pump in the correct circumstances is likely to make 50% savings, but only 20% of all the pumps are suitable for use with VSDs then the savings show are averaged out across the whole stock (i.e. 50% x 20% = 10% overall).

The tables show the improvements that are possible by moving to the most efficient motors, however it should be noted that all motors above 120W will be covered by the Ecodesign Preparatory Study ENER Lot 30 and so the present study will not explore policy options for these motors.

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<sup>1</sup> Please note: all statements on improvement potentials for the different pumps (BC 1 to BC 12) and their BATs are based on estimations and have to be evaluated in combination with assumptions on user behaviour

Table 6-1 Summary of BAT options for BC-1: Swimming pooling pumps (integrated motor+pump with built in strainer up to 2.2kW) (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.5%	-22	1,404	2.0%	7	337	0.0%	0	0.0%	0
Motor improvements	0.5%	-7	1,433	2.0%	7	337	0.0%	0	0.0%	0
VSD	10.0%	-144	1,296	200.0%	660	990	20.0%	50	0.0%	0

It is not expected that the improvements in efficiency will require any changes to the installation. These types of pumps tend not to be repaired on failure so maintenance costs are unlikely to change.

**Table 6-2 Summary of BAT options for BC-2: Swimming pooling pumps (integrated motor+pump with built in strainer over 2.2kW) (Estimates by study authors)**

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.5%	-304	19,946	2.0%	30	1,530	0.0%	0	-1.0%	-1
Motor improvements	0.5%	-101	20,149	2.0%	30	1,530	0.0%	0	-2.0%	-1
VSD	40.0%	-8,100	12,150	100.0%	1,500	3,000	10.0%	50	5.0%	3

It is not expected that the improvements in efficiency will require any changes to the installation.

Table 6-3 Summary of BAT options for BC-3: Fountain and pond pumps to 1kW (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements*	1.5%	-2.2	142	2.0%	2.0	102	0.0%	0	0.0%	0
Motor improvements	0.5%	-0.7	143	2.0%	2.0	102	0.0%	0	0.0%	0

It is not expected that the improvements in efficiency will require any changes to the installation. These types of pumps tend not to be repaired on failure so maintenance costs are unlikely to change.

\* 1.0% of Annual energy consumption change [%] are linked to strainer improvements

Table 6-4 Summary of BAT options for BC-4&5: Aquarium pumps and power heads to 120 W (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.5%	-0.8	51.54	2.0%	1.0	51	0.0%	0	0.0%	0
Motor improvements	0.5%	-0.3	52.06	2.0%	1.0	51	0.0%	0	0.0%	0

It is not expected that the improvements in efficiency will require any changes to the installation. These types of pumps tend not to be repaired on failure so maintenance costs are unlikely to change.

Table 6-5 Summary of BAT options for BC-6: Spa pumps for domestic &amp; commercial spas (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.0%	-4.6	457.38	0.0%	0.0	275	0.0%	0	0.0%	0.0
Motor improvements	1.0%	-4.6	457.38	2.0%	5.5	281	0.0%	0	2.5%	0.8

It is not expected that the improvements in efficiency will require any changes to the installation. These types of pumps tend not to be repaired on failure so maintenance costs are unlikely to change.

Table 6-6 Summary of BAT options for BC-7: Counter-Current Pumps (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.0%	-1	71	0.0%	0	1,325	0.0%	0	0.0%	0
Motor improvements	1.0%	-1	71	2.0%	27	1,352	25.0%	125	2.5%	0.8

It is not expected that the improvements in efficiency will require any changes to the installation. These types of pumps tend not to be repaired on failure so maintenance costs are unlikely to change.

Table 6-7 Summary of BAT options for BC-8: End-Suction Close Coupled pumps from 150 kW to 1 MW (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.00%	-6,480	641,520	2.5%	200	8,200	0.0%	0	-2.0%	-10
VSD	12.5%	-81,000	567,000	200.0%	16,000	24,000	100.0%	2,000	0.0%	0

It is not expected that the improvements in efficiency will require any changes to the installation. Note that the motors used in the basecase are already considered as high efficiency and therefore no improvement is considered here.



Table 6-8 Summary of BAT options for BC-9: End-Suction Close Coupled Inline from 150 kW to 1 MW (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.00%	-6,480	641,520	2.5%	200	8,200	0.0%	0	0.0%	0
VSD	12.5%	-81,000	567,000	200%	16,000	24,000	100.0%	2,000	0.0%	0

It is not expected that the improvements in efficiency will require any changes to the installation. Note that the motors used in the basecase are already considered as high efficiency and therefore no improvement is considered here.

Table 6-9 Summary of BAT options for BC-10: End-Suction Own Bearing from 150 kW to 1 MW (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.00%	-11,700	1,158,300	2.5%	250	10,2500	0.0%	0	0.0%	0
VSD	12.5%	-146,250	1,023,750	200.0%	17,500	28,000	100.0%	2,000	0.0%	0

It is not expected that the improvements in efficiency will require any changes to the installation. Note that the motors used in the basecase are already considered as high efficiency and therefore no improvement is considered here.

Table 6-10 Summary of BAT options for BC-11: Submersible bore-hole pumps (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.00%	-2,108	208,734	1.5%	109	7,403	0.0%	0	0%	0
VSD	12.5%	-26,355	184,487	50.0%	3647	10,940	20.0%	607	0.0%	0

The figures shown for the cost are based on a weighted average of all the pumps in scope. It is not expected that the improvements in efficiency will require any changes to the installation. Note that the motors used in the basecase are already considered as high efficiency and therefore no improvement is considered here.

Table 6-11 Summary of BAT options for BC-12: Vertical multi-stage pumps (Estimates by study authors)

BAT	Annual energy consumption change [%]	Annual energy consumption change [kWh]	Total annual energy consumption [kWh]	Impact on Purchase Cost	Consumer purchase price change [€]	Total purchase price [€]	Impact on Installation Cost [%]	Consumer installation price change [€]	Impact on repair & maintenance costs [%]	Consumer repair & maintenance change [€]
Pump/hydraulic improvements	1.00%	-2460.6	243,599	2.5%	302	12,376	0.0%	0	0%	0
VSD	12.5%	-30757.5	215,303	35.0%	4226	16,301	30.0%	600	0.0%	0

The figures shown for the cost are based on a weighted average of all the pumps in scope. It is not expected that the improvements in efficiency will require any changes to the installation. Note that the motors used in the basecase are already considered as high efficiency and therefore no improvement is considered here.

## 6.4 State-of-the-art of best existing product technology outside the EU

The pump products in this study – both residential and non-residential - available in the EU are essentially of similar design to appliances sold outside the EU. Therefore, no different technologies have been identified outside the EU.

## 6.5 Best next available technology

Pumps are a very well established technology that has been refined for several hundred years, and therefore there is very little in terms of BNAT appearing on the horizon. There will inevitably be small improvements in efficiency as computational fluid dynamics allows more experimentation and refinement to take place in the design process, and as closer manufacturing tolerances become feasible.

An area where savings are likely to be realised in the future is in optimum control of swimming pool pumps. This is already seen to a limited fashion at the moment through variable speed drives, however in the future the potential exists to combine the pump operation with a greater level of intelligence regarding the water quality, such as through the use of turbidity monitors to detect the suspended solids, or chemical analysis to control the chemical dosing requirements. With more intelligence the VSDs can be used to a greater extent and the savings made will be more significant.

## 6.6 Conclusions

This report has discussed the many ways in which efficiency of centrifugal pumps can be increased. Each of the design options has an economic cost, and in some cases may impact adversely on pump lifetime. The detailed decisions on what options are most appropriate for a particular pump will vary from design to design, and it is seen that a generic relationship between efficiency and production cost exists.

Beyond improvements to the actual design of the pump itself, the use of electronic speed controls frees the designer from the specific speed constraints of standard fixed speed induction motors. This enables the efficiency of some pump sizes to be improved by being designed to operate at a more favourable speed and hence specific speed. In certain specific swimming pool pump applications where a variety of flow rates can be used at different periods in the operating cycle this may be of particular interest. With close control of the pumps' operation at these different periods, the potential for energy reductions exists.



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